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ABSTRACT

A collection of 18 essays originally published in "The American Biology Teacher" in a column headed "Biology Today" are presented. The essays have been reprinted in chronological order and begin with an essay published in March 1982. A variety of types of writings were selected: some focus on teaching biology, others on the science itself. Several deal with books and articles that have excited and interested the columnist over the years. The following essays are included: (1) "Books and Biology"; (2) "Turning Teaching Around"; (3) "Naturalists"; (4) "The Importance of Trivia"; (5) "Broadening Our Horizons"; (6) "Branching Out"; (7) "Things I'd Never Thought About"; (8) "Bitten by the Insect Bug"; (9) "Beginning Again"; (10) "Who Could Have Guessed It?" (11) "The Other Side of the Coin"; (12) "In the Flower Garden"; (13) "Of Chaperones and Dancing Molecules: The Power of Metaphors"; (14) "Communicating Biology"; (15) "Eye on Biology"; (16) "Loving Biology--It's About Time"; (17) "Human Biology"; and (18) "Telling About the Lure of Science." Most chapters include references. (KR)

Bitten by the Biology Bug

Monograph VI

Essays from *The American Biology Teacher*

Bitten by the Biology Bug

Monograph VI

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National Association of Biology Teachers

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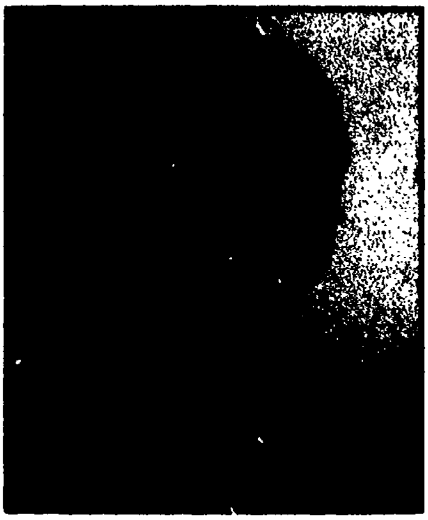

Robert M. Hendrick

About the Author

Maura C. Flannery's column "Biology Today" has appeared regularly in *The American Biology Teacher* since 1982. A favorite among *ABT* readers, it deals with critical science issues and how they affect our lives today. Flannery teaches biology to nonscience majors at St. John's University, Jamaica, New York, where she serves as chairperson of the computer science, mathematics and science division.

She earned a B.S. in biology from Marymount Manhattan College and an M.S. in biology from Boston College, where she studied molecular biology and conducted research with Dr. Maurice Liss. In May of 1990, Flannery completed her Ph.D. in science education at New York University under the direction of Dr. Cecily Selby.

She is married to St. John's history professor Robert M. Hendrick and spends her spare time fixing up their house on Long Island and writing, her "first love."

For:

Henry E. Flannery and Elton J. Hendrick,
two great teachers.

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Introduction

When I was asked to gather a collection of my columns for reprinting, I was flattered and looked forward to the task, but it turned out to be a more difficult assignment than I had expected. Writing these columns is hard work; now I have found that dealing with them a second time isn't easy either. First, it required rereading my work, something I religiously avoid. Second, it involved selecting those pieces which would be most interesting to readers, but how was I to judge this? And third, it meant finding a rational way to organize the articles and give the collection structure. Science is an ordering process, so as a scientist, I feel a need to organize, but as every scientist knows, order is often difficult to find in a chaotic world!

I survived the rereading process and discovered, to my relief, that many of the columns have aged better than I had expected. One of the aims of "Biology Today" had been to discuss some of the latest findings in biology. But today's news is what becomes most quickly dated, especially in such fast-moving fields as molecular biology. However, I've been able to find pieces that still seem sufficiently fresh to bear reprinting. The amount of editing I've done is minimal. I removed a couple of sentences I disliked and a few very dated items. At other points, I added a sentence or two to update the material in the article. For all the columns, the date of publication is given as a guide for the reader.

In an effort to select columns that would be most interesting to readers, I chose a variety of types of writings. Some focus on teaching biology, others on the science itself. Several deal with books and articles that have excited and interested me over the years. I included these because I don't think there's anything more valuable to a teacher than information on where to find sources of ideas and inspiration. One of the first essays I wrote, *Books and Biology*, is included for this reason. I have a few authors whom I find particularly exciting, so their names keep popping up in different contexts in these articles; though not, I hope, to the point that the repetition becomes excessive. Several pieces I chose because, frankly, I like them. They deal with ideas that I find particularly interesting, and I hope others will feel the same way about them. And a few have been omitted because I found them deadly!

In attempting to order these columns, I initially tried grouping together those with similar themes. But reading several essays on the same theme can be tedious. I opted instead for chronological order, so there is at least some rationale to the sequence, and yet the conscientious reader who tackles the book from beginning to end will find at least some variety in approach in going from one essay to the next. For example, in the first few essays, references are listed throughout the body of the essay, whereas later on references are listed at the end of each article.

I hope these articles will prove interesting and helpful to biology teachers, but the rewards teachers may gain from reading these pieces will never equal the joy I derived from writing them. Though writing each column causes severe anxiety, I truly love the process of coming up with an idea, researching it and then finding the words to express it. I will always be grateful to Alan McCormack, the *ABT* editor who took a chance and gave me the "Biology Today" column. And I appreciate the continued support and assistance of his successors, John Jungck, Randy Moore and Dan Wivagg, and NABT Executive Director Patricia McWethy. I am also very grateful for the editorial assistance of Michelle Robbins, who has to deal with all my mistakes, and Cheryl Merrill for her work on this publication. At St. John's, the Dean of St. Vincent's College, Catherine Ruggieri, has always provided great support and encouragement. And though it is *de rigueur* to thank one's spouse, in this case it is absolutely necessary because, before Bob came along, I had never published anything longer than a paragraph. He has greatly improved my English and my life.

Maura C. Flannery
St. Vincent's College

March 1982

Books and Biology

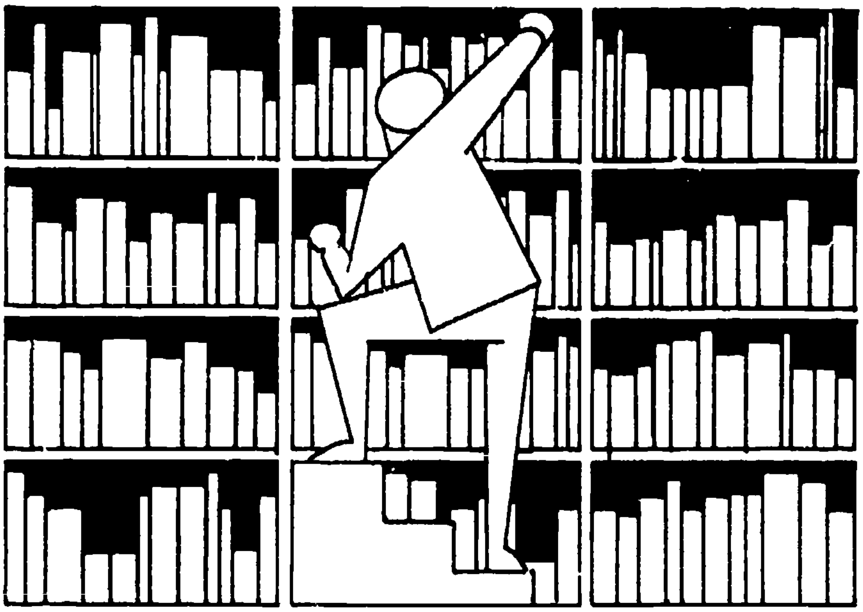
Biologists make good writers. Of course, there are some writers in biology who are as boring and obtuse as they come, but they shall remain nameless. I want to concentrate on the wealth of good biology writing that is available to teachers. These works can be used to inspire our students and, even more importantly, to prevent ennui in ourselves.

I am not speaking of textbook writing, though a well-written text is as valuable as gold; I am talking instead of what may be called "popular" science writing, writing geared to the layperson, but writing so perceptive that it stirs the expert as well. There are good writers in other fields of science–astronomy and physics especially–but I think biology still has an edge. René Dubos, Lewis Thomas and Stephen Jay Gould, for example, each combine depth of insight with a smooth, articulate writing style. Their writing is more than informative, it is a pleasure to read.

I am an essay addict. Perhaps because my brain cells can only absorb ideas in small doses, I find a short, well-written piece, developing one theme, a joy. When I read or reread the essays of Lewis Thomas (*The Lives of a Cell* and *The Medusa and the Snail*) or Harold Morowitz (*The Wine of Life and Other Essays on Societies, Energy and Living Things*), I ration myself to one or two a day, as I would with chocolate candies. I want to spread the enjoyment out for as long as possible; each essay is so rich, in ideas rather than calories, that it deserves to be savored as an independent unit.

I think the attraction of these authors is that they are good scientists with good ideas and a real humanity. Not everyone will agree with all their scientific notions, but they clearly explain the views they hold, buttress them well with facts and, perhaps most importantly, reveal their humanity as they go along. They present themselves as well as their scientific views in their writing; that is what gives them their wide appeal. They make biology a very human enterprise. By discussing the parts of biology that interest them and why, they reveal to the nonscientist the fun in science. They convey to the reader their obvious delight in learning and discovery, in trying to figure out the mysteries of nature and life.

Stephen Jay Gould (*Ever Since Darwin* and *The Panda's Thumb*) is another master of the essay, but his pieces are less personal. In *The Panda's Thumb* he



Courtney Smith From "RE:SOURCES"

writes that he promised himself when beginning these essays that. "I would not tell the fascinating tales of nature merely for their own sake. I would tie any particular story to a general principle of evolutionary theory." He has kept his word. Each essay is a simply told, logical and fascinating exposition of some often-subtle point which Gould handles so expertly that the reader can grasp the most difficult concepts. And this is all done in eight or ten pages.

I am including in this survey of biology writers those in the medical field because it happens to be of special interest to me–this column isn't claiming to be anything but personal–and because there are writers in this area who are too good to miss. June Goodfield's *The Siege of Cancer* is not an exhaustive survey of the subject, but an investigation into several types of cancer research. It gives insights not only into the cancer problem but into the scientific enterprise. *The Body in Question* by Jonathan Miller is an interesting approach to the history of medicine. He stresses the interactions among medicine, science and technology; how for example, the concept of the heart as a pump could not develop until after mechanical pumps had been devised. Finally, *Mirage of Health* by René Dubos has influenced my thinking on health and disease for years. He argues that although diseases may subside or disappear, disease does not. Dubos has also written several rather philosophical works including *So Human an Animal* and *The Dreams of Reason*. Biology teachers can sometimes become obsessed with facts, and books like these remind us of the philosophical underpinnings of science.

Finding a new author is like discovering a new world: It means seeing the world through a brand new pair of eyes. I recently read Roger Swain's *Earthly Pleasures*, a group of essays on gardening and botany that is full of information on such topics as parsnips, philodendrons and maple syrup. Each blends biology, folklore and common sense with insights into the relationships between humans and the rest of nature. I live in a large apartment building and own only half a dozen plants, but Swain fascinated me with instructions on how to start a beehive and what to do about a hungry woodchuck.

Because there are so many good writers, there are always good books waiting to be read. Right now I am looking forward to reading June Goodfield's *An Imagined World*, a book that follows the research of one scientist, an immunologist. It is an investigation into the day-to-day work of research and into the mind of one researcher. *Bumblebee Economics* by Bernd Heinrich is another work that has received good reviews and seems fascinating even to someone–I suppose a biologist shouldn't admit this-who is not too thrilled with insects.

I am running out of space, but there are a few other favorites I want to mention. I was trained as a biochemist, so my exposure to zoology has been minimal. Archie Carr's books on sea turtles, *The Windward Road* and *So Excellent a Fishe*, made me regret my narrow education. Then I read Victor Scheffer's *The Year of the Whale*, and that has sent me to the library for more works by zoologists and naturalists to ease my ignorance enjoyably.

Finally, P.B. Medawar's *Advice to a Young Scientist* is a book for all scientists and for those who teach them. It is a very personal and insightful book, though I do not agree with his every word, especially:

> Science does not have a major bearing on human relationships . . . on the causes of exaltation or misery and the character and intensity of aesthetic pleasures.

I think many of the books I have mentioned prove the contrary. Their authors have sought and found the relationships between science and humanity; that is what makes these works so appealing. They help us as teachers to see how our discipline relates to the larger world. I think they would do the same for our students if we encourage them to sample what's available. Finally, each of these books is a good read. Someone else's list of favorites might be very different, but I chose to include here only those works that still excite me when I thought of them, that still evoked a feeling of pleasure. When a semester is going badly, when exhaustion seems to be the only result of my labors, reading one of these books is sure to make me realize that biology is still fun, still filled with wonder and still a very human enterprise.

Since this column was published, many of the authors I mentioned have written other equally good books. These include Roger Swain's Field Days; *Lewis Thomas's* Late Night Thoughts on Listening to Mahler's Ninth Symphony *and* The Youngest Science; *P.B. Medawar's* Pluto's Republic, The Limits of Science *and* Memoirs of a Thinking Radish *and Harold Morowitz's* Mayonnaise and the Origin of Life. *Stephen Jay Gould has been the most prolific with* Hen's Teeth and Horse's Toes, The Flamingo's Smile, An Urchin in the Storm, Time's Arrow, Time's Cycle, *and* Wonderful Life.

September 1982

Turning Teaching Around

I look forward to reading anything by Lewis Thomas (*The Lives of a Cell* and *The Medusa and the Snail*), but as a teacher I particularly enjoyed "The Art of Teaching Science" (*The New York Times Magazine*, March 14, 1982). Thomas says flatly that our approach to teaching science is all wrong. We are stressing facts and making those facts seem somehow better, more valid, than facts in other disciplines. In the process we are overwhelming our students, making them feel that this body of knowledge is too large and complex to master.

Thomas suggests that we turn things around and stress what we don't know. With most sciences still in their infancy, the facts of science are not unchangeable, but highly mutable, as we discover when we delve deeper into the world around us. In many ways the sciences are no more objective or unalterable or unambiguous than the humanities. All these disciplines are human creations and, as Jacob Bronowski has shown in *Science and Human Values*, the creative process is the same in the arts and in science.

The idea that the foundations of science are not as firm as we might assume is disturbing for many of us who were never taught this. Most of us were trained in a positivist tradition, so it's natural for us to approach teaching in that way. The idea of getting up in front of students and saying "We don't know this and we don't know that," at first seemed absurd to me. But as I mulled it over, it became an exciting possibility. It doesn't mean throwing out the entire body of knowledge accumulated over thousands of years, but approaching it from a different angle that may give students a better idea of what science is all about.

With our present approach, it's hard for students to appreciate the marvelous process of scientific discovery. Since we give them the end-product, it's impossible for them to visualize the situation that existed when such information was unknown. The wrong turns of a hundred years ago in the development of ideas on proteins, for example (*Annals of the New York Academy of Sciences*, Vol. 325), seem stupid in light of what we know today. But they become more understandable if we look at some present-day unknown like the biological basis of memory, explore the possible explanations and examine the number of blind spots that exist in our understanding of brain processes, making a definitive explanation of memory impossible at this time.

In *The Search for Solutions*, Horace Judson uses examples from all the sciences to explain the process of science in a more realistic way than most textbooks do and more in line with what Thomas suggests. Judson emphasizes the unity of science by discussing basic themes–pattern, change, chance, feedback–that run through all the sciences. In talking about evidence, modeling and predictions, he shows what a theory is and is not, and how theories develop. We often present our students with theories in a congealed form, as if they were etched in stone. Judson shows that the production of theories is a dynamic process in which the human mind is really at play, developing all kinds of outlandish ideas. Sir Peter Medawar has said that "Scientific reasoning is a kind of dialogue between what might be and what is in fact the case." This interplay is much more exciting to students than an endless barrage of facts.

Of course, many of these theories die soon after birth; they don't conform with available facts. Others may linger for awhile before they're proven untenable. But these aborted theories are often as useful as those proven right since they goad thinking, force experimentation and push the mind in new directions.

Thomas emphasizes the tentativeness of theories: "Next week's issue of any scientific journal can turn a whole field upside down, shaking out any number of immutable ideas and installing new bodies of dogma." In one of those coincidences which make academic life exciting, the very next day after reading Thomas' article, I saw an article in *Science* (March 12, 1982) reviewing the work of Jesse Roth and his associates who have developed a new theory of hormone function and evolution.

When Roth found insulin receptors in the brain, he began to question one of the basic concepts of endocrinology, that only specialized glands make hormones. Roth reasoned that since insulin can't penetrate the blood-brain barrier, the brain itself must make insulin. This turned out to be true not only of the brain, but of the testes and liver as well. Roth then searched farther afield and found insulin-like material in flies, worms, protozoa, fungi, and even in *Escherichia coli.* He also found several other peptide hormones in primitive organisms. But what are they doing there? Roth argues they may be used in an ancient form of cell-to-cell commmunication, and hormones may have begun as such cell tissue factors. As organisms became more complex, and cells became highly specialized, certain cells overproduced these substances, which then came to be used in different ways by the body. Many present-day hormones still act locally as tissue factors which would explain the presence of insulin in the brain and other tissues. Roth also thinks that exocrine and endocrine functions overlap. Since at the unicellular level there is no such distinction, it must be a later evolutionary development. This would explain why hormones like gastrin, luteinizing hormone-releasing hormone, the prostaglandins and prolactin are found in exocrine fluids–saliva, semen and milk.

This is a new and different way to look at hormones. Whether this theory is right or wrong perhaps isn't as important as the fact that it's exciting. A field that might appear humdrum suddenly has new life. Even if it is wrong, this theory will spark a great deal of research; in fact, it already has. Hormones have been found in tissues and organisms which in terms of the old theories were very unlikely locations; no one even looked for them there until the old theory was questioned. I think it's important for students to see that the value of a theory is not just in its rightness, or even primarily in its rightness, but in its ability to stimulate the mind.

But even "successful" theories are always tentative. They are just the best the limited human mind can come up with at a given moment. Newton's mechanics had to be modified by Einstein's relativity. And in this year of the 100th anniversary of Darwin's death (April 19, 1882) and of court cases involving the teaching of creationism, there is a great deal of discussion about the validity of Darwin's theory of evolution. Biologists aren't questioning the fact of evolution, but the means by which evolution takes place. Stephen Gould, in an article on Darwinism (*Science*, April 23, 1982), defines it in terms of two claims: First, natural selection is creative; and second, it operates through the differential success of individual organisms. Gould contends that many ideas on evolution that are considered important today, including neutral selection, punctuated equilibrium and selection among genes and species as well as among individuals, are not legitimate in terms of strict Darwinism. He isn't saying that Darwin's theory is dead, that it no longer has validity, but that it must be modified or, as he puts it, expanded. Evolution is such an intrinsic part of biology that it may be difficult for students to understand how such a powerful theory can be questioned unless they have been given some understanding of the tenative nature of theories.

> *We think we're making science look good by stressing objectivity, but often all we do is make science look inhuman and sterile. . .*

Powerful theories are those that are strongly predictive, that explain a great deal. But every theory has its limits, and when those limits come to be explored and tested, then even the most powerful theories must suffer the fate of all theories-they must be questioned, altered and perhaps even abandoned. Considering the very limited amount of information upon which many theories are based when first formulated, it's amazing how accurately they are able to predict. There was no direct evidence for Einstein's theory of general relativity when he published it, and though Darwin buttressed his theory with a multitude of careful observations and experiments, the information available to him on the fossil record and on genetics was extremely scant when compared to what exists today. The brillance of these men becomes apparent when you consider the factual darkness in which they worked.

Not only do we make theories seem immutable, but we also, as Thomas says, make the facts of science seem somehow better than facts in other disciplines. We stress facts in our presentations and demand facts back from our students on exams. There is a reason for this. Concepts and theories are based on facts and are meaningless without them. But the opposite is also true. In an article on the role of factual knowledge in biology teaching (*ABT*, October 1979), Thomas Mertens declares: "Facts, as isolated fragments of information, are meaningless and are not useful to the scientist or the science student. Facts must be related to concepts and principles if they are to be meaningful." Facts must be used as a means to an end, as in problem solving.

Not only should we be sparing in our use of facts so they don't overwhelm concepts and our students, but we should also show that facts are not always as solid and immutable as they may appear. Some facts turn out to be just plain wrong, and others must be carefully qualified. In *The Search for Solutions*, Judson downplays the importance of facts in developing theories. Theories seldom arise from induction, but from a much more creative act, a subtle interplay of fact and imagination.

Experimental data can even mislead. They may turn out to be wrong or not as significant as was thought. The fact that DNA was composed of only four types of building blocks, nucleotides, while proteins were composed of twenty amino acids, for years led people to assume that DNA was far too simple to possess genetic information, that only protein could fit the bill.

While a good theory is powerful, has a wide scope in that it can predict a great deal, a fact–no matter how good, how carefully arrived at–is very limited. It tells you something about a particular situation and nothing else. Trying to extrapolate from that situation to others may be possible, but it's often dangerous. Facts can't be stretched too far.

How difficult interpretation can be is pointed up by two recent articles on cancer research. In a review article in *Science* (January 8, 1982), Robert and Wanda Auerbach show that even small differences in location within the body trunk can make a big difference in how cells function. For example, there is a higher mitotic index in the epidermis surrounding wounds in the anterior part of the body as opposed to those in the posterior. Cells, both cancerous and normal, behave differently when inoculated into different areas of the trunk. And when pellets of the carcinogen methylcholanthrene are implanted subcutaneously in mice, implants in the axillar region produce tumors more readily than those in the inguinal region. These results can be explained by regional differences in vascular supply, pattern of nervous system development, temperature differentials and metabolic gradients. Obviously, if these factors aren't taken into account in experimental design by standardizing the body location of the procedure involved, the facts generated by such an experiment may be meaningless.

"Tumors: A Mixed Bag of Cells" (*Science*, January 15, 1982) points up a source of variability in cancer research that is only beginning to be appreciated. A single cancerous tumor is composed of a mixture of cells with different properties. Some cells are more able than others to spread to different parts of the body, to resist chemotherapy and to avoid immune attack. If this is the case, then assuming a tumor to be a homogeneous group of cells can be dangerous for the patient. A particular therapy may seem effective, but it may be useless against a small population of cells that continue to proliferate. At the moment most drug screening procedures don't take this cell heterogeneity into account. This new evidence may help to explain certain facts that before were inexplicable, that didn't fit in with the established theories, for example, the flare-up of cancers that were thought to be cured. *(Update: A great deal of evidence supports the idea of tumor cell heterogeneity and indicates that tumor cells can accumulate mutations and become more and more abnormal [Science, 246].)*

Students must also appreciate subtle forces that act on the production and interpretation of facts. Observation is always affected by theory. Certain experiments are done and other topics left unexplored because of the intellectual climate of the time. *The Mismeasure of Man* by Stephen Gould is a study of craniometry and intelligence testing and of how the data produced by these techniques was used to "prove" theories about differences in intelligence among races. Gould shows the danger of using scant data to substantiate large theories and of formulating questions so only one answer is possible–the one sought by the questioner. He condemns biological determinism because it is based on two fallacies relating to how facts are used. The first is reification, converting abstract concepts into entities, as we've done with the concept of intelligence. The second fallacy is ranking, our tendency to order variation on a gradual ascending scale. Ranking ignores the fact that variability does not necessarily imply differences in value.

Gould shows not only how limited facts were used to bolster the theory of racial differences in intelligence, but also how the facts themselves were distorted; facts that didn't fit with the theory were ignored. Though we condemn the misconceptions bred by this line of research, we can't just dismiss it as the work of prejudiced minds. We are all biased. As Gould says, "I criticize the myth that science itself is an objective enterprise, done properly only when scientists can shuck the constraints of their culture and view the world as it really is. Science, since people must do it, is a socially embedded activity."

Though one of the hallmarks of science is objectivity, total objectivity is impossible, an idea we don't always convey to our students. We think we're making science look good by stressing objectivity, but often all we do is make science look inhuman and sterile, while, as Thomas says, it is as passionate as art or literature.

Stressing that science is a very human endeavor will make it more attractive to students. It will prevent them from being so in awe of science that they are afraid of it, and it will also prevent them from expecting too much of science, which has led to today's disenchantment with it. Humans are imperfect, therefore the scientific enterprise is imperfect. *The Nobel Duel* by Nicholas Wade illustrates this well. It's the story of the competition between Andrew Schally and Roger Guillemin to find the hypothalamic hormones or releasing factors that control the production and release of hormones by the anterior pituitary. Many consider the competition between these men useless and wasteful because they duplicated each others' work and refused to share data. On the other hand, the work was so tedious, time- and energy-consuming, and discouraging that perhaps neither would have succeeded without a competitive spirit that sometimes bordered on the fanatic. Obviously, personality played a large role in the conduct of this research. As Wade says, "They would not have achieved what they did, if either had ever had any sense of moderation." It is a classic, though extreme, example of how human science is.

Thomas says that science teachers have taken the fun out of science, and K.C. Cole (*The New York Times*, April 1, 1982, page C2) makes a similar point: "Science is too lovely to be left to the scientists." We chose careers in science because we thought it was lovely and exciting; Judson talks of the "rage to know" that infects scientists and of the unspeakable joy of discovery. Part of our problem in teaching is that we think the beauty of science is self-evident. We feel we don't have to work at getting students to see it; it's just there. But for many students, all that's apparent are facts and unpronounceable terms. We were attracted by the wonder of discovery, and we deprive our students of that wonder by stressing the known. Starting with what we don't know gives an opportunity not only to present the process of science more realistically, but also to put some mystery back into science. As Thomas says, it's the mystery that makes science engrossing.

January 1983

Naturalists

My last two columns have been devoted to molecular biology, which, I again confess, is my favorite branch of biology. However, my recent reading has reawakened in me an interest in nature originally sparked when I was a high school freshman. The homework assignment for spring vacation was to "notice the signs of spring around you." Everything seemed much more alive and fascinating that spring, but unfortunately, my interest wasn't intense enough to be self-sustaining, and my teachers in later years were more concerned with pounding the phyla into my head than with getting me to experience the intricate beauty of living things. Lately I've been making up for lost time by reading the works of naturalists.

The book that really got me hooked on natural history is *The Outermost House–A Year on the Great Beach of Cape Cod* by Henry Beston. Last year I was visiting Cape Cod for the first time and I wanted to learn something about the area, so I picked up a paperback copy of this 1928 classic. For one year, Beston lived alone in a two-room cabin on the dunes of Cape Cod's outer beach facing the Atlantic. This was a relatively unpopulated area in the 1920s, even in the summer, so Beston had direct and relatively uninterrupted contact with Nature. Being alone he had the time not only to observe carefully, but to reflect on what he observed. And, fortunately for us, he had the ability to convey his observations and musings to his readers in beautiful prose. He noted changes in the sea and in the creatures that depend on the sea for life–migrating birds, maritime locusts, swarming amphipods. And he described what seems to me to be the essence of natural history and the goal of the naturalist:

> To be able to see and study undisturbed the processes of nature–I like better the old Biblical phrase "mighty works"–as an opportunity for which any man might well feel reverent gratitude, and here at last, in this silence and isolation of winter, a whole region was mine whose innermost natural life might shape itself to its ancient courses without the hindance and interferences of man.

A naturalist can be defined as someone who studies animals or plants, usually at a nontechnical or even an amateur level. But the more I've read, the harder I find it to define the breed. Some are obviously amateurs while others have dedicated their lives to the study of the life around them. But what all naturalists have in common is a love of Nature. As Alan Ternes, editor of *Natural History*, says in an introduction to a collection of articles from that magazine (*Ants, Indians, and Little Dinosaurs*): "Naturalists may attempt to achieve a scientific objectivity toward the creatures they study, but fortunately for editors they fail."

There have probably been naturalists around as long as there have been human beings; the caves of Lacaux attest to that fact. Humans have wondered about nature even as they tried to control it. That has certainly been true of the development of the New World, though the contemplation and the controlling weren't necessarily done by the same people. *A Species of Eternity* by Joseph Kastner is a history of naturalists in America during the 18th century and the first half of the 19th, or more accurately, it is a history of the United States from the naturalist's perspective. Drawing on the writings of these naturalists, Kastner portrays the biological richness and abundance of this continent before civilization tamed it. These men could reach wilderness simply by walking out of Philadelphia, the center of natural history at the time.

Kastner describes Charles Wilson Peale's natural history museum in Philadelphia, and how he organized the country's first paleontological dig. He also recounts Lewis and Clark's trek west and the wanderings of Audubon. He introduces other naturalists who are less well known, at least to me–Alexander Wilson, Audubon's predecessor in bird portraiture; Constantine Rafinesque, a genius at identifying new species;Thomas Nuttall, an absentminded, but brilliant botanist. Toward the end of the book, Kastner discusses "The Closet Botanists," John Torrey of Columbia University and Asa Gray of Harvard. They did not collect specimens for themselves, but instead studied the results of other collectors' labors. By 1850, the era of freewheeling naturalists who considered the entire country their field of study had come to an end.

Kastner is saddened by the end of this era of bounty and freedom, but it was inevitable that naturalists would change as the country changed. That doesn't mean, however, that naturalists aren't still roaming the land. It's just that their training and approaches are different; they are more likely to fly or drive now, rather than to tramp over long distances on foot. Botanist May Theilgaard Watts traveled by plane, train and car to gather information for *Reading the Landscape of America*, which depicts the different ecosystems within the United States. But Watts doesn't just describe a particular bog or river valley or forest; she tells how and why it slowly got to be that way; how fires, glaciers, or man have affected its development and what changes can be expected in the future. She walks across dunes and shows how wind ordains not only the contours of the landscape, but what type of vegetation will grow there. She literally reads the landscape, and what makes her book so fascinating is that she derives so much information from what she reads. She can even read in the dark! In one essay, she describes the changing silhouettes on a night train ride from Chicago to Denver.

A major asset of Watts' book is that in many cases she revisits areas she had explored perhaps 20 years before. In some, she finds few changes except those wrought by natural forces. In others, the effect of man's hand has been tremendous. Drainage can change a bog and split-level homes can alter dunes with a speed that nature cannot imitate. Aldo Leopold presents that same theme in *A Sand County Almanac*. Though originally published in 1949, a year after Leopold's death, it could easily have been written during the height of the ecology movement in the 1970s. The dangers that Leopold saw have only intensified with time. But I can't say that I enjoyed this book, though his descriptions are vivid and full of love. Perhaps it wasn't meant to be enjoyable, but to disturb, to act as a spur to action, as Rachel Carson's *Silent Spring* did in the 1960s. But it seems to me that *A Species of Eternity*, without ever hammering home the point, made the best case for preserving our environment by describing the abundance and variety that existed almost everywhere in this country 200 years ago.

Few places in the United States have been altered so profoundly as New York City, my home. Wall Street originally got its name from the barrier erected there to keep out the wilderness that extended northward over the rest of Manhattan Island. In the 1700s, going to Harlem was visiting the country, and it took a day to get there and back from lower Manhattan. (Of course, it can still take a day if the Lexington Avenue subway breaks down!) John Kiernan's *A Natural History of New York City* contains many such intriguing facts about New York. He writes that minks still occasionally wander down to the Bronx from the more rural areas of the state, and that this borough also harbors the city's last stand of virgin forest. Most of the book is a catalogue of the plants and animals to be found within the city's limits. This can become tedious at times, but it does give an idea of the surprising variety of organisms that can adapt to so altered an environment. It also made me want to help preserve what is left, to keep New York as biologically rich as possible.

All naturalists are careful observers. Things catch their eye that are completely missed by the untrained observer. Most of us don't have the patience–and patience seems to be the key ingredient–to sit still and let nature tell us secrets at its own pace. *Curious Naturalists* by Nikolaas Tinbergen is full of the fruits of careful observation. Tinbergen won the Nobel prize in 1973 along with Karl von Frisch and Konrad Lorenz for their work on animal behavior. He has followed many lines of research, most of them dealing with insects and birds. He describes how he decided to study animal behavior when, as an aimless zoology student, he started to observe the habits of the digger wasp, *Philanthus*, while on summer vacation. From there he went on to work with Snow buntings, sand wasps, graylings, kittiwakes and Black-headed gulls. In each case, he devised simple, but ingenious and fruitful, experiments to dissect complex behaviors and determine what triggers various responses in these animals. He went far beyond simple observation of animals in their environments; he manipulated those environments to get at least partial answers to such questions as how do animals home, and what triggers mating behaviors. Tinbergen and others like him prove that while natural history may be nontechnical, it nonetheless can yield scientifically sound results.

Other naturalists observe rather than manipulate, but that doesn't mean that we can't learn a great deal from their work. There are dozens of these individuals who have committed their careful observations to writing and have thus enriched both our intellects and our spirits. As Loren Eiseley, himself a writer and naturalist, mused in *The Night Country:*

> . . . one feels at times that the great nature essayists had more individual perception than their scientific contemporaries . . . The world of nature.once seen through the eye of genius, is never seen in quite the same manner afterward. A dimension has been added, something that lies beyond the careful analyses of professional biology.

There are many writers who have seen the soul of man in nature, who have deepened our appreciation for the life around us and for our own humanness as well. Thoreau, of course, is one. Eiseley himself, in such books as *The Immense Journey*, is another, though I find his writing a bit florid. And a more recent addition to this literature is Peter Mathiessen's *The Snow Leopard*, an account of his journey through the Himalayas. But for prose of poetic beauty I don't think anyone could improve on the writing found in *Travels*, William Bartrams' journal of his four-year trip (1773-1777) through the Carolinas, Georgia and Florida.

One of my new favorites is an old book that was recently returned to print. It's *The Desert* by John C. Van Dyke. In the last years of the 19th century, Van Dyke, a professor of art history, roamed the deserts of the Southwest. He recorded not only what he observed, but his thoughts and emotions as well, as he ranged over one of the most daunting of ecosystems. I've never visited desert country, but if I do, I'll appreciate the experience much more because of Van Dyke's writing. I'll feel the desert's atmosphere more acutely and observe its life more carefully.

As I experience the desert with Van Dyke or Cape Cod with Beston and John Hay (*The Great Beach*) or the sea with Rachel Carson (*The Sea Around Us*), my only regret is that I didn't discover the joys of natural history sooner. Now that I have discovered nature, I want everyone to be so blessed! I don't want my students to have to wait until they're middle-aged for the light to dawn on them. Most of my students are nonscience majors; their lives are not going to be dedicated to science, and many of them come to me with a definite prejudice against science. Talking to some of them makes C.P. Snow's two cultures look very real.

If their interest in nature could be sparked, as mine was, then perhaps they would want to know more, rather than being coerced into learning more. There is a national outcry at the moment about the poor level of science education for those not training to be scientists. I think that one way to overcome this problem is to make ourselves into a nation of naturalists. Since many naturalists are amateurs, anyone can join their ranks. And as people become more aware of the life around them, they may begin asking questions about how this life developed, why animals behave as they do, or why plants grow where they do. They may begin to wonder at how organisms respire and photosynthesize and reproduce. They may come to the study of science willingly, rather than reluctantly. Not only would our problem of scientific literacy wane, but the goal of preserving the environment might prosper.

This isn't a far-fetched idea. Many of the great naturalists of the past were amateurs. Theodore Zeldin in *France: 1848-1945* observes that:

> In the eighteenth century, the study of science was a common hobby among educated men of leisure . . . A list has been compiled of nearly 500 people known to have had *cabinets d'histoire naturelle*-aristocrats, priests, actors, collectors of taxes, factory inspectors, and the duc d'Orleans's chief cook.

Many of the early naturalists in this country were clergymen (John Banister, the New World's first resident naturalist), politicians (Samuel Latham Mitchill, whom Jefferson called "the Congressional Dictionary") and military men (John Charles Fremont, the "pathfinder of the West").

I think it's possible to renew this trend with the help of the books I've discussed as well as a host of others. It's conceivable that an ever-larger portion of the population can experience nature and feel what John Kirk Townsend, a physician and pharmacist, described in 1834:

> None but a naturalist can appreciate a naturalist's feeling-his delight amounting to ecstasy-when a specimen he has never before seen meets his eye, and the sorrow and grief which he feels when he is compelled to tear himself away from a spot abounding with all he has anxiously and unremittingly sought for.

February 1983

The Importance of Trivia

I enjoy trivia, although I don't know the pitchers in the last game of the 1953 World Series or who played Clarabelle in "Howdy Doody." I'm interested in biological trivia, like the fact that the human body breaks down more than 2 million erythrocytes each second, or that, on rare occasions, a human being is born with a tail. My students also seem interested in such facts. These rather useless pieces of information stick in their minds the way chewing gum sticks to the sole of a shoe; my sister still remembers the human tail story from a biology course she took 15 years ago. But are such inconsequential bits of information really useful in teaching, or do they just eat up classroom time and clutter students' brains?

The Tale of a Tail

I think the answer depends upon how we use such tidbits. Recently, after a discussion of birth defects, my students arrived at the next class with clippings from several newspapers reporting the birth of a child with a tail. Everyone was interested. The human mind, and particularly the student mind, craves novelty, and this new item had the added appeal of being a bit bizarre. The tail reminded everyone of our primate ancestry.

Luckily, I was prepared to meet their interest. I had just read the report on which the news articles were based, because the story fascinated me as much as it did my students (*The New England Journal of Medicine*, May 20, 1982). As Fred D. Ledley admits at the beginning of this article: "The birth of a child with a caudal appendage resembling a tail generates an unusual amount of interest, excitement, and anxiety." But Ledley does more than describe this case. He takes this rare anomaly and gives it significance by using it to illustrate several important points.

This anomaly is very uncommon; this was the first reported case at Children's Hospital Medical Center in Boston since 1936. Nor can it really be called a tail. There are several morphologic differences between this 5.5 cm long caudal appendage and the true tails of other vertebrates. The caudal appendage had no vertebral structures, while normal vertebral tails always contain caudal vertebrae. It was composed of a fibrous, fatty core covered with normal skin containing dermal and epidermal layers and hair follicles. Also, the appendage wasn't at the end of the vertebral column where a tail is normally found. Instead, it was attached to the back of the area of the sacrum and about 1.5 cm to the right of the midline.

How does such a structure arise during the development of an otherwise normal individual? Ledley looks to studies on mutant tails in mice for an answer. In the truncate or boneless phenotype, the notochord doesn't extend properly into the tail of the developing embryo. Without the presence of the notochord, somite cells in the area degenerate. With no neurotube or neural cord, the embryonic tail constricts, leaving a filamentous appendage that is often found displaced from the midline.

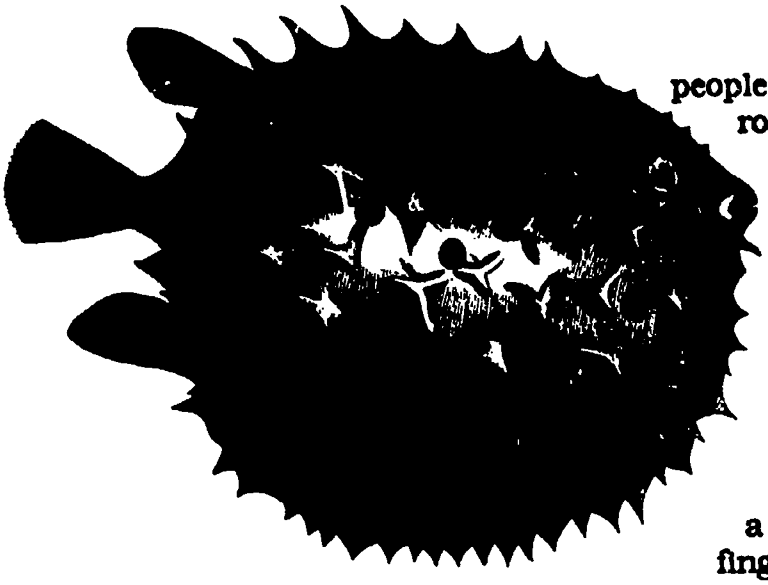
Ledley uses this lesson in comparative embryology to make two points. First, the human caudal appendage doesn't support the theory of Haeckel that "ontogeny recapitulates phylogeny," though it was cited in this context in the 19th century. The caudal appendage doesn't signify a reversion to our ape ancestry any more than the mouse with truncate phenotype represents a regression to a lower vertebral form. Secondly, the structural elements in the human caudal appendage are almost identical to those in the tail of the truncate mouse, so that their origins may be similar, although normally one species ends up with a tail and the other one doesn't. The morphological development of a tail depends upon a precise temporal sequence and spatial relation among caudal structures during a critical period. Thus, if the timing of tail-bud formation isn't correct, or the spatial relation between the notochord and adjacent structures in the developing tail is off, the result will be an abnormality such as the truncate phenotype in mice or the human caudal appendage.

Comparative studies of the proteins and DNA of humans and chimpanzees show about a 99 percent identity between the two species. The rather large differences between them in appearance and behavior between them are attributed to differences in regulatory genes that control the timing and kinetics of gene expression. Thus, the caudal appendage shows that at least some of the structural elements necessary for tail formation remain in the human genome, and that some as yet unknown abnormality in gene regulation allows them to be expressed. Therefore, teratology, the study of malformations, may be able to tell researchers something about gene regulation and the processes of development.

Ledley has taken a rare and benign anomaly–one might say a piece of trivia–and used it to illustrate several points about the history of science evolution, development and gene regulation. Mentioning in class that sometimes a baby is born with a tail may make students wake up and take notice, but the effort is wasted if it goes no further. We have to do what Ledley has done. After getting their attention, we have to capitalize on our ploy and lead them further into a discussion of basic concepts that are worth remembering more than a tale about tails.

The Fatal Fugu

Fugu is a tropical blowfish that, though highly poisonous, is considered a gourmet food in Japan (*Science* 82, September). It is relatively safe if prepared correctly, but fugu still was responsible for 60 deaths in Japan in 1980. Why do



people continue to play Russian roulette with fugu when there are plenty of other fish in the sea? Apparently they get a zip out of fugu. Even when properly prepared, which involves removing the skin and viscera and washing the muscle, the fish still contains enough of the poison, tetradotoxin, to cause a tingling sensation in the fingers, toes and tongue. So fugu fanciers are getting more than protein from their meal.

The Food and Drug Administration has prohibited Japanese restaurants in this country from serving fugu, so our students are unlikely to encounter it. But it's worth mentioning because it's a great way to introduce a discussion of food additives and put this often controversial subject into perspective. Butylated hydroxyanisole (BHA) or sodium benzoate might not whet their appetites for this topic, but a little-known fish that packs a wallop might.

After cyclamates and saccharin, the public has become suspicious of food additives and likes food to be "natural," but the fact remains that food additives are difficult to eliminate. They do have a role to play in making packaged foods available. Sodium nitrate does prevent botulism, and BHA does prevent fats from becoming rancid. Nor are even the most natural of foods free of suspect substances. Much of the sodium nitrate we consume comes not from bacon and ham, but from green vegetables like spinach. Shrimp contain arsenic, potatoes have the alkaloid poison solanine and the seemingly innocent carrot harbors both the narcotic and psychoactive substance, myristican, and the nerve poison, carotoxin.

I'm not suggesting that we warn our students that vegetables can be hazardous to their health. Most of these toxic substances are present in such small quantities that they produce no harmful effects. In this regard, fugu is the exception that we can use to prove the rule. A discussion of natural toxins can help clarify the food additive question. Adding substances to food can create a health risk, so the safety of these substances must be rigorously tested, but it's impossible to reduce risk to zero–even natural foods have hazards–and a small risk is sometimes more than balanced by a large benefit, as in the case of sodium nitrate (*The New York Times*, December 10, 1981).

Tiny Trivia

Bacterial research is a great source of fascinating trivia, probably because we find it hard to believe that organisms so small can be so chemically complex or that any living thing can survive in the harsh environments some bacterial species find hospitable. Within weeks of the eruption of Mount St. Helens, volcanic lakes were teeming with microbial life (*Nature*, March 4, 1982). In thermal vents deep beneath the ocean, bacteria grow rapidly at temperatures up to 300°C and pressures higher than 200 times atmospheric pressure (*Science*

News, June 19, 1982). And William Ghiorse of Cornell University has discovered bacteria growing in soil samples taken from a depth of 25 feet. Previously such subsurface material was thought to be devoid of life.

Not only can bacteria adjust to widely differing habitats, but they are chemically versatile as well. Though silver is toxic to many bacteria, some can accumulate large quantities of it in the form of silver sulphide granules on their surface. This may make them useful in the recovery of silver from sulphide ores (*Nature*, April 15, 1982). But their chemical versatility can make bacteria a nuisance, too. There is now evidence that microbes can methylate tin compounds, and the resulting chemicals may be toxic. Since tin compounds are found in insecticides, herbicides, fungicides and antifouling paints, large quantities find their way into the environment each year, so the effects of their methylation might be environmentally harmful (*Science*, March 19, 1982).

If any bacterial substance can cause trouble, the botulinus toxin tops the list. But now researchers have found a use for it in the treatment of strabismus, crossed eyes. The toxin prevents nerve cells from releasing the acetylcholine needed for muscle contraction. If minute quantities of toxin are injected into the muscle responsible for the eye cross to prevent its contraction, the muscle relaxes and stretches. The muscle on the opposite side of the eye can then pull the eye back into line (*Science News*, May 22, 1982).

A litany of bacterial properties can be numbing, but used sparingly such facts can bring home the idea of the adaptability of organisms and their chemical complexity. Harold Morowitz makes this point beautifully in an essay called *On First Looking into Bergey's Manual* (in *The Wine of Life and Other Essays on Societies, Energy & Living Things*).

The Difference Between Left and Right

When my husband is driving and I'm giving directions, I usually want him to turn left when I tell him to turn right. I suffer from impaired left-right discrimination. This may not make for marital harmony, but the consequences aren't too dire. I usually correct myself before the turn is made–my husband is getting good at changing lanes–or, at worst, we end up exploring a new part of town. When I mention this defect in class during a discussion of handedness, several students nod in knowing agreement as fellow sufferers. But I was interested to discover that I may have compatriots in the animal world as well.

Migrating birds, though known for their navigational accuracy, sometimes make mistakes that look like real whoppers; they don't end up on the wrong side of town, but on the wrong side of the continent. Members of almost every species of New World warbler (Parulidae) typical of eastern North America have been sighted on the west coast. Though wind may have blown some of them off course, the majority seem to be purposively flying in the wrong direction.They are "misoriented" rather than disoriented (*Nature*, January 28, 1982). Parulid warblers usually fly southeast in autumn. Much of their flight is over water, so they have few landmarks to follow. Immature birds, on their first flights south, seem to be directed by a genetically specified compass, while adult birds have already made one round trip and thus have stored information on direction. Since it is usually immature birds found on the wrong coast, it appears that their genetically controlled orienting system has failed, and they have no past experience to guide them.

Most of these "vagrants" probably die during their wanderings. But two warbler species now have regular West Coast winter ranges as well as their main ranges in the Southeast. The location of these western ranges is consistent with mirror-image migration, so this "misorientation" may have an adaptive advantage if it leads to the development of new wintering grounds.

Though biology teachers must guard against anthropomorphizing, sometimes analogies are valid. It would be interesting to see if the brain lesions that occur in some humans with impaired left-right discrimination also exist in these warblers. And, at the very least, this phenomenon is a nice way to introduce the navigational systems used by migratory animals.

Playing the Numbers

Statistics are a great source of trivia. Too many numbers can make the head spin, but a well-placed statistic is often worth a thousand words. Numbers can make ideas concrete. I'll just mention a few of my present favorites. Seventeen billion cells are sloughed off the walls of the intestine each day. This item graphically illustrates the renewal process constantly going on in the body (*Scientific American*, November 1981). There are more species in the order Coleoptera, the beetles, than in the class Angiosperma and even, perhaps, than in the whole plant kingdom (*Nature*, December 10, 1981). I can't say that this piece of information has increased my appreciation of beetles, but it does point up the great variety in the class Insecta relative to other classes. And speaking of insects, the gut of the termite, *Pterotermes occidentis*, harbors at least 100 species of protozoa and bacteria (*Scientific American*, February 1982). This fact can be used to introduce the idea of the digestive tract as ecosystem. And the unique demands put on cardiac muscle can be illustrated by the statistic that the heart beats 100,000 times a day.

I must admit that in this column I've been guilty of a sin common to those who enjoy trivia: I've overdone it. But I hope I've demonstrated that trivia can be used for more than a trivial purpose. If it is presented not for its own sake, but firmly tied to some basic concept, it can be a valuable teaching aid.

May 1984

Broadening Our Horizons

Last summer my husband spent two months in Paris doing research at the Bibliothéque Nationale, France's equivalent of the Library of Congress. I wasn't that enthusiastic about accompanying him on the trip, but my fear of missing out on something dictated that I go! The trip turned out so well that leaving Paris was difficult. One of the most enjoyable parts of the visit was learning about attitudes toward science in a country with such a rich scientific history and such a commitment toward a scientific future.

We went to the library almost every day, and while my husband delved into 19th century French bourgeois ideology, I explored the history of French science. It was exciting to do research on Louis Pasteur in the city where so much of his work was done and to read Marie Curie's doctoral thesis and early editions of Lamarck's *Philosophie zoologique* in which he presented his evolutionary theories.

I also discovered a great deal about French attitudes toward science just by strolling through the streets of Paris. Much more than Americans, the French revere the memory of those who have enriched their intellectual heritage. There are streets in Paris named after Berlioz, Rossini, Balzac, Victor Hugo and Rodin. There are Metro stations named after Dumas and Zola, and Delacroix graces the 100 franc note. Scientists are by no means shortchanged in these forms of immortality. It could be said that Pascal surpasses Delacroix because he appears on the 500 franc note, and there are Metro stops dedicated to the memory of Louis Pasteur and Pierre Curie. Streets named for scientists are found all over Paris. Pasteur's assistants, Roux and Duclaux, are honored on streets around the Pasteur Institute. The names of Lavoisier, Claud Bernard, Buffon and many others are also found on street signs. Coming from New York ,where most streets are numbered, it's great fun to turn a corner and find a familiar name on a street sign. Of course, finding the street signs isn't always easy since they're attached to building walls rather than to signposts!

Also on buildings throughout Paris are plaques marking intellectually important spots such as the place where Stendhal wrote *The Red and the Black* and where Alexandre Dumas was born. Again scientists are duly represented. In the Rue d'Ulm, on a wall of the École Normale Superieure, there is a plaque enumerating Louis Pasteur's accomplishments during the 24 years (1864-1888) he worked there. In this very unassuming building he did research on such varied diseases as anthrax, chicken cholera and rabies. Just seeing that plaque gave me a thrill. It seemed to bring me close to a man whose scientific achievements I had studied so many times.

On another outing, I passed the Necker Hospital where a sign reminds the passerby that this is where Laennac developed the stethoscope. Wandering around the Ile de la Cité, I found a narrow street behind Notre Dame, where the anatomist and physiologist Marie Francois Bichat died in 1802. It was exciting to come so close to places–and hence to people–that have always seemed so distant, to walk through the Museum of Natural History where Lamarck and Cuvier worked, to see the building in which Becquerel discovered gamma radiation.

> *As teachers, we obviously can't be experts on every country's scientific specialities, but I think we should make our students aware of what it really means when we say that science is an international endeavor.*

Now I fully realize that many great scientific discoveries were made in New York–Avery's work on DNA at Rockefeller University, Morgan's *Drosophila* experiments at Columbia. Perhaps, it was just the excitement of being in a foreign country that made my coming upon these signposts of history so exciting. But I think it was also because I felt proud that scientists are so publicly honored in France. Benjamin Franklin, for example, is more revered in Paris than he is in most American cities. The French think of him not primarily as a political figure–the facet of his accomplishments that Americans stress--but as a savant, a thinker. There is a Rue de Franklin, busts and portraits of him are found in several museums and, at the Musée d'Art Moderne, he is included in Raoul Dufy's huge mural on the history of electricity .

Another thing that makes the history of science so fascinating in this city is that there's so much of it. The Hôtel Dieu, one of Paris's largest hospitals, was founded in 660. The Jardin Des Plantes, the botanical garden on the Left Bank, was established during Louis XIII's reign. For an American 200 years seems like a long time, but in a city with Roman baths (at the Musée de Cluny) and a 12th century cathedral (Notre Dame), perspectives change. In a small park on the Left Bank, in sight of Notre Dame, is a tree said to be the oldest in Paris, planted by the botanist Jean Robin in 1601. Ironically, it is not a European species but a black locust, *Robinia pseudoacacia*, brought back from the then very New World.

Obviously I enjoyed my trip to France, and though I didn't have much direct contact with French scientists, this trip changed some of my attitudes toward science. It helped me to break through my provincialism and see that others view science differently than we do in the United States.

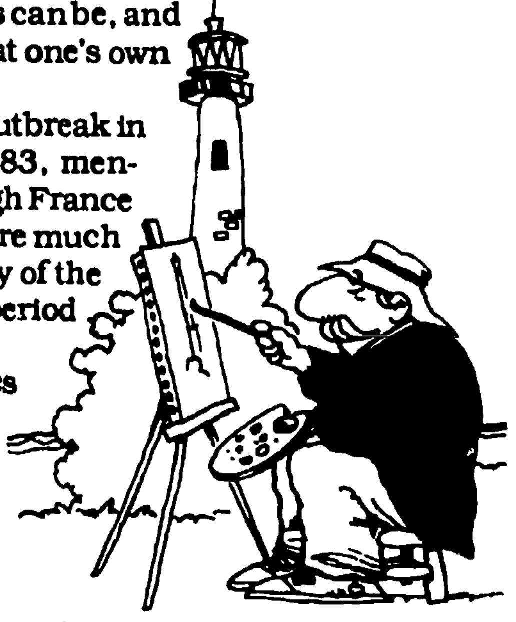
Sometimes the difference in approach is trivial. In nutrition, for example, we organize food into four basic groups–milk products, meats, breads and cereals, fruits and vegetables. The French take the same foods and come up with six groups by creating a separate category for fats and by differentiating between raw and cooked fruits and vegetables. Not surprisingly, I like our system better because it's simpler. But the French can easily justify their approach. Butter does have a much higher fat content than any other milk product, and it's stretching a point to include vegetable oil in the fruit and vegetable category. Also, cooking does, at least in some cases, radically alter the chemistry of fruits and vegetables.

Science is always proclaimed as a universal endeavor, one that knows no national boundaries. Scientific evidence should be freely disseminated throughout the world, and the same experiment, done in five different countries, should yield the same results. This is all true, but it denies the reality that there are, in fact, national differences in the way science is done. Several articles published recently in the Paris newspaper *Le Figaro* illustrate this point. One dealt with the French government's efforts to designate certain areas as *espaces verts*, green spaces. In most European countries there are few wilderness areas comparable to what we have in Alaska or the western states because these countries have borne too large a population for too long. But they too want to preserve what green they have, so they concentrate on smaller areas. While we talk of national parks with thousands and millions of acres, they are concerned with preserving small forests and parks. They are also much more conscious of preserving green spaces in cities. There are beautiful parks all over Paris that are treasured by the inhabitants. This love of *jardins* goes back to the time of the monarchy. Many of the public gardens–the Luxembourg and the Tuileries gardens and the garden of the Palais Royal–were once the private preserves of royalty.

Another article in *Le Figaro* dealt with AIDS, or what the French call SIDA, syndrome immuno-deficitaire acquis (the French do everything a little differently!). It's not surprising to find the French covering a story to which the American press has devoted so much space, but it is interesting to note subtle differences in approach. *Le Figaro* focused on the role of human T leukemia virus (now called HIV) in the disease because work on this virus is being done by Jean-Luc Montagnier at the prestigious Pasteur Institute in Paris. While American reports question the extent of U.S. research, as if AIDS were solely a U.S. concern, the French report stressed the cases in Europe. Reading this report made me realize how provincial the press can be, and how difficult it is to guard against the idea that one's own perspective is the only valid one.

A third article, on the bubonic plague outbreak in Arizona and New Mexico during August 1983, mentioned the plague epidemics that swept through France in 1348 and 1368. These ancient epidemics are much more real to people living in a city where many of the buildings they pass every day date from this period or even earlier.

I think it's important to remind ourselves and our students that our view of science is very provincial. Science is indeed an international endeavor, but in science as in everything else, we are much more aware of what's happening in our own backyard. Of course, scientists and educators in other countries are often just as provincial as we



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are. A book called *Le darwinisme aujourd'hui*, edited by Émile Noël, contains transcripts of radio interviews with leading French experts on evolution. The first chapter is devoted to Lamarck, something that would be unlikely in an English-language book on Darwinism today. While this interview might overstate Lamarck's place in the development of the theory of evolution, it does serve to counterbalance the relative neglect he has suffered in English and American writings where Darwin's name casts a deep shadow over all others. When we think of Lamarck, we think of giraffes stretching to make not only their necks, but those of their descendants, longer. This is a far cry from the French view, expressed at the base of a statue to Lamarck in the Jardin des Plantes where Lamarck served as professor of botany and then of comparative anatomy. There he is described as the founder of the idea of evolution. Lamarck carried on important investigations in the comparative anatomy of invertebrates and used this work to support his theory of continuous organic evolution. The inheritance of acquired traits was, in fact, only a secondary element of his theory (*A History of the Sciences* by Stephen F. Mason).

Le darwinisme aujourd'hui goes on to examine the influence population genetics, paleontology and molecular biology had on Darwin's theory. The treatment is just about what you would expect from an American publication on the same subject. But a glance at the bibliography reveals that virtually all the publications cited are French. Very few of those we consider leaders in this field –Mayr, Simpson, Eldredge, Stanley–appear. I'm not saying that this leads to serious distortion, but it does change the tone and flavor of the presentation. It also illustrates what a serious barrier language presents to the flow of ideas.

The French are painfully aware of this problem (*The Sciences*, December 1982). Many feel publishing in English-language journals increases the impact of their research. At science conferences, even those held in France, up to 75 percent of the French scientists present their papers in English. But when writing for a native audience, they fall into the rut of almost exclusively citing French writers. In *The Logic of Life*, a history of genetics written by the Nobel-winning French biologist François Jacob, the majority of the references are to French scientists. Though the French have obviously played an important part in the development of this field, its history would be approached differently and different trends emphasized if it were written by a British scientist.

The French are not at all unique in this national chauvinism. More than once I've picked up a book in English and realized from the number of references to British writers that the author must be from Great Britain.

Two months in France do not qualify me as an expert on that country, but it did serve to jolt me out of my provincialism. The way we approach science in this country is hardly the only way to do it. Science cannot help but be done differently in a country such as France that has a different tradition from our own. Yet we both share the same basic Western philosophical and cultural tradition. So it is not surprising that approaches to doing science will be even more varied in countries with very different traditions.

As teachers, we obviously can't be experts on every country's scientific specialities, but I think we should make our students aware of what it really means when we say that science is an international endeavor. While scientific results should be the same no matter where the work is done, the scientific process is not without a national character. The results of an experiment may not vary from country to country, but the experiments that scientists choose to do may indeed show such national variance. This, I think, adds to the richness of science rather than detract from it. The English and French, with their love of gardens, put more emphasis on botanical research than we do. A great deal of interesting agricultural research is being done in developing nations where ingenious solutions are being found to the problem of feeding rapidly growing populations. The Chinese are experts at devising inexpensive solutions to medical problems, for example their use of glossypol, a constituent of cottonseed oil, as a male contraceptive.

A small change of emphasis in our courses might make students more aware that American science is just one part of a larger picture; the research problems we choose to tackle here often have little relevance in other parts of the world. For example, a health class presentation on infectious disease might include a discussion of parasites as well as of bacteria and viruses. There are many examples of ecological problems in Asia, Africa and South America. And the flora and fauna of Australia make perfect illustrations of themes in evolutionary biology.

One night in Paris we ordered "Rognon de veau de Madeira" for dinner. We felt that veal cooked with Madeira wine couldn't be too bad, but we were surprised when the waiter asked what wine we'd like with our kidneys! I knew the French word for kidney as *rein*, but I learned that evening that in cooking it's called *rognon*. Neither of us had ever eaten kidneys, and if our knowledge of French were better, I'm sure we wouldn't have ordered them. But we would have cheated ourselves, because this was one of the best meals we had in Paris (and we had many great meals). I think we should expand the menu in our biology courses; we should treat ourselves and our students to a taste of international science. It might turn out to be a pleasant change.

April 1985

Branching Out

When I began teaching 14 years ago, I had a B.A. and an M.A. in biology. I suffered under a delusion shared by many beginning teachers: I thought I knew a great deal about my subject. Surely I knew enough to handle my first assignment, teaching introductory biology to nonscience majors. I easily knew ten times, a hundred times more biology than these students. So, armed with this vast background, and with lessons prepared using the assigned textbook and several backup texts, I confidently entered the classroom. Needless to say, it took no more than a week of teaching to make me realize that all my knowledge was little more than a thin veneer over a vast mass of ignorance.

My students might not have known a great deal of biology, but their very lack of knowledge caused my problem. They wanted to know more, so naturally they asked questions. And as any beginning teacher knows, questions can be deadly. It's like a presidential candidate at a news conference; no matter how many possible questions you've considered, they can always hit you with something out of left field. Do men develop breast cancer? What's a hiccup? Why do prunes have a laxative effect?

I soon discovered that it wasn't so much that I didn't know enough biology, but that I knew the wrong biology. I had taken several courses in biochemistry and molecular genetics, and my master's thesis had dealt with bacterial enzymology. I could have given weeks of enthusiastic lectures on protein synthesis, but the syllabus restricted me to a week, and my students' lack of background limited me to a simple explanation of the process. They rarely asked questions about transfer RNA or DNA polymerase where I could have dazzled them with my erudition. No, they wanted to know if tight jeans really cause infertility in men and what diet pills do to the nervous system.

During that first semester there was little I could do about my knowledge gap. Like most new teachers, I treaded water and tried to stay at least one class preparation ahead of my students. But from then on I tried to branch out, to leave my little world of biochemistry and survey the rest of the world of biology. I gave up reliance on textbooks as major sources of information and started to read rather randomly in biology. It was at this point that I first subscribed to *The American Biology Teacher*, *Scientific American* and *Science*, hoping that these

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journals would help make me a better biology teacher. They certainly helped to keep me abreast of new trends in science and in teaching, but I still had to deal with the gaps in my background.

My students' interests, the topics about which they most frequently asked questions, were my primary guides. Since I was teaching a course that covered the organ systems, I delved into physiology, particularly human physiology, because students were more concerned with what was going on inside their own bodies than with how earthworms or frogs digest or reproduce. At the time, I had neither the knowledge of frogs and earthworms nor the teaching skill to relate the strategies used in our own systems to those used in other animals. When I read Homer Smith's *From Fish to Philosopher* (1953) in which he describes such relationships for the kidney, I realized how this topic could be approached and how interest in the functioning of their own bodies can be used to develop students' interest in other animals. Schmidt-Nielsen's *How Animals Work* (1972) was another fascinating guide in this area.

I must admit that at this point in my development I found Isaac Asimov's *The Human Body* (1963) and *The Human Brain* (1963) useful sources of information to make my presentations more lively; Gustav Eckstein's *The Body Has a Head* (1970) served in the same way. But I did not limit myself to physiology. I also read in zoology-*The Year of the Whale* by Scheffer (1969), entomology-*Life on a Little-known Planet* by Evans (1968) and botany-*Plants, Man and Life* by Anderson (1952). I delved into ecology-*Silent Spring* by Carson (1962) and evolutionary biology-*Evolution and the Diversity of Life* by Mayr (1973). I read classics such as Schrödinger's *What is Life?* (1944) and Cannon's *The Wisdom of the Body* (1939).

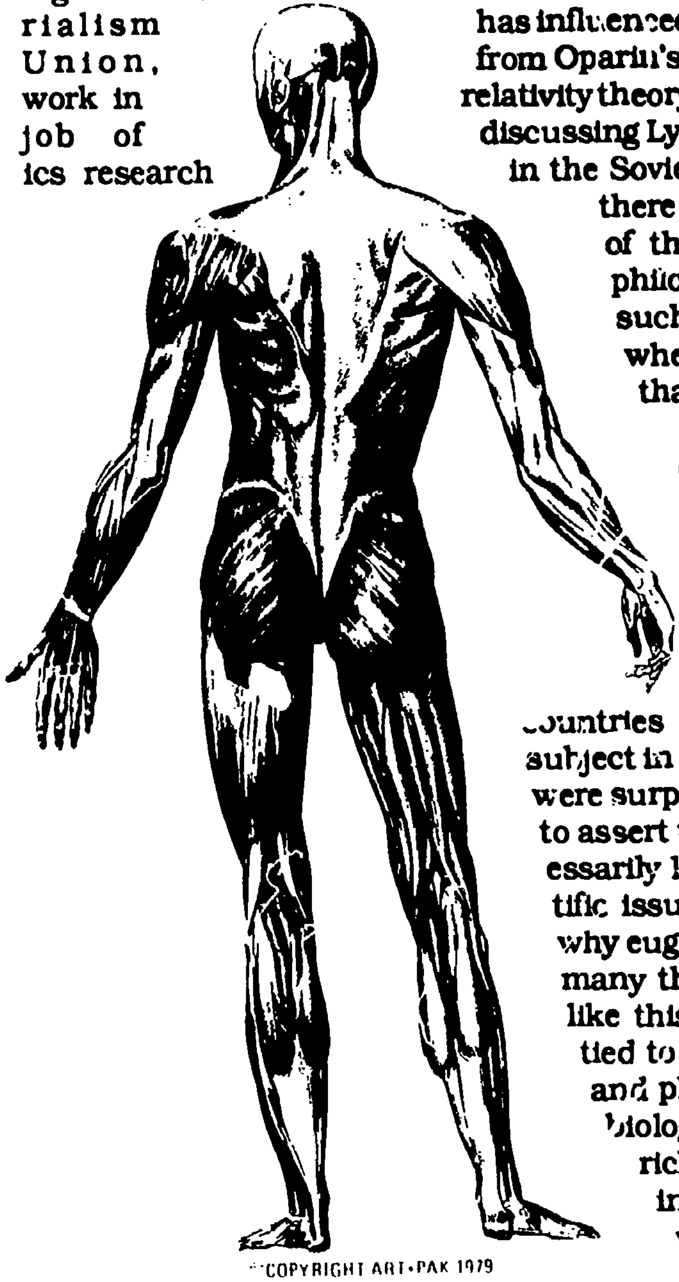
I thoroughly enjoyed myself through all this reading, but I began to realize that to reach my goal I had to learn more than biology. There was a world outside of biology that six years of education in the sciences had made me almost ignore. But to my students this world was very real, and it was biology that was peripheral. Teaching biology to nonmajors, I discovered, requires more than a knowledge of biology; it requires an awareness of biology's links to other disciplines, to the rest of the world. For example, health issues came up constantly. I bought myself Best and Taylor's *The Physiological Basis of Medical Practice* (1966) and read Dubos' *The Mirage of Health* (1959) and Rosebury's *Microbes and Morals* (1973). I even tackled Helpern's *Autopsy* (1977) to satisfy my criminal justice students and Selzer's *Mortal Lessons-Notes on the Art of Surgery* (1976) to please the more poetic members of the class.

Finding answers to health questions rapidly led me into questions of ethics, and *The Hastings Center Report* has been an invaluable asset in exploring this terrain: What are the moral problems involved in embryo research (Abramowitz 1984), in screening for genetic defects (Rosenfeld 1984), in feeding dying patients (Steinbock 1983). I soon realized that I was not only branching out into an exploration of health problems, but philosophical questions as well.

I found reading ethical discussions a bit unnerving at first because the aims of philosophers seem different from those scientists. Scientists try to find answers to questions, while philosophers are more interested in exploring the questions and the consequences of possible answers without necessarily coming down on the side of a particular alternative. But the issues philosophers raise are becoming crucial as the power of biology and medicine increase. The questions involved with genetic engineering are an example of this. *The Limits* *of Scientific Inquiry* (Holton & Morrison 1978), written in response to the early debates on recombinant DNA technology, takes a broad view of the problems and includes contributions from philosophers, historians and political scientists. Such a volume illustrates the variety of links that biology forms with other disciplines. These links can lead not only to enrichment of the fields involved, but also to conflicts between them. If the interests of science conflict with other interests of society, how are these difficulties resolved? In this volume, Loren Graham gives what he terms a "taxonomy of concerns" about science. For example, he differentiates between concerns about technology and concerns about basic research, and in the latter case he further differentiates between research on human subjects and other types of investigations. I found this article helpful because it brought order to issues often lumped together under the heading "Science and Society."

Graham's "taxonomy of concerns" led me to some of his other work, including *Science and Philosophy in the Soviet Union* (1972). This is a fascinating book that discusses how the philosophy of dialectical materialism has influenced 20th century science in the Soviet Union, from Oparin's work on the origin of life, to Fock's work in relativity theory. Though Graham does a thorough job of discussing Lysenko's role in the eclipse of genetics research in the Soviet Union, he makes the point that there are many more interesting examples of the interplay between science and philosophy in the Soviet Union, examples such as research on the origin of life where the effects were positive rather than negative.

In a more recent work, *Between Science and Values* (1981), Graham examines value issues in both the physical and biological sciences. In one chapter he compares the eugenics movements in Germany and the Soviet Union in the 1920s. Though these two countries developed opposite views on this subject in the 1930s, earlier their approaches were surprisingly similar. This leads Graham to assert that differing ideologies do not necessarily lead to different attitudes on scientific issues; he then goes on to investigate why eugenics proved more attractive in Germany than in the Soviet Union. A volume like this illustrates how closely biology is tied to history, political science, sociology and philosophy. But rather than making biology seem less important, it makes it richer and more stimulating by showing how it is tied to the rest of the world.



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Lynn White, another contributor to *The Limits of Scientific Inquiry*, also uses a historical approach which he develops in *Dynamo and Virgin Reconsidered* (1968). He traces the beginning of what C.P. Snow labeled the Two Cultures back to the Middle Ages. In attempting to curb the Thomistic effort to integrate Christian dogma with Aristotelian log, the Church asserted that the type of investigation appropriate to the study of religion was different from that appropriate to the study of nature. This left the study of nature relatively free from theological intervention. Also during the Middle Ages, the idea of God as lawgiver developed. This led to the concept of laws of nature which humans could discover by studying nature. For these and other reasons, religion helped rather than hindered the development of science in the Middle Ages, and this development paved the way for the blossoming of science in the Renaissance. I found this idea surprising.The case of Galileo is always used as a classic example of the clash between religion and science. But White says the clash is not inevitable, and this leaves open the possibility for a future fruitful relationship between these two expressions of the human spirit.

A historical perspective can in many ways make science more intelligible, particularly to nonscience majors, but such an approach is rare. As Thomas Kuhn mentions in the preface to *The Structure of Scientific Revolutions* (1962), he was first exposed to the history of science only when he was close to completing his doctoral dissertation in physics! It is significant that this exposure was due to his teaching a college physical science course for nonscientists. This course was based on the work of James Conant who, in *On Understanding Science* (1951), suggested a historical approach to science as a way to create a scientifically literate public. But Kuhn sees a flaw in the way the history of science is usually taught. Science textbooks, he says, describe only that part of the work of past scientists that fits into our present theories. This distorts the historical record. Views that do not seem valuable today are denigrated, though in the past they may have been useful in the development of science. Stephen Jay Gould (1983) cites an example of this in the work of French paleontologist Georges Cuvier (1769-1832). As Gould says, "Cuvier has suffered primarily because posterity has deemed incorrect the two main conclusions that motivated his work in biology and geology–his belief in the fixity of species and his catastrophism." Gould contends that, for Cuvier, these two ideas produced fruitful research that established the basis of modern geology. Cuvier's ideas seem much less wrongheaded when viewed in the context in which they developed. He worked at a different time, in a world with different values and attitudes, and, very importantly, with much less information available to him.

Viewed in this way, the history of science becomes more interesting. It becomes more than the series of names, dates and achievements often found in the first chapters of textbooks as lip service to great scientists of the past. The book that made me realize how fascinating the history of science is, and how it can teach important lessons about the process of science, is Robert Frank's *Harvey and the Oxford Physiologists* (1982). Frank explains the background against which Harvey made his discoveries on circulation and shows the influences that changed Harvey's thinking over the years. He also explains why Harvey did not carry his work further and what preconceptions and assumptions kept him from doing more. If we jump from this type of historical analysis back to the present, we may become more aware of the assumptions made in doing research today and of the ethical, social and political influences now playing a role in deciding on what research is done and how it is approached. I think such points must be understood by students if they are to be scientifically literate.

But to help our students become scientifically literate we must be scientifically literate ourselves. When I began to teach I was, at best, semi-literate in science. I had been taught the facts and theories of science, but not what science is about, not how science fits into the larger picture. My branching out has led me toward scientific literacy. My views on the process of science have changed since reading Beveridge's *The Art of Scientific Investigation* (1950) and Judson's *The Search for Solutions* (1980). I developed a better idea of the differences between science and technology thanks to Florman's *The Existential Pleasures of Engineering* (1979) and *Blaming Technology* (1981). Though I have always been afraid to tackle the philosophy of science, my fears have subsided after reading and enjoying Bronowski's *Science and Human Values* (1956) and *The Identity of Man* (1966), Hanson's *Pattern's of Discovery* (1962) and especially Kuhn's classic that I mentioned earlier. Kuhn also delves into the sociology of science, and I've done a little more exploration in that area, reading Merton (1973) and Barber and Fox (1958). On the lighter side of sociology, I found Marston Bates' *Gluttons and Libertines* (1967) a revealing look at human nature. As to the future of science, I've read both a pessimistic view in Stent's *Paradoxes of Progress* (1978) and a more optimistic prediction in Thomas' *The Youngest Science* (1983). Finally, I've come to relish the history of science, particularly the history of evolutionary theory as recounted in such books as Mayr's comprehensive *The Growth of Biological Thought* (1982), Irvine's *Apes, Angels, and Victorians* (1955) and Barzun's *Darwin, Marx, Wagner* (1941).

By branching out, I've tried to compensate for the deficiencies in my education, deficiencies that, I think, are shared by many science majors and that are unfortunate for several reasons. First, the type of education that focuses almost exclusively on science isolates scientists from people in most other fields. Scientists' interests become so narrowly focused that they verify the stereotype that many nonscientists have that scientists are cold, uninteresting people because they can talk of nothing but science. Second, without understanding the context and process of science it is impossible to appreciate science's full beauty and richness. Obviously, if I didn't find science fascinating I wouldn't have majored in it. But today, though I am more aware of science's limitations and problems, I am more thrilled than ever to be involved with it and to have the opportunity to teach others about it. Finally, it is in teaching that a lack of background in the history, philosophy and sociology of science is most unfortunate. It was almost impossible for me to convey to my students the full scope of science when I was so poorly prepared myself. In fact, it was the inadequacy I felt when I tried to reply to student comments such as, "This must be true, a scientist said it" or "It must be true, they did experiments to prove it," or the proverbial "Evolution is only a theory," that fired me to keep reading.

When I teach introductory biology, the history, philosophy and sociology of science are not main topics of discussion. I am firmly opposed in introductory courses to diluting the science content with too much interdisciplinary material. Nonscience majors get little enough science without diluting it further. But I think that, as a teacher, my own background in these areas is important in conveying to students a full picture of what biology is about, its strengths and weaknesses and beauty.

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Things I'd Never Thought About

There's so much I don't know! I think all general biology teachers feel this way. A field that encompasses the entire living world is daunting. We are comfortable in certain areas while in others our ignorance may be coated by only a thin veneer of information.

This ignorance can be divided into two categories: things we know that we don't know and things we have never even considered. In the first category I would, in my own case, include the fine points of taxonomy, invertebrate physiology and any botany beyond the most elementary. In the second category it is impossible to know just what to include. That's the point; the category includes all those things that it never even dawned on me to contemplate. For example, how can microscopic bacteria slow down a supertanker? Can a mastectomy reduce fertility? Does the intestinal lining develop and atrophy in response to changes in use the way muscle tissue does? I've recently discovered answers to these and other questions, questions I'd never thought to ask. In some cases, it seems that no one else thought to ask them either until quite recently. In others, curiosity led investigators to these areas years ago, and it was just my ignorance that prevented me from discovering them until now. In this column I'll discuss a few of these points in the hope that at least some of them will come as news to you, too.

Sticky Bacteria

Bacteria are so small they can be swept along by the gentlest currents in an aquatic environment or by cilial motion in the respiratory tract. In both cases, they need to adhere to a surface to prevent endless drift and to establish viable communities. The layers of organisms produced by this adhesion are called biofilms and have become of interest in fields from medicine to economics (Lewin 1984). Adhesion is produced by means of exocellular polymers called adhesions. In some cases, as when disease-causing bacteria adhere to mucus membranes, the adhesion is specific and microorganisms like the gonorrhea-causing *Neisseria gonorrhoeae* may be able to alter their adhesions to escape immunological attack and to attach to, and penetrate, different types of host cells.

Biofilms are also of economic interest. If a large ship's hull is covered with a biofilm just a few hundred micrometers thick, its speed can be slowed by as much as 20 percent. Similar films in pipes and in steam driven turbines can cause economically significant losses in efficiency. In these cases, the adhesion is nonspecific, but still effective. Ian Robb, a British researcher in the field, estimates than an adhesion molecule, even with only 30 percent of its potential contacts touching a surface, can make at least 10,000 contacts. This efficiency may be related to the importance of adhesion to microorganisms; stickiness increases in starved cells, an indication that adhesion increases a cell's food-gathering potential.

Of course, adhesion isn't always a nuisance. Water quality in natural systems is maintained by metabolism in biofilms on underwater surfaces. And biotechnologists are using adhesion to immobilize bacteria in various types of bioreactors. Though I had never given it a second thought, bacterial stickiness is something people in many fields are considering.

Exercising the Intestine

Something I have thought about is how various parts of the body respond to use and disuse, behaving like muscles in this regard. Nerve calls, for example, often fire more efficiently when there is an increase in stimuli, and the skin thickens to form callouses in response to abrasion. But it never crossed my mind that the intestine would change in response to fluctuations in use, though such a phenomenon does indeed exist (Diamond & Karasor 1983).

The intestinal mucosa receives more "exercise" when food intake increases during pregnancy and lactation. Studies at such time on female rats show increased absorption of glucose, amino acids and minerals brought about through increases in intestinal length, villus height and mucosal area. If the food intake of lactating rats is restricted, mucosal growth fails to occur. This points to a direct effect of nutrients on the mucosa, though some evidence indicates indirect hormonal or nervous effects as well. During periods of starvation, on the other hand, the intestinal mucosa atrophies and absorption rates decrease. This beautiful system makes a good illustration for students of the body's subtle responses to changing demands. And for those who enjoy eating, it's nice to know that this, too, is a form of "exercise!"

A Mammary Gland Hormone?

Though few researchers have considered the mammary gland as an endocrine organ, this now seems to be a real possibility, at least in some species, and it's not a new idea at all (Diamond 1982). In 1906, researchers working with mastectomized guinea pigs found it difficult to get them to breed and to produce viable offspring. Recent studies on goats show similar problems, including infertility, mastitis, abortion and maternal death at parturition. Studies indicate that breast tissue can produce estrogen, and researchers are now trying to determine if the reproductive problems are caused by decreased release of this hormone or by some yet-to-be-discovered substance.

A Cardiac Hormone, Too?

New hormones seem to be popping up all over. It is exciting to think that the body still has so many hidden surprises that even such well-traveled ground as endocrinology can regularly yield up marvels. There is now evidence that a peptide released from the heart's atria can influence the kidney's fluid excretion (Balfour 1985). An expansion in blood volume causes increased stretching of the atrial walls which then release a peptide called atrial natriuretic factor. This factor reduces renal vascular resistance which leads to the excretion of more urine. It also acts to increase urine flow by reducing secretion of renin. Simply by producing this peptide, the heart helps to prevent overworking itself in the pumping of excessive blood volume. It is an effective regulatory mechanism whose existence has only recently been discovered. *(Update: Tests have become available on the clinical use of atrial natriuretic hormone in controlling blood pressure.)*

A Growth Modifier

Another area where new substances are frequently discovered is embryology. Many growth factors have been identified, but growth-inhibiting substances are also crucial to normal development. Mullerian-inhibiting substance is an example. In a human embryo, the genital system can be detected at about the sixth week of development. At that time, the embryo's sex cannot be determined by examination because the gonads are undifferentiated and two sets of ducts are present, the Mullerian ducts which will develop into the fallopian tubes and the uterus in the female, and the Wolffian ducts which become the vas deferens, epididymus and seminal vesicles in the male.

As differentiation continues, the ducts associated with the embryo's sex continue to develop, while those of the opposite sex regress. Thus, in the male, it is the Mullerian ducts that disappear, and it is Mullerian-inhibiting substance that induces this regression. Even though this recently discovered substance has only been partially purified, it may have already found a role in medicine (Richardson, Scully, Nikrui & Nelson 1985) because it inhibits the growth of ovarian cancer cells both in culture and in mice. It seems to act only on reproductive tissue as it fails to inhibit colon-carcinoma cells. This is the first time an embryologic growth modifier has been found to have anticancer activity and opens up the possibility of a new type of cancer treatment.

Nutrient Carriers

If the field of physiology, with which I am familiar, constantly presents me with ideas I've never before considered, imagine the number of unconsidered topics that pop up to amaze me in zoology and ecology, areas in which I claim no expertise! For example, I've never thought about animals as nutrient carriers, but as Peter Moore (1983) points out, "It has long been recognized that the movement of grazing animals from one terrestrial ecosystem to another, feeding in one and defecating in the other, may result in a significant movement of certain elements between them." Only recently have ecologists considered whether or not the same process occurs in aquatic ecosystems. When fish were removed from certain coral heads, coral growth was only 55 percent of that on heads where fish remained. This growth differential can be explained by the fact that where fish schools were present, water samples were significantly richer in ammonium ions and in particulate matter containing phosphorus and nitrogen. Thus, the contribution of fish nutrients to coral growth is significant. While the topic of defecation is one that many would rather not consider, those who work in this area have provided a useful contribution to ecology.

Slow Plants

Other ecologists, studying plant communities, have called into question the use of plant fossil records as climate indicators (Lewin 1985). A study of geological and paleoecological records from the same locale shows there is a lag time of about 2,000 years separating climatic and subsequent vegetational change. This "vegetational inertia" is not a new idea, but it has taken on new significance since being used to clarify the fossil record. Kenneth Cole, a researcher at the Indiana Dunes National Lakeshore, has developed a model which suggests that a combination of factors, including competition and physical microenvironment, allows a plant community to remain in a locale long after the conditions necessary for its establishment have disappeared. A dominant species in a community can influence the microenvironment, including soil chemistry and the availability of sunlight and moisture. This would serve as a buffer against climatic changes. Thus during periods of rapid climate change, plant communities would be replaced more slowly than expected, making the plant fossil record a less reliable indicator of climate than had been previously assumed. By revealing how tentative findings often are, such revaluations of assumptions are humbling to scientists because things never thought about, never considered, can cause a reappraisal of supposedly firm calculations.

Running and Breathing

In zoology, Bramble and Carrier (1983) have published a review of a phenomenon I'd never considered: Mechanical constraints require locomotion and breathing to be synchronized in running quadrupedal mammals. It makes sense once you think about it. Synchronization is necessary because both locomotion and respiration involve cyclic movement of the same anatomical structures, particularly the ribs, sternum and associated musculature. In other words, as Bramble and Carrier explain it, "Locomotion imposes limits on respiratory function, and breathing must therefore be made to fit the locomotor cycle." Evidence for synchronization is abundant. Phase locking of limb and respiratory frequency has been recorded in jack rabbits, dogs and horses. In all these quadrupeds, the locomotor and respiratory cycles are normally synchronized at a constant ratio of 1:1 (strides per breath), while in humans, several phase-locked patterns are observed including 4:1, 3:1, 2:1 and 1:1, with the 2:1 ratio favored. As to how such synchronization is controlled, both the peripheral and central nervous systems seem involved, though the exact mechanisms have not been fully worked out.

One Body

When I introduce human physiology to students, I remind them that even though we treat each system of the body individually, we are talking about one organism, a unity. Each system isn't churning away on its own; there is constant interaction among, and coordination of, the parts. Yet this concept isn't easy to keep in mind when each system is covered in a separate chapter with mention being made of only the most obvious relationships, like the connection between the excretory and reproductive systems in the male.

> *Confronting new ideas we had never considered previously is what makes science exciting, challenging and humbling. There's always something new–at least new to us.*

Of course, part of the problem is that some of these connections are so subtle and our understanding of the body still so incomplete, that many interrelationships have yet to be discovered. Nobody has given them much thought. One such system, which even researchers in the field have regarded as autonomous, is the immune system. But recent studies in several areas have revealed numerous connections between the immune system and the nervous system, the reproductive system and the skin (Golub 1982). Hampering an elucidation of these interconnections is our very partial understanding of the immune system itself, but even the bare outline of what is known so far is fascinating.

The skin obviously serves as a physical barrier to infectious agents, but it is an immunological barrier as well. For example, after migrating from the bone marrow, Langerhans cells become part of the epidermis and act there to induce a helper T-cell response, one of the first steps in an immune reaction. These cells also share surface molecules with the immune organ, the thymus; while, on the other hand, the skin protein keratin is also found in thymic cells (Edelson & Fink 1985). So immune-epidermal interconnections abound.

As far as reproductive-immunological interactions are concerned, estrogens and androgens act to suppress cellular immunity, with each suppressing different lymphocyte populations (Grossman 1985). But estrogens also stimulate humoral immunity, which may explain why females produce more immunoglobulin than do males. Progesterone, the hormone that remains at high levels during pregnancy, depresses cellular immunity, and thus helps to prevent a maternal-fetal rejection response. Finally, thymic hormones stimulate the hypothalamus to release luteinizing-hormone-releasing hormone (LHRH) which, in turn, stimulates the pituitary to release the gonadotrophins FSH and LH.

The connections between the immune and nervous systems are the most tantalizing of all. It has long been known that stress, by influencing hypothalamic control of the pituitary's release of ACTH, could increase secretion of corticosteroid hormones which suppress immunity. Now it appears that the immune system can also influence the nervous system (Marx 1985). Immune responses change the firing rate of brain neurons. Though the factor responsible hasn't been identified, some data points to interferon, which some have already dubbed an "immunotransmitter." Even more amazing are studies showing that animals can "learn" to suffer an allergic response, even in the absence of the offending allergen (Lesser 1984). There's obviously much we have to learn about both these systems, and many questions we haven't even thought to ask.

Confronting new ideas we had never considered previously is what makes science exciting, challenging and humbling. There's always something new–at least new to us. It's good for our students to realize how incomplete each of our views of the living world is, how we are always hampered by individual ignorance of what we've yet to learn, and collective ignorance of what the biological community as a whole has yet to explore. Perhaps our students won't feel so overwhelmed by the complexities of biology if they realize that we are all in the same boat, all trying to make some headway toward knowledge and understanding.

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December 1985

Bitten by the Insect Bug

I must admit that I do not like insects. I avoid them as much as possible, not only by swatting at any fly I see, but also by pushing aside unread most writing on insects. There seem to be two reasons for my aversion. One is early memories of my mother on "cricket patrol" on summer evenings. Insects were something to be crushed if they ventured inside the house. Spiders, worms and everything else classified as "creepy crawlies" received the same treatment–rapid extermination. It never dawned on me that some people thought of caterpillars as beautiful or spent hours observing the behavior of beetles.

Nor did my estimation of invertebrates in general improve when I became a biology major. Invertebrates were disgusting rather than interesting organisms since they were usually presented as pickled specimens floating, and often decomposing, in foul-smelling fluid. To make them even more distasteful, they were used merely as problems in classification. What organisms had radical versus bilateral symmetry? What differentiated arachnids from arthropods or roundworms from flatworms?

But even as inveterate an invertebrate hater as myself cannot avoid six-legged creatures completely. Insects are everywhere, abundant both in quantity and variety. As John Alcock has written: "When you consider that there are several million species of insects, each wonderfully distinctive, and fewer than 10,000 species of birds, it is strange that there are millions of bird watchers but only thousands of insect enthusiasts." It occurred to me recently that among this relatively small band of enthusiasts are a large number of good writers, too good for even me to resist. Bernd Heinrich's *In a Patch of Fireweed* (1984), Karl von Frisch's *Bees* (1950) and Edward O. Wilson's *The Insect Societies* (1971) immediately come to mind. But above them all stand two books which I found tremendously fascinating and which changed my perception of insects. They are a collection of the writings of J. Henri Fabre, edited by Edwin Way Teale (1949), and Howard Ensign Evans's *Life on a Little-known Planet* (1984). These books have not made me love insects–just yesterday, when a beetle crawled up my arm I crushed it rather than try to classify it or observe its behavior. But these books have given me an appreciation for such creatures, at least on an intellectual level. From now on, when I discuss insects in class it will be less out of a sense of duty and more with a sense of wonder.

The writings of Fabre and Evans are very different from each other. Though they both dedicated their lives to the study of insects, their viewpoints and writing styles were very dissimilar. Fabre was a 19th-century French naturalist; Evans is a 20th-century American entomologist. Fabre's writings describe primarily his own observations and experiments, while Evans draws on the work of a host of researchers, the insect enthusiasts that Alcock mentions in his introduction to Evans's book. Perhaps most importantly, Fabre's world was a relatively stable one, a peasant community in one of the more backward areas of France, while Evans's world, our world, is a rapidly changing one.

These men, however, have one thing in common: their love of the insect world. Fabre exults, "O my pretty insects!" (p.2); Evans quotes from *Dragonflie* (Corbet, Longfield & Moore 1960) "Animals (especially dragonflies!) are valuable because they are beautiful" (p. 81). This love of insects comes through in their careful and vivid depictions of insect activity. Fabre minutely describes the coverings worn by psyche moths in their larval form. These caterpillars are called bag-worms because they cover themselves with a silken bag to which are attached tiny sticks. Fabre devotes pages to how this sack is woven, how the attached ornaments are chosen, depending upon what is available:

> What predominates is remnants of very small stalks, light, soft and rich in pith. . . . Next come bits of grass-leaves, scaly twigs provided by the cypress-tree and all sorts of little sticks, coarse materials adopted for the lack of anything better. Lastly, if the favorite cylindrical pieces fall short, the mantle is sometimes finished off with an ample flounced tippet, that is to say, with fragments of dry leaves of any kind. (p. 260)

Evans lavishes the same kind of detail on a description of female Florida cockroaches burying their eggs:

> When a suitable place had been selected, each roach made a series of backward strokes with her head, piling the sand beneath and behind her. After a hole about a third of an inch deep had been completed, she changed tactics completely, dribbling saliva into the hole and picking up the moistened sand grains with her mouth, eventually molding a trough-shaped cavity of proper size and shape to fit the egg capsule. (p. 59)

Evans goes on to describe how these "giant" roaches then lay their eggs in these holes and carefully cover them with sand moistened by saliva.

Fabre's descriptions are often anthropomorphic. He writes of male moths in search of mates: "This feverish agitation marks them as lovers in search of their brides" (p. 263). He says that caterpillars "lack perspicacity" (p. 71), and that the song of the Cicada has a "throaty exuberance" (p. 141). Evans is more circumspect, more clinical in his descriptions, but even he cannot resist describing the bedbug as "innocent as a lily" (p. 178), innocent of spreading disease, that is. And he sighs, "If only our aircraft were as agile and dependable as flies" (p. 144), since they perform better in wind tunnels than do most airplane models.

Both Fabre and Evans are fascinated by the large numbers constantly encountered in discussions of insects. Fabre describes the thousands of eggs laid by the praying mantis, and then vividly portrays the extermination that befalls most of them (p. 162). He speaks of the "riotous multitude" (p. 194) of parasites that prey on cabbage caterpillars. Evans uses more precise figures. There are 3,683,000 bacteria on the average fly from a slum district, while a mere 1,941,000 on one from a clean community (p. 141). And if all her progeny were to survive, a housefly could produce 5,598,720,000,000 offspring in five months (p. 160). Fortunately, the fly mortality rate is high enough to prevent what would be a population explosion not only among flies, but among bacteria as well!

As someone involved in the care and feeding of two teenage boys, I particularly enjoyed the numbers mentioned in feeding experiments cited by both authors. Fabre describes an "eight days' feast" in which a wasp larva of the species *Bembex julii* consumed 82 items, mainly droneflies and houseflies (p. 121), all provided by its very busy mother. Evans says that a dragonfly larva "consumed 3,037 mosquito larvae in the course of its life of about one year, as well as 164 mosquito pupae and a few other things, including 17 larvae of dragonflies and damselflies!" (p. 80).

Both Fabre and Evans also remark on how much we do not know about insects. Fabre speaks of "the inexhaustible entomological mine" (p. 166) and stresses the importance of experimentation in yielding treasure from that mine. "Observation sets the problem; experimentation solves it, always presuming that it can be solved; or at least; if powerless to yield the full light of truth, it sheds a certain gleam over the edges of the impenetrable cloud" (p. 327).

The very title that Evans chose for his book indicates his estimation of our understanding of insects; the world of insects is little-known. In studying locusts, for example, one can do little more than "begin to glimpse the problems waiting to be studied" (p. 225). In speaking of fireflies, he addresses the problem of biology in general:

> Such is the complexity of living systems that tens of thousands of research workers all over the world each year push our knowledge forward by only a minuscule, with now and then a breakthrough that opens up a new area of ignorance. A century from now our great-grandchildren may marvel at how little we knew about fireflies. (p. 115)

Despite this sea of ignorance in which entomology, along with all the other branches of biology, is swimming, and perhaps floundering, these books hold a wealth of fascinating information. Fabre's essay on burying-beetles is a beautiful treatment of a topic most of us hardly give a thought: the important role of insects in the disposal and recycling of dead organisms (p. 232). Beetles of the species *Necrophorus vestigator* work in groups to bury dead mice, rats, snakes and even moles. The buried carrison is used to nourish the beetles' grubs. Fabre's description of dung beetles at work is another example of how he can make an unpleasant topic riveting (p. 93).

Evans does the same thing for a creature even most insect-lovers despise–the bedbug! He also writes of springtails, insects that receive little publicity because most of them remain well below ground and "live obscure and uneventful lives" (p. 32). But they are in the soil in tremendous abundance, for those with the patience to count them. George Salt, a University of Cambridge professor, calculated that there were 248,375,000 springtails in an acre of English pasture soil. Not to be outdone, an American entomologist, Kenneth Christiansen, calculated that an acre of Iowa farm soil contains 400 billion springtails (p. 32).

"It appears difficult for man to develop a rapport with insects" (p.82). With this understatement, Evans begins an essay on crickets. He claims, though my mother would not agree, that crickets seem less alien than most insects. Citing Jiminy Cricket as proof, he feels humans have developed a rapport with crickets because of their rhythmic chirping. The cricket also drew Fabre's attention, so it is interesting to compare each writer's treatment of an insect that both view very positively. Evans dwells primarily on the cricket's song. He describes how the male's front wings are specially designed with ridges and a scraper so that when a cricket raises its wings and rubs the file of one wing over the scraper of the other, the wing membranes vibrate, creating a "song." For those particularly interested in the mechanics of this performance, Evans even mentions that most crickets are "right-winged," that is, they always sing with the right wing overlying the left (p. 85). He goes on to discuss the function of the cricket's song in mating (only males sing) and how some cricket species can only be differentiated on the basis of their songs.

Fabre, on the other hand, does not dwell solely on the cricket's vocal production. He describes its dwelling, a tunnel in the ground, widened at the end, "devoid of luxury, with bare and yet not coarse walls" (p. 282). He gives careful attention to how the cricket lays its eggs and how those eggs develop. Here, as in all his essays, Fabre is a master storyteller. Even someone like myself who is not a member of the insect fan club cannot resist turning the pages to find out what happens next. In this case, "The cricket pops out like a Jack-in-the-box... The Cricket's egg opens like an ivory case. The thrust of the inmate's head is enough to work the hinge" (p. 283). Fabre then tells of the countless predators that beset these newborn crickets, and ends where Evans begins, with the mature male's song "developing into a general symphony," as others of the species join in.

Both write extensively about wasps too. Wasps are Evans's specialty and he has devoted an entire volume–*Wasp Farm*–to them. In *Life on a Little-known Planet* he limits himself to one chapter on his life's work, parasitic wasps. While this may seem a rather esosteric topic, Evans makes a good case for its importance. First of all, it is a large topic. Fifty thousand species of parasitic wasps have been described, but the world total is probably closer to half a million. It's also an economically important subject because some species may be useful in controlling insect pests. Most of these wasps are very fussy and parasitize only one species, so they could be used to limit the size of a pest population without being detrimental to other insects. For example, the caterpillar of the brown-tail moth was a major pest of New England shade and fruit trees until several wasp species that parasitize it were introduced into this country from Europe (p. 247).

Fabre also described many aspects of wasp behavior, including how the Sphex wasp paralyzes its prey by a very accurate sting driven into the thoracic ganglia (p. 45). But Fabre is not interested in the usefulness of insects to humans, he is driven solely by a yearning to know them. He lived in a world very different from Evans's world. He didn't view insects as pests, as enemies to be controlled, though he speculates that there wouldn't be a head of cabbage left in the world if the cabbage caterpillar weren't beset by pests that keep it under control (p. 190).

Nor does Fabre mention a topic that Evans raises in almost every essay–

the problem of extinction. Fabre spent his life in rural communities in a relatively backward and unchanging part of France. It didn't occur to him, fired solely by a desire to learn about creatures he loved, that these creatures might someday cease to exist. Evans's passion for insects is fueled by the knowledge that what isn't learned now may never be learned because the subject of study may soon disappear from the face of the earth. He mentions repeatedly that we are neglecting our own planet while planning explorations of space. (This book was originally published in 1968 as final preparations were being made for a manned moon landing). In many areas of the world, habitats, and untold numbers of species along with them, are being destroyed at an alarming rate. The average person's distaste for insects compounds the problem; people are more likely to want to save pandas and seals from extinction than species of beetles or flies, though the latter may be as important to the structure of their respective ecological communities as the former.

Entomology is obviously a topic too important to ignore. But while most insects have remained unknown and unstudied, a few–including ants, wasps and bees–have been the subject of extensive researchers. This may be because all these groups include social insects that in many ways mimic human social structures. Armies of ants, queen bees, workers–such terms indicate the rapport humans feel with these insects. In *Bumblebee Economics* (1979), Bernd Heinrich sees the bumblebee as having to solve economic problems similar to those humans handle, such as energy conservation and the efficient use of resources. Evans even believes insects' huge reproductive potential perhaps can teach us something about our own population problems. Like humans, insects are builders, builders who often make their own materials, including paper and wax. Insects are doers; their constant activity, easy to observe because of their small size, mesmerizes those with the patience to appreciate it.

Insects are also good subjects for study because their small size makes them easy to capture, maintain and observe. Evans cites a great deal of research done by amateurs and by investigators working in small schools and colleges. Even with limited resources there is much to be learned, as the often poverty-stricken Fabre proved a hundred years ago. In these days of tight budgets, insects make attractive laboratory materials, often available free for the collecting. Though my own conversion hasn't extended that far, I do own a basket designed as a cricket cage, so who knows what it may hold in the future!

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Beginning Again

As another school year begins and I look back on 15 years of teaching, I ask myself if I'll ever get good at it. Teaching is a humbling profession: As soon as you think you're improving, some student bursts your bubble. There's nothing more deflating than a well-timed yawn of boredom, or a question that reveals a total lack of comprehension of a concept that has just been exhaustively discussed.

I think I am a better teacher than I was 15 years ago: I couldn't be much worse. When I recall the amount of material I tried to cram down unwilling throats per hour of class, I shudder. I had yet to grasp the idea that many people do not find biology inherently interesting. While pursuing a bachelor's and then a master's degree in biology, I was surrounded by others with similar interests. After six years in this atmosphere, I thought everyone loved to read about, talk about and study living things. It was a rude awakening to be thrust into class after class of nonscience majors who saw biology not as a joy, but as a trial to be endured.

Having lived in this real world for the past 15 years, I have made my peace with it. In fact, I love it. I have developed a missionary zeal to convert my students to science. My aim is not to make them into science majors (I am not naive enough to believe I can work miracles!) but rather into nonscience majors with a positive view of science.

This is a rather idealistic goal. At the end of most days of teaching, when my students' only signs of life appear two or three minutes before the end of class as preparation for the exodus begins, it seems totally unrealistic. But it is a goal that more and more of our national leaders, as well as educators, see as vitally important to our future (Walberg 1983). If the nonscientists who make up the vast majority of the American public continue to perceive science as a complex mass of incomprehensible information, they are unlikely to consider funding of scientific research as an important national priority. But I see it as more than just a question of future resources. A public that thinks of science as distasteful is unlikely to encourage its children to develop interests in science. In teaching nonscience majors, I see myself as indeed preparing future scientists, but one generation removed.

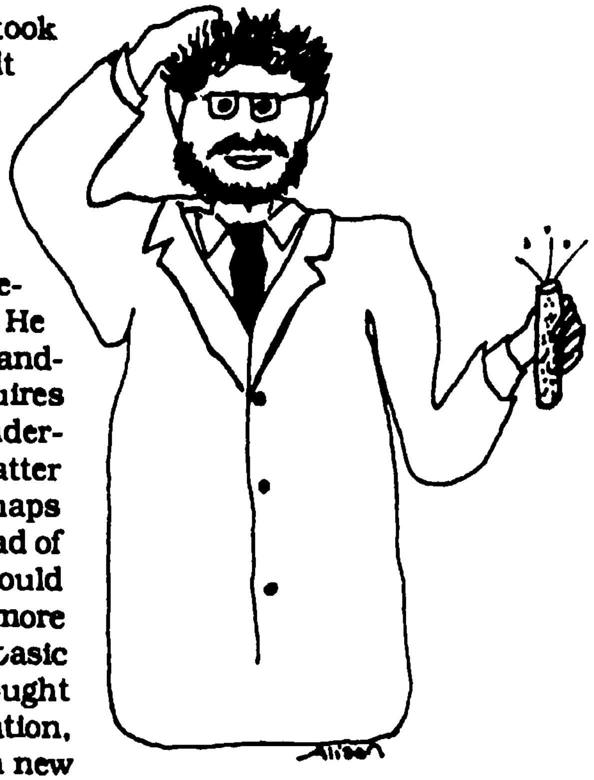
The problem for me, and seemingly for everyone else in science teaching today, is how to get students more interested in science. Several recent reports are very discouraging (National Commission on Excellence in Education 1983; National Science Board Commission on Precollege Education in Mathematics, Science and Technology 1983). Interest in and knowledge of science are at a depressingly low level. It seems too big a problem for any teacher to tackle, and yet, as another school year begins and while we still have the enthusiastic feeling of a fresh start, perhaps it's time to ask ourselves what each of us can do to improve science education.

This is not easy, especially for those of us who have been at it for awhile. How can anyone get excited and be creative in a general biology course they are teaching for the umpteenth time? The answer, of course, is not to teach the same old thing but rather to freshen it up a bit. For many of us this means introducing new material, keeping the subject matter up-to-date. But, as Robert Yager (1986) warned recently, this can present a problem. Many teachers feel that what they learn, the new knowledge they amass, must be passed on to their students in the form of ever more "essentials" to be covered. They fail to evaluate what knowledge is appropriate for their students.

I plead guilty to this vice, though I try to control it. I'm always coming upon fascinating pieces of information that I'm tempted to inflict on my students. I became a biologist because I find the living world fascinating, and I teach biology because I have a strong desire to share my fascination with others. But Yager's warning is a reminder to check this urge to broadcast the latest tidbits of information I've unearthed.

I'll admit that this isn't easy to do. I'm always discovering things that are just too good to keep to myself. For example, recent studies seem to indicate a genetic relationship between testis size, dizygotic twinning and breast cancer (Diamond 1986). Testis size varies with ethnic group; in groups in which testis size is small, there is less twinning and less breast cancer. Or this interesting item: though dill pickles have been produced since 2100 B.C., scientists have only recently identified the microorganisms, a bacterium and a yeast, that are responsible for this culinary delight (McNish 1986). And finally, paleontologists and ecologists, by examining the drill holes found in shells, can tell a great deal about the gastropods that did the drilling. Many drilling gastropods leave distinctive holes such as ones that taper inwards (Benton 1986). All these findings are fascinating, but their significance will only be clear to students after a great deal of explanation. Just tossing these pieces of information at students may make them sit up and take notice for a moment–the word "testis" is always a good attention getter–but in the long run this will do little to increase their understanding of science. It will just become more unrelated information that sinks into neural oblivion. One of the benefits I derive from this column is that it serves as an outlet for such items: I can tell other teachers about them rather than deluging my students. Perhaps that's how such information should be used: to share with fellow teachers to refresh our own joy in science, rather than to smother our students.

The idea of easing up on the information load to which we subject students seems to be gaining credence. Thomas Mertens made this point in an *ABT* editorial several years ago (1979), and James Wandersee (1985) reiterated it in relation to terminology. Sheila Tobias (1986) also stresses this in reporting on a recent teaching experiment at the University of Chicago. Nonscience professors attended physics lectures and took notes on their experiences. Several felt overloaded and inundated with information because they lacked the background to put it into context. This is a point that A.B. Arons (1983) develops in his article on scientific literacy. Arons writes in terms of physics, but his remarks apply to all science teaching. He says we stress facts rather than understanding, but to develop understanding requires time, patience and a deep level of understanding in our own minds. It is in this latter area that Mertens faults teachers. Perhaps we are not using our time wisely. Instead of accumulating more information, we should be forcing our minds to examine ideas more carefully, to delve more deeply into the basic concepts we teach. If we analyze the thought processes we go through in this exploration, we may be able to lead our students in new paths of understanding.This is the thrust of John Moore's (1984a) work in the American Society of Zoologists' "Science as a Way of Knowing" project, which is cosponsored by several organizations including NABT. Each year the project selects one broad topic for analysis, such as evolutionary biology (Moore 1984b) and human ecology (Moore 1985).



> *The test grew out of work by Mead and Metraux (1957) who showed that high school students had a very stereotyped image of the scientist: a male, often with facial hair and glasses, wearing a white coat, and surrounded by test tubes, flasks and sometimes more sinister-looking equipment.*

I think we can also continue to improve our teaching by listening to each other. Though science education may be less than what we'd like it to be, there are many teachers doing beautiful things in the classroom. In my own case, I have found that the simplest ideas are the most useful and meaningful. Years ago, a friend told me that her students wrote one-page reports on science-related newspaper articles. This is a simple idea used by many teachers, but I had never considered it. Now, the more I use it, the more I realize its value. By forcing students to read news items they would usually avoid, it not only makes them realize that many news stories are science-related, but also that such articles are readable, that science as encountered in everyday life can be understandable.

Such exercises, repeated several times during the semester and sometimes varied by requiring magazine articles, help students to feel more comfortable about science, which I think should be one of our main goals in teaching. In the study mentioned above, Tobias reports that some professor-students experienced strong feelings of panic, frustration and helplessness as soon as they found they couldn't understand the subject matter. These were successful, mature adults, so our own students must experience similar emotions, but probably more strongly and frequently. In discussing what the goals of science education should be, Anna Harrison (1982) repeatedly stresses the need to develop student confidence: confidence to acquire competence in science and technology, confidence to participate critically in societal decisions involving science, and confidence to follow scientific developments in the media. The frustration and helplessness many students experience in the face of our presentations obviously militates against their ever developing such confidence. While exercises such as the newspaper reports may go some way toward increasing confidence, Tobias's findings are a reminder that it is very possible to do more harm than good in the classroom and that how we present material is as important as what we present.

One way to deal with students' negative feelings about science is to face them squarely. An easy and painless approach is the Draw-A-Scientist-Test (DAST), developed by David Chambers (1983). Students are simply given a sheet of paper and told to draw a scientist. The test grew out of work by Mead and Metraux (1957) who showed that high school students had a very stereotyped image of the scientist: a male, often with facial hair and glasses, wearing a white coat, and surrounded by test tubes, flasks and sometimes more sinister-looking equipment. Chambers has given DAST to younger students to see how early the stereotype develops (usually by the fourth grade), but I give it to my students at the start of the semester to make them aware of their often unconscious perceptions of scientists. I hope that the discussion that follows their artistic endeavors makes them aware of their feelings, and that my teaching loosens the grip of the stereotype. After all, in biology it is just as likely that a researcher will be wearing hip boots as a white lab coat, and though I have been known to carry a test tube from time to time, I stand before them as living proof that not every scientist has facial hair.

In describing good teachers they've had in the past, students often stress these teachers' enthusiasm; in other words, they were teachers who loved teaching, loved their subject matter and weren't afraid to let their students see this. Again, this is a very simple idea, but a powerful one that we sometimes ignore. Rubin Battino (1960) recommends that "you should put emotion into your lectures, and that your physical feelings for and about nature are best transmitted by demonstrating your emotional involvement. How can students possibly get excited about something that you find dull or boring or trivial?" He suggests that we imbue students with a sense of the awesomeness and grandeur of nature. But it's hard to be enthusiastic when facing four, five or six classes a day, when teaching the same course for the 20th time, and when trying desperately to cover the syllabus. It's at times like these that we need a transfusion of enthusiasm in the form of a gab-session with a fellow teacher, or the discovery of fascinating new findings like the ones I mentioned before or others (I've got a slew of them!), including the discovery of the genes for color vision (Botstein 1986), work on knots in DNA (Kolata 1986; Wasserman & Cozzarelli 1986), and development of bird chimeras that may provide clues to the cause of degenerative changes in multiple sclerosis (Barnes 1986). We have to be careful to keep our own sense of wonder in robust condition; it is probably the most enduring thing we can impart to our students.

While I have tried to model my teaching after that of other successful teachers, I must admit that I have stopped doing many things that good teachers are supposed to do. For example, I've stopped assigning research papers. I got sick of receiving retreads of last year's papers, bits and pieces of sundry encyclopedias and endless descriptions of the circulatory system. My students still must hand in written reports, but these are structured so that students are forced to think rather than copy. If they read their notes and study the textbook (admittedly a big "if"!), it seems to me that they have acquired sufficient information; in-depth research, at least in the way it is usually done, seems unnecessary. Instead, I think they should be made to do something with what they have learned, to make it their own, to relate it to their lives.

After I've covered the nutrition section in the health course, I ask them to write an essay on how their eating habits have changed in the past five years and what changes they can anticipate in the next five. I usually do this in an evening class where there are some older students, and I get interesting results. Dietary changes are often linked to health problems like hypertension, or changes in life-style like marriage or leaving home, or new health information such as the increasing evidence of a link between atherosclerosis and blood cholesterol levels. In the future, many, not surprisingly, anticipate eating lower calorie foods in order to lose weight. Even with younger students, this can be a worthwhile assignment. The densest adolescents must be aware that the sheer volume of their food consumption has gone up appreciably, or if they aren't, their parents will make them aware of the fact. At any rate, students are forced to think about what they eat, and such introspection may be the first step toward improved eating habits.

In another assignment, I ask students to discuss the disease they fear most and why they feel that way. Most choose either heart disease or cancer, but a variety of other diseases appear in the essays, including diabetes, arthritis, and recently, AIDS. In discussion after the assignments are handed in, students defend their choices and usually discover that their attitudes are colored by their personal experiences, and that one disease is not more inherently awful than the others. All have their frightening aspects, and such an assignment sometimes helps students to understand and deal with that fear.

In still another assignment, this one for a course that covers drugs, I ask students to pick a drug and describe why they would want to be that particular substance. The results are fascinating. Some are literary masterpieces that would make any English teacher proud, including an interview with crack and a poem on alcohol. At the moment, about half choose cocaine, but there are a few humanitarians who choose penicillin and several, of course, opt for alcohol. This assignment gives students a chance to examine their feelings about drugs and gives me an opportunity to keep abreast of their changing attitudes. As usual, I end up learning from my students. Perhaps that's the best way to improve teaching: by learning from students and by being sensitive to their frustrations and enthusiasms and queries. Perhaps with another 15 years of students as my teachers, I will finally get good at it.

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Who Could Have Guessed It?

Although I greatly enjoy reading about science, my reading rarely follows my organized plan. This approach may not be the most effective or efficient way to improve my mind, but at times it yields some nice surprises. Recently I read an editorial by Gerard Piel (1986) in which he quoted James B. Conant as saying, "Being well informed about science is not the same thing as understanding science." This quote from *On Understanding Science* (1947) struck me as pinpointing a basic problem in science education today: We are much more successful in presenting students with facts about science than in giving them what Conant calls a " 'feel' for the Tactics and Strategy of Science."

This quote led me to reread *On Understanding Science*, which I found much more interesting than when I first read it. Perhaps I am now more convinced of the need to lead our students to understanding, instead of just to information about science. Conant's argument was that, for the average person, the best approach to science is through the history of science, through studying case histories of scientific discoveries. This can be a less anxiety-producing approach since many people are more comfortable with history than with science. Also, little factual knowledge is needed to understand the early days of a science. Most importantly, as Conant said, "in the early days one sees in clearest light the necessary fumblings of even intellectual giants when they are also pioneers." In other words, a historical approach can give students insights into the tactics used and the problems encountered by scientists in their work. It brings students much closer to the "feel" for science that Conant saw as crucial to what we now call scientific literacy.

Shortly after rereading Conant's book, I happened to pick up *The Transforming Principle* by Maclyn McCarty (1985). McCarty worked with Oswald Avery and Colin MacLeod in identifying DNA as the genetic material within cells or what they called the "transforming principle." McCarty's description of the discovery that genes are made of DNA provides an almost perfect case history with which to give students an understanding of science. The examples that Conant used involved 17th- through 19th-century chemistry and physics. But biology is a younger science and many of its central concepts, including the chemical basis of genetics, are of 20th-century origin.

McCarty's book begins with autobiographical material explaining the path that led him to join Avery's lab in 1941. He then describes what Avery called "the sugar-coated microbe,"*Streptococcus pneumoniae*, a bacterium that in its virulent form is covered with a thick capsule of polysaccharide. He notes that research on this organism was aimed primarily at finding ways to control it, because it caused most cases of pneumonia, the leading cause of death at the turn of the century. McCarty makes the point that work in medicine, an applied science, can at times lead to new findings in basic science, in this case to the chemical basis of genetics. This is a good example for students of the interplay between pure and applied science, which, though different from each other, are intimately related.

Early work had shown that there were several different kinds of pneumococci. These types were differentiated on the basis of reaction with antisera which were specific for the capsular material that coated the bacteria. McCarty reviews the research that led to this simple typing system. The amount of work required reminds us that the simple concepts of today were not always obvious. The process of research is never easy because the necessary facts, and often the crucial ideas, have not yet emerged. All research by its nature involves a search, a groping that always takes place in the dark.

Avery and his colleague, Alphonse Dochez, discovered that these antisera also reacted specifically with the fluids in which the pneumococci had been grown; in other words, the capsular material was dissolved in the fluid. Conant noted that one experiment often leads to the next, and with developing experimentation comes an evolution of concepts. In the course of his work Avery became convinced that the capsular material, which he called soluble specific substance (SSS), could be characterized chemically, and so he attempted its purification and identification.

Another theme that Conant stressed comes into play here: the constant presence of difficulties that stymie research. Techniques for purification of biological material were relatively crude in the 1920s when this work was done, and "fumblings" were inevitable. Not only did the work require several years to complete, but Avery needed help to do it; he did not have the necessary chemical expertise. Here again, one of Conant's points is involved, namely that science is an organized social activity. Avery was a member of one of the elite scientific organizations in the United States, the Rockefeller Institute (now Rockefeller University). He enlisted the aid of a chemist at Rockefeller, Michael Heidelberger, who purified the SSS from type II pneumococcus and identified it as a polysaccharide containing glucose as well as several other sugars that could not be identified because of difficulties in analysis. So Avery and Heidelberger then studied the polysaccharide from type III organisms. This turned out to be a simpler substance having just two components, glucose and glucuronic acid, which alternate along the linear molecule. This work led to a further conceptual evolution because it showed for the first time that polysaccharides can express biological specificity and act as antigens.

The social nature of science again came into play when this work was published. For a discovery to be significant it must be accepted by other scientists. But, as McCarty writes, "scientists tend to be conservative," and as Conant noted, "a useful concept may be a barrier to the acceptance of a better one if long-intrenched in the minds of scientists." The major objection to Avery's work was that only proteins had enough diversity for the kind of specificity and antigenicity displayed by the capsular material. Conant argued that such controversy is a useful spur to further research, as was the case here. Avery set out to prove conclusively the polysaccharide nature of the SSS.

It was part of Avery's genius to find researchers who could aid him effectively in reaching his goals. In this case, René Dubos, who had already done work on purifying polysaccharide-dissolving enzymes from bacteria, discovered an enzyme that split the type III SSS. It could also destroy the capsules of living type III pneumococci. This enzyme not only verified the polysaccharide nature of the SSS and thus of the capsule, it also served as a useful tool in the study of pneumococcal infection and, ultimately, in the purification of the transforming principle. This clearly illustrates another of Conant's major premises, that new techniques–new research tools–influence the development of experimentation and, in turn, the evolution of scientific concepts.

. . . a problem in all research is the fruitless dead end where researchers often find themselves.

Avery's early work in purifying the SSS of S. *pneumoniae* not only exemplifies Conant's tactics and strategy of science, but also contains several elements that are found again in work on the transforming principle (TP). In both cases, as McCarty notes, Avery displayed "two of the characteristics that were responsible for his extraordinary success as an investigator: an uncanny ability to ask the right questions and dogged persistence in finding the answers." In the 1920s, Fred Griffith, a British medical officer, observed that a single sputum sample could contain as many as four or five different types of pneumococci. He did not think that one individual could have acquired so many different strains, but instead favored the idea that the pneumococci underwent changes in type while in the body. He followed up this observation; something, Conant noted, that does not always occur in science. Not every path is tried in research, and it is the superior researcher who can sense which observations are worth a second look.

Griffith used a strain of pneumococcus that had lost the ability to form capsular material and with it, the ability to cause infection. It was called the R or rough form because its colonies had a rough appearance compared to the normal form, designated S for smooth since accumulation of capsular material gave its colonies a smooth appearance. In one of his experiments, Griffith injected mice with a culture of live type I R pneumococci along with a preparation of type II S organisms that had been heat-killed. Some mice died of a type II pneumococcal infection. As a control, he injected animals with just the heat-killed type II organism; no mice became ill, showing that the organisms were in fact dead and couldn't be responsible for the infections. It appeared instead that something in the type II material was transforming the R organisms into the virulent S form. Conant would have called Griffith's use of controls crucial both in keeping Griffith from following false leads and in convincing others of the results.

Published in 1928, Griffith's work was so thorough that although Avery's group wasn't "entirely convinced," they were "greatly interested," McCarty says. The social aspect again comes into play; other researchers try to reproduce experimental results and then build on them. As Conant said, experimentation "evolves." Avery, who at the time was working on the characterization of SSS, gave Martin Dawson the job of replicating Griffith's results. With this done, Dawson went on to simplify the transformation experiment by developing an *in vitro* system. The ability to produce transformation in a test tube as well as in mice was an important technical advance since it made experimentation easier, quicker and cheaper. Many people don't realize the importance of such factors in research. With limited time and funds, scientists are likely to neglect areas of study that present too many difficulties.

The stage was now set for Avery to ask one of his simple, yet more important questions: What is the chemical nature of TP? But the answer did not come easily. Even with *in vitro* transformation, the results were unreliable. This problem was to plague Avery and his coworkers all through the quest for TP, a quest that is, in fact, a case history of the problems of purifying biological material and of the "fumblings" of scientists. In most of their work they used an extract of type III pneumococcus as the source of the TP, because from their earlier identification of SSS they had Dubos's enzyme to destroy the type III SSS and thus aid purification. The R strain to be transformed was a type II pneumococcus that MacLeod had found while testing R variants early in his work with Avery. Designated R36, it was selected because it showed little tendency to revert spontaneously to the S form, and yet could be transformed easily when exposed to S extracts. The discovery of R36 is an example of the small but significant changes in their materials and techniques that finally brought success.

McCarty describes the work as "dogged." There were no big breakthroughs, and he notes, "Nothing in my memory or in the laboratory notes suggests that there was a moment of sudden revelation, a single experiment that resulted in a flash of insight." In 1943, at the end of their quest, Avery wrote a letter to his brother Roy in which he recounted the problems involved:

> The crude extract (Type III) is full of capsular polysaccharide, C (somatic) carbohydrate, nucleoproteins, free nucleic acids. . . lipids and other cell constituents. Try to isolate and chemically identify the particular substance that will by itself when brought into contact with the R cell derived from Type II cause it to elaborate Type III capsular polysaccharide, and to acquire all the aristocratic distinctions of the same specific type of cells as that from which the extract was prepared! Some job–full of heartaches and heartbreaks. But at last *perhaps* we have it.

As Conant noted, a problem in all research is the fruitless dead end where researchers often find themselves. MacLeod worked on TP for three years, from 1934 to 1937, without making much progress. One of his dead ends involved a long effort to identify the factor from serum that was needed in the transformation reaction. He was unsuccessful, and it wasn't until much later that Roland Hotchkiss identified it simply as serum albumin which neutralized substances toxic to pneumococci.

MacLeod's efforts were so unsuccessful that he and Avery put aside their work on TP for three years, from 1937 to 1940. This illustrates several things about the social aspect of science. First, MacLeod was concerned because despite all his work he had little in the way of publishable results, and therefore his future success as a researcher was in jeopardy. Another factor was the appearance of the sulfonamide drugs and their potential in treating pneumonia. Avery's lab was, after all, attached to the hospital of the Rockefeller Institute and always had as its goal the development of ways to control this disease. MacLeod therefore turned to research on sulfonamides. Avery, who was over 60, no longer initiated experiments, so the TP work faltered. No other group took up this work, indicating both the slower pace of research at the time and the fact that the significance of TP was not readily apparent to other researchers.

Avery and MacLeod restarted their TP work in 1940 and slowly perfected the purification process. Conant would stress the importance both of better techniques and of what he called "practical arts" in bringing about their success. One example of the latter was a Sharples cream separator, adapted to separating pneumococci from large volumes of medium. This machine made it practical to grow the bacteria in large batches and thus obtain sufficient quantities for extensive work.

After the SIII organisms were collected, they were killed and disrupted. Protein was then removed by chloroform extraction. They used ribonuclease to remove RNA and Dubos's SIII enzyme to remove the polysaccharide. The remaining material, which still contained all the transforming activity, was first tested for the presence of DNA in January 1941, and the results were positive. McCarty says, "This first indication that the pneumococcus contained DNA came as something of a surprise. Knowledge of the occurrence and distribution of the nucleic acids in nature had not yet reached the point where one could assume that all living cells contained both RNA and DNA." Insights such as this are, I think, what make McCarty's book so valuable as a case history. They help us to see why research is so difficult. Less than 50 years later, it's hard to believe that Avery's group was working that much in the dark, and it makes their achievement even more noteworthy.

McCarty himself arrived on the scene in 1941, as MacLeod was leaving to take a position at New York University. One of McCarty's first tasks was to make the transforming system more reliable. Throughout the book, he repeatedly mentions the "vagaries" of the system, the lack of "tidy" results. One problem was that the TP extract was crude and needed further purification. McCarty accomplished this and also developed a more sensitive test of transformation. This helped to make results more clear-cut and is a nice example of the concept of sensitivity in testing, a major problem in many fields of research.

By the fall of 1943, 15 years after the publication of Griffith's paper, Avery was ready to publish his results (Avery, MacLeod & McCarty 1944). By that time, the TP extract had been tested for purity by both ultracentrifugation and electrophoresis. Many controls had been run in which the TP had been treated with DNA-destroying enzyme (DNase), and all activity was lost. As in his work with SSS, Avery found this evidence particularly convincing, and even after their initial paper was published in February 1944, he and McCarty continued studies with this enzyme to strengthen their results.

McCarty carefully analyzes why their results did not seem to have an immediate impact on most researchers. His discussion illustrates several points about science as a social activity. First of all, they published in the *Journal of Experimental Medicine*, which was unlikely to be read by most bacteriologists and geneticists. Also, at the time there was little communication between these two groups; geneticists weren't interested in bacteria, which seemed to lack any type of sexual reproduction. Another factor points to science as an international endeavor. This paper came out during World War II when scientific communications were disrupted. Fewer researchers than usual read it, especially overseas.

Both Gunther Stent (1972) and H.V. Wyatt (1972) see "prematurity" as the main reason for the slow acceptance of Avery's work. If, as Wyatt says, a premature result is one that can't be extended experimentally, then the identification of DNA as the transforming principle was not premature, according to McCarty. Erwin Chargaff (1978) has credited Avery's paper with spurring his work on nucleotide content in different organisms, and his findings, in turn, were important in Watson and Crick's work on the structure of DNA (Watson 1968). McCarty also cites other research that flowed directly from Avery's work and makes a good case against critics who claimed that Avery and his coworkers didn't even realize the significance of their work. Again from Avery's letter to his brother, McCarty quotes passages indicating that TP "may be a gene" and that the problem "bristles with implications."

Avery's work also bristles with examples of the tactics and strategy of science that were originally outlined by Conant 40 years ago. As McCarty recounts the work it makes an almost perfect case history. For those who want to put it into the larger context of 20th-century genetic research, the histories of Mayr (1982), Olby (1974), Dubos (1976) and Judson (1979) are all valuable. One aspect of science that McCarty doesn't stress is the importance of intuition, but it comes through implicitly in the story he tells, as does the idea of the joy and surprise that science can provide. As Avery wrote of his discovery, "Who could have guessed it?"

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The Other Side of the Coin

The human body's ability to function well under an amazing variety of conditions is a result of its extreme intricacy. One reason for this complexity is that most functions of the body involve two opposing activities; there is what Erwin Chargaff (1978) calls a "dialectical character" to life processes. Every bone contains cells that make bone tissue and others that dissolve it; the blood has both clotting and anticlotting factors; the nervous system releases both pain-producing and pain-killing substances. The balance arising from these opposing processes includes homeostasis, the balance of the body's internal environment. This yin and yang of the body is a beautiful idea, but one that students don't always appreciate. When my stepson Geoff took high school biology, he mentioned that they had covered homeostasis in class. His teacher became excited about it, but Geoff felt the topic didn't warrant such enthusiasm. Now Geoff is a straight-A student and interested in a career in science (It's okay for a stepmother to brag!), so I can assume that he grasped the concept of homeostasis as well as most students would. After considering his comment for some time, I'm beginning to think that the problem does not lie wholly with the students or even with the teachers. The problem seems to be that, in many cases, research on these opposing activities itself has been unbalanced with one activity, one side of the coin, receiving most of the attention.

For example, medical researchers have a much clearer picture of the processes involved in inflammation than those associated with anti-inflammatory effects. This picture is now changing with the discovery of substances such as the lipocortins, which block the enzyme that mediates the generation of such inflammation-producing substances as the prostaglandins and leukotrienes (Flower 1986). There is also much more emphasis placed on proteolytic enzymes than on their inhibitors such as α-antitrypsin.Yet lack of this enzyme recently has been found to lead to emphysema because it inhibits tissue-destroying elastase in the lungs (Carrell 1984).

In a recent article on cancer, Jean Marx (1986) notes that:

> Investigators who have been trying for the past several years to decipher the mysteries of cancer have concentrated mostly on the forces–such as growth

> **factors and oncogenes-that might actively stimulate the uncontrolled growth of cancer cells. Largely neglected until recently were the inhibitory forces that might check cell division and the development of malignancies.**

This imbalance has begun to be righted with researchers focusing more attention on growth inhibitors. [One such substance has the misleading name transforming growth factor-type β (TGF β).] It does stimulate the growth of fibroblasts, but it inhibits the growth of most other cell types. There is evidence that loss of responsiveness to the growth-inhibiting effect of TGF may lead to the uncontrolled division of cancer cells. Other researchers have identified chromosomal regions that appear to code for tumor suppressor genes (Hunter 1986). Loss of these regions leads to cancers such as retinoblastoma and Wilm's tumor, to which some individuals have hereditary pre-dispositions. *(Update: There is now a great deal of further evidence to support the importance of growth suppressor genes [Science, 246, 1406].)*

Another example of skewed perception of bodily processes involves blood clotting. For years the intricacies of the clotting process have been studied in depth, with less attention being paid to how the body dissolves clots or prevents unwanted clots from forming. In the last 30 years, this situation has changed as researchers and physicians have tried to find ways to deal with dangerous clots within blood vessels. Wessler and Gitel (1984) note that to maintain open blood vessels a delicate balance must exist between seven complex interrelated systems: the endothelium, the platelets, coagulation, fibrinolytic system, their plasma inhibitors, the deformation and flow characteristics of blood, and vascular tone. It is the clot inhibitors and the fibrinolytic or clot-dissolving systems that are receiving increased attention recently.

Protein Ca, the activated form of protein C, is a potent anticoagulant, and its activation illustrates the complex nature of blood maintenance. The clotting factor, thrombin, catalyzes the change of protein C to the Ca form (Clouse & Comp 1986). This reaction, which is obviously designed to prevent the clotting process from getting out of hand, is particularly efficient when thrombin is attached to its receptor, thrombomodulin, which is found on cells of the capillary endothelium. Thrombomodulin controls thrombosis or clotting both by binding thrombin to reduce its coagulant activity and by generating protein Ca as a circulating anticoagulant which then inactivates several clotting factors. Protein Ca not only acts to slow further clotting, it also aids in the breakdown of already-formed clots. It neutralizes an inhibitor of tissue-type plasminogen activator (TPA). TPA, in turn, converts plasminogen to plasmin, the protein responsible for the lysis of fibrin in clots. If all this seems very complicated, it is, and it ought to be. As I never tire of telling my students, the more important an activity is for the body, the more ways there are in which that activity is controlled. Blood clotting is one such crucial activity. The complexity of control enables the body to deal effectively with a wide variety of situations.

This complexity also gives researchers a variety of points at which to try to intervene in the clotting process when clotting is the result of some pathology in the blood vessels. Over the past few years, intravenous injections of either streptokinase or urokinase, both plasminogen activators, have been given to patients within hours of their having suffered heart attacks. These enzymes dissolve heart attack-causing thrombi or clots. Unfortunately, they not only break down the fibrin within the clots, but also degrade circulating fibrinogen and clotting factors V and VII. This can lead to dangerous bleeding complications. Increased knowledge of the clot-dissolving process had led researchers to substitute TPA for the other two enzymes (Sherry 1985). TPA only changes plasminogen into plasmin after binding to fibrin clots. Thus, plasmin's lysis of fibrin occurs only at the site of the clot, and there is less effect on circulating clotting factors than with the other enzymes (Relman 1985). Of course, TPA does cause some bleeding complications, so researchers are delving deeper into the intricacies of blood clotting in a search for safer and more effective substances, including a prourokinase that would be activated only when in contact with a fibrin clot (Laffel & Braunwald 1984). *(Update: Recent research has added to evidence of both the efficacy of and problems with TPA and streptokinase [The New England Journal of Medicine, 320, 861].)*

Perhaps part of the responsibility for the public's skewed perceptions about vitamins stems from the fact that teachers, physicians and researchers all have failed to emphasize the concept of balance in bodily processes.

Though it seems to make sense that dissolving a thrombus will, by restoring blood flow to the heart muscle, reduce the extent of damage, researchers are finding that in some cases the opposite may in fact be true. The culprit seems to be oxygen. While we usually think of oxygen as a giver of life, there is another side to the oxygen coin, a destructive side, in the form of highly reactive oxygen-derived free radicals such as the super-oxide radical O_2 – (McCord 1985). When a thrombus cuts off the blood flow to tissues, there is no longer oxygen present for ATP production. As the available ATP is used, there is an increase in the concentration of AMP, which is metabolized to hypoxanthine. When blood flow to the tissue is restored, the newly present oxygen and hypoxanthine serve as substrates for a reaction which produces dangerous superoxide radicals. So it appears that merely restoring blood flow to heart muscle may not be enough to prevent extensive tissue damage.

Thus, as commonly occurs in medical research, manipulation of one bodily process has revealed another previously hidden activity. At such times, the complexities of the body can be very daunting, but investigation of these intricacies can often lead to new therapies. In this case, the body's homeostatic mechanisms again come to the rescue In a sense, the body has always been dealing with the problems we are now trying to solve. For the problem of free radicals, most of the body's cells are equipped with glutathione, a tripeptide thiol which neutralizes many free radicals (Meister 1983). Cells also contain the enzymes superoxide dismutase and catalase. Superoxide dismutase converts the superoxide radical into hydrogen peroxide which catalase then decomposes to water. Studies with rabbits show that the presence of these enzymes in the perfusion fluid greatly enhance left ventricle recovery from a period of oxygen deprivation. This work may lead to ways to prevent cardiac muscle damage after a coronary thrombus has been dissolved.

High concentrations of oxygen-free radicals and other forms of active oxygen, including hydrogen peroxide, can create intracellular prooxidant states that play a role in carcinogesis by promoting the growth of abnormal cells. Active oxygen can induce chromosomal aberrations and thus also is involved in neoplastic progression. Many carcinogens and tumor promoters create intracellular, prooxidant states, and as Peter Cerutti (1985) notes, these states "may modulate the expression of a family of prooxidant genes, which are related to cell growth and differentiation." Many antioxidants, which work to suppress such states, are antipromoters and anticarcinogens. β-carotene, a precursor of vitamin A, is one such radical-trapping antioxidant that works best at the low oxygen partial pressures found in most tissues (Burton & Ingold 1984).

Though oxygen-free radicals obviously can cause a great deal of trouble in the body, they can also be used as weapons against disease. Again, as researchers learn more about how the body itself maintains its homeostatic balance, they can find ways to make distortions of that balance work for, as well as against, the body. For example, there is evidence that oxygen radicals can kill malaria parasites (Cox 1983). As malaria-infected red blood cells squeeze between the fixed macrophages of the spleen and liver, oxidative bursts are released by the macrophage. These bursts subject the blood cells to toxic oxygen products. Similar bursts are the primary mechanisms for the destruction of phagocytosed microorganisms, and now it appears the macrophages can export such radicals too (Lachmann 1986). This evidence could lead to the development of new anti-malarial drugs that act by releasing oxygen radicals. *(Update: The importance of oxygen radicals both in disease processes and in immune response is becoming more and more evident through research [The New York Times, April 26, 1988, p. C1].)*

Another example of a beautifully balanced physiological activity that can go awry and cause debilitating disease involves the bone. Normally bone formation and resorption occur continually and are balanced processes. At the beginning of each remodeling cycle, which takes place in discrete areas called bone remodeling units, the cells that dissolve bone, the osteoclasts, start the process. In cortical bone, they construct a tunnel and in trabecular bone, a gap on the surface. This takes about two weeks. Over a period of three or four months, the bone-forming cells, the osteoblasts, fill in the resulting cavities to create a new structural unit of bone (Riggs & Melton 1986). The rate of activation of such remodeling units determines the rate of bone turnover. In young people the processes of resorption and formation are tightly coupled, so bone mass is maintained. Researchers have identified a protein called skeletal growth factor which may be at least partially responsible for this balance, since it appears to be released by the action of osteoclasts and, in turn, stimulates osteoblasts (Fackelmann 1982). But, like all the essential processes of the body, bone remodeling is subject to a variety of controls. For example, bone resorption is stimulated by parathyroid hormone, calcitriol (1, 25-dihydroxyvitamin D_3), prostaglandin E_2 and osteoclast-activating factor, a lymphokine, while it is slowed by calcitonin and diphosphate compounds (Coccia 1984).

It is no wonder that, faced with this complexity, researchers are having difficulty understanding osteoporosis, the disease in which bone mass decreases. Postmenopausal women are at greater risk than men because of a loss of bone-sustaining estrogen, but both sexes suffer a slow, age-related deterioration. This bone loss seems to be caused by reduced osteoblast activity in remodeling units. Since healing of fractures isn't slowed in the elderly, the osteoblasts still can make bone effectively. The problem, instead, seems to be that regulation of osteoblast activity is defective. There is a great deal of controversy as to who is at risk of osteoporosis and whether or not the degree of risk can be reduced. Though calcium tablets are now among the most popular of nutritional supplements, some researchers have found that calcium intake in adults may have little to do with osteoporosis. In one study estrogen supplements retarded bone loss in women, while calcium supplements of 2,000 milligrams daily did not (Kolata 1986).

Though a great deal of attention is being focused on problems of bone deterioration, there is another side to the bone-formation coin, a rare disease in which the problem is not a lack of bone, but too much. Here it is not the osteoblasts that are defective, but the osteoclasts, reminding us that the balance of physiological processes is indeed a balance that, when tipped in either direction, can cause problems. The disease is called osteopetrosis, and in its most severe form it is an inherited, autosomal recessive disorder which is usually fatal during childhood because the nervous system and the bone marrow are both damaged by bony sclerosis (Key et al. 1984).

Careful study of osteoclasts and of the bone resorption process has led to a therapy that can help at least some patients with this disease. Research on mice has revealed that bone resorption is caused by cells derived from the hematopoietic stem cell, the same cell from which red and white blood cells arise. In fact, as Peter Coccia (1984) notes, "Evidence is accumulating that mononuclear phagocytes, including peripheral-blood monocytes and tissue macrophages, also have an important role in bone resorption." These cells have organelles and enzyme systems similar to those of osteoclasts. The similarities between phagocytes and osteoclasts had never dawned on me, but it makes sense; all these cells are involved in the demolition of living material. Thus, a bone marrow transplant that includes stem cells, which have the potential to develop into both osteoclasts and phagocytes, could provide osteopetrosis patients with the cell in which they are deficient. Several such transplants have been done, and about half of them have been successful. If the transplant is performed in infancy, the child develops normal nervous, skeletal and blood-making systems. In other words, the genetic imbalance in the bone-forming apparatus, which the body itself cannot right, can be corrected by human intervention.

In other cases, imbalances in the body are the result of human intervention. Throughout history, vitamin deficiency diseases have taken a tremendous

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toll. As the causes and cures of these diseases were discovered, people came to realize the importance of these chemicals to health. Now, unfortunately, the balance seems to be tilting in the opposite direction–the toxic side effects of vitamin overdoses are becoming more and more common (Brody 1984). This problem stems from the widely-held view that if something is useful to the body in low doses, it will be even more useful in high doses. But, as Luciano Caglioti (1983) has said, "There is no safe substance; anything taken in sufficient quantity is toxic."

Vitamin A is associated with the largest number of vitamin poisoning cases. Since it is fat soluble and stored in the liver, megadoses on a regular basis can lead to toxic accumulations. The same is true of vitamin D. But while some people are becoming aware of these problems, they still assume vitamin C is safe in any quantity because excess of this water-soluble vitamin is flushed out of the body in the urine. They don't consider that their poor kidneys must bear the brunt of this chemical onslaught, and that vitamin C can cause kidney stones in susceptible individuals.

Part of the responsibility for the public's skewed perceptions about vitamins might stem from the fact that teachers, physicians and researchers all have failed to emphasize the concept of balance in bodily processes. Maybe it is time that we make a more conscious effort to stress the yin and yang of biology. This isn't always easy to do. First of all, it takes more time to discuss both sides of the coin, both clotting and anti-clotting processes, for example, rather than to take the more traditional approach and focus just on clotting. The second difficulty is, as I mentioned before, that a balanced view isn't always available; often much more is known about one side of the coin than the other. Thirdly, in most cases, the negative side of the balance is the aspect that is slighted because, obviously, it is easier to discuss what is there than what is not there, a clot rather than the absence of a clot, inflammation rather than no inflammation, etc. Despite these problems, I think we should at least attempt a balancing act in the classroom. Maybe we can't do a perfect job, but then neither does the body; balance isn't maintained perfectly, body activities are allowed to fluctuate within limits. Such fluctuation, such tension, between opposing functions constitutes life, and it is this aspect of life that I think we should stress when we cover physiological processes.

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May 1987

In the Flower Garden

I'm not exactly sure how I ended up as a biology teacher. My parents were neither teachers nor scientists, though they had the attributes of good teachers: inquiring minds, a desire to share their learning with others and the patience to do it well. They were the best of teachers because they seemed to do it effortlessly, unlike many parents who are self-conscious in their teaching, who try too hard to get their children to learn. Some of my clearest childhood memories are of my parents sitting in the living room reading and then telling each other, and my sister and me, the fascinating items they'd just discovered.

Though my background might explain my interest in teaching–I was imbued with a desire to share learning with others–it doesn't explain why I'm teaching biology and not literature, my mother's passion, or political science (as a tavern-owner my father talked politics all day!). Science just doesn't come into the picture; in fact, my mother was one of those people who lumped together science and math and professed a loathing for both. But a closer examination reveals a slightly different picture. There was one aspect of science that my mother didn't hate: botany. She still has a school certificate proclaiming, in Gaelic, her excellence in botanical science. She always loved growing plants, both indoors and out. Maybe it was kneeling beside her in the garden, planting and weeding, that first sparked my interest in living things, in watching growth and change.

Yet, ironically, when I got to college and majored in biology, botany held no interest for me. I liked gardening, working with plants, but the more I learned about plants, the more confused I became. There was just too much variability. Most animals are diploid, but plants could be haploid, diploid, triploid or even tetrapoloid! The multiplicity of flower structures also seemed unfathomable, and I don't know how many times I memorized the distinguishing features of angiosperms and gymnosperms, monocots and dicots, only to have all these facts quickly slip from my brain.

I have always felt guilty about this blind spot in my biological education. There's something wrong about ignoring one of the great kingdoms of living things. It is particularly distressing because I am not alone in my prejudice; to many botany is synonymous with what is dry, complicated and uninteresting in biology. Considering my own attitude, I am probably the last person to prescribe a remedy for this situation, but perhaps I can learn something from my mother. She liked botany because she liked to see things grow, and especially because she liked to grow beautiful flowers.

So maybe the place to start is with flowers. Flowers are beautiful to look at; many flowers even undergo subtle color changes as they open. This is very true of roses and daffodils; the trumpet of the daffodil "Rima" is creamy yellow when the flower first appears, but then develops to a salmon pink with "a hint of lilac" (Lacy 1982). Studying such changes is a great way for students to hone their observation skills. And, to give a new and fresh perspective on observation, flowers can even be X-rayed! For the past 25 years Albert Richards (1986), who taught radiography in dental school, has been X-raying flowers as a hobby. The radiographs lack color, of course, yet they strikingly reveal the venation of petals and the intricate internal structure of the flowers. But it makes sense to study flowers for many reasons aside from the aesthetic one. Flowers are of primary importance because they contain the plant's reproductive organs. They also were the basis of the first successful plant classification scheme, that of Carl Linnaeus, who was introduced to the field by his botanically-minded father (Gilbert 1984).

Perhaps the best place to start a discussion of flowers is at the beginning, though there are obstacles to this attempt. It is difficult to trace the evolution of flowering plants, angiosperms, because flowers so rarely fossilize. One clue comes from apparently primitive flowering plants that still flourish, such as the magnolia. In a beautiful description of its properties, May Theilgaard Watts (1975) called the magnolia "the flower at the base of the 'family tree' of flowers." The petals are separate, not joined at the base as in more modern flowers, where a fused construction makes it more likely that an insect will make contact with the flower's sexual parts and thus pick up pollen. The large number of carpels and stamens also indicates an ancient design, as does the fact that each flower is a separate entity, as opposed to composite flowers of later evolutionary origin. Even the leaves seem primitive since they are unlobed. Recently, a fossil of an *Archaeanthus linnenbergeri* flower from Kansas was analyzed (Collinson 1986). It is about 95 million years old, and as would be expected if indeed the magnolia is an ancient form, it closely resembles modern magnolia flowers, though it is more primitive.

Angiosperms first appeared at least 115 million years ago when dinosaurs roamed the earth. In fact, Robert Bakker (1986) sees dinosaurs as instrumental in the success of early flowering plants. According to Bakker, it is significant that the first flowering plants appeared in the early Cretaceous era, just following the extinction of many herbivorous dinosaurs that were "high feeders" grazing on the branches of trees rather than on plants near the ground. When these animals died out, the dinosaurs that became dominant were "low feeders" browsing close to the ground. This type of feeding is more dangerous to plants. High feeders often just prune large, well-established plants; low feeders can destroy young plants before they become established and reproduce. Bakker contends that, "Intense low cropping placed a premium on any and all plant adaptations for fast spreading, fast growing and fast reproduction. And early angiosperms performed exactly these biological functions especially well." In other words, the flowering plants gained dominance because they were able to survive dinosaur predation more successfully than were conifers, cycadeoids and other nonangiosperms.

Bakker's thesis is controversial; many other factors influenced angiosperm evolution, including climatic changes and the co-evolution of pollinating and dispersing agents such as insects and birds. But the flower-dinosaur story is a good one, an attention getter, that may help overcome student indifference to the plant world. Though a few students may be interested in gardening, most–at least in urban areas–think of flowers merely as something to buy, not grow. Last Valentine's Day, my stepson spent a fortune on a dozen roses for his girlfriend; that is the extent of Greg's and most other teenagers' interest in flowers. Any interest is better than none. Maybe a discussion of flowers could include the question: Why are they so expensive? Flowers are ephemeral; they're not supposed to last. The most beautiful are designed to attract a pollinator. Having accomplished this mission, a flower's beauty can fade fast. The orchid flower is an extreme example. It shrivels up and loses its petals within hours after pollination. That's why commercial growers go to extremes to prevent pollination.

It is unfortunate that, for most of us, our only experience with orchids is through the florist. . . Orchids can serve as excellent examples of the evolution of adaptions (Gould 1980).

But humans are attracted to the beauty of flowers and have developed many strategies, from placing aspirin in vase water to refrigeration, to prolong that beauty. Yet nature still balks, so humans have to work fast. Lee Lockwood (1984) has written a fascinating article about Holland's Aalsmeer Flower Auction. The largest in the world, it handles more than 2 billion flowers a year. Flowers sold there each morning are on sale in United States flower shops about 48 hours later. The operation is computerized, mechanized and highly efficient. It has to be, with such a perishable product. But such modern efficiency is expensive; that's one reason Greg spent so much for his roses.

Another reason for high prices is that plants do not naturally flower according to human schedules. If we wanted to make things easier on the pocketbook, Valentine's Day should be in June. Day length, temperature and moisture level are all factors that influence flowering, though to varying degrees with each species. Chrysanthemums, for example, bloom naturally in the fall, but now they've become a popular Easter plant. Greenhouses are a must for "forcing" such plants to bloom on cue. Poinsettias need 15 hours of uninterrupted darkness each night if they are going to bring cheer, rather than just green leaves, to the Christmas holidays (Swain 1983), and the Vanda orchids used in corsages require the warm, moist environment of a greenhouse. They have other special requirements too. Orchid seeds are very small and have no nutrient reserves. To germinate, they must be infected with a fine fungal mycelium which provides the sugars necessary for development. This symbiotic relationship explains why early botanists could get orchid seeds to germinate only by planting them near other orchids from which the fungus could be passed. Now agar-based nutrient solutions make germination more certain (Schofield 1983).

It is unfortunate that, for most of us, our only experience with orchids is through the florist. The Orchidaceae is one of the largest families of flowering plants, with about 30,000 species ranging from *Vanilla planifolia*, whose pod is a familiar source of flavoring, to the coralroot orchid which can survive the rigors of the arctic. Orchids can serve as excellent examples of the evolution of adaptions (Gould 1980). Specific pollinators, usually insects, and orchids have adapted to each other and formed complex relationships. That's one of the reasons Darwin was attracted to the study of this plant family and ended up writing *On the Various Contrivances by Which British and Foreign Orchids are Fertilised by Insects* (1862).

Orchids have fascinated a great many people besides Darwin. Both amateur and professional botanists have been hybridizing orchids for centuries; there are now more than 60,000 registered hybrids. Of course, orchids are not unique in this regard; botanists and gardeners have always tried to make beautiful flowers more beautiful. Color is of special interest to hybridizers, and their successes and failures can teach students much about the complexities of genetics. For example, there are no red or yellow African violets. A bright red violet, a seeming contradiction in terms, appears to be a Holy Grail for lovers of the species. In fact, the African Violet Society is sponsoring research at Penn State University toward achieving this goal (Allen 1984). Though a red violet still eludes these researchers, their breeding studies have been fruitful in revealing much about the genetics of color in these plants. They have sorted out four intensifier genes, as well as genes responsible for flower shape. Richard Craig, the chief investigator, thinks it's only a matter of time before red and even yellow African violets are perched on windowsills.

I think the best looking African violets are the purple ones, and I'm also not thrilled with the idea of a black tulip. But, in Holland, Geert Hageman, who has just developed the blackest tulip to date, is a national celebrity and is taking elaborate precautions to protect his precious bulb from theft. He is also trying to breed deep blue and bright green tulips. Neither will replace bright red in my garden--red is fine for tulips if not for violets. But it will be years before I'll have to make a decision about such things. Tulip breeding is a slow process (Furland 1986). After pollen transfer, in this case from "Wienerwald" with dark purple flowers bordered in white to "Queen of the Night" with eggplant-colored flowers, the seeds are allowed to mature and then are planted. But it takes at least five years for a bulb to mature enough to produce a flower, and thus for a breeder to know the results of a cross.

It seems that breeders can't leave any flower color alone. Some of the results are spectacular; irises and daylilies have become more and more varied over the years (Lloyd 1986; Mosher 1983). Yet sometimes breeders don't seem to know when to stop. I happen to think that marigolds should be gold, or at least some shade of orange or yellow. But breeders spent years developing a white marigold. Each year they selected seeds from the palest flowers for use the following year (Perényi 1981). This is a nice example for students of a traditional selective breeding program, the type that has been used for millenia to bring about gradual improvements in desired traits, and the type that so attracted Darwin's attention and played a role in the development of his theories.

Now I can't see the point of bleaching such a sunny flower as the marigold, but as Roger Swain (1983) says, "There is nothing that excites some gardeners more than the sudden appearance of a white blossom instead of a colored one." The white color in most flowers is due, not to a white pigment, but to tiny, light-scattering air pockets in the intercellular spaces of the petals. These air pockets are always present, but usually the petals contain pigments that mask this effect. In many species, white flowers appear only when a mutation prevents normal pigment production. Swain sees several problems with white flowers, including the fact that they get dirty! Many, though not all, white-flowered cultivars are less vigorous and less hardy than their colored relatives. Also, these albinos may not be pollinated as successfully. Experiments with deep blue larkspurs and with white ones revealed that the albino plants produced less seed because they weren't visited as frequently by the larkspur's pollinators. This may be because the pollinators had a harder time finding the white flowers without a white center against a blue background to serve as a target.

> *. . . flowers can be looked at from a variety of perspectives, as examples of genetic interactions, as successful reproductive structures and as foci for acute observation. Students can learn a great deal of biology from flowers . . .*

While I have concentrated on color, there are a variety of other flower traits that could be used as examples of breeders' skills and limitations. Petal number and shape are favorite targets, though the results aren't always received enthusiastically. Now there are zinnias so full of petals that they are advertised as looking like asters, while others look like dahlias and some resemble chrysanthemums. This led Katherine White (1979) to remark, "I like chrysanthemums, but why should zinnias be made to look like them?" This topic makes a nice starting point for a discussion of genetic plasticity and also of the question of how to define a species. As Peter Moore (1984) has noted, "Gardens can be frustrating places for the botanist" because of taxonomic problems.

Another much discussed flower trait is fragrance. Give someone a rose and usually their first response is to smell it. Sean McCann (1987) explains the source of fragrance: "Tiny droplets of perfume are manufactured on the inner part of the rose petal and burst from minute papillae, or nipples, on the petal's surface." The more papillae present, the more fragrant the rose will be, but unfortunately the more easily the petals will bruise, too. That's one reason why Greg's roses may impress his girlfriend, but not her olfactory receptors. Another reason many modern roses are not very fragrant is that disease resistance, flower production and growth properties are valued more highly by breeders than is fragrance. As Henry Mitchell (1981) says, there is no perfect rose: "The trouble is there are no roses, none, that do not fail in one or more of these desirable qualities."

Considering the fact that roses have been cultivated for more than 3,000 years (Houghton 1978), it would seem that someone would have come up with the "perfect rose." The fact that they haven't is a good illustration of the genetic recalcitrance with which breeders must contend. This inflexibility has several sources. It is good for students to understand these so that they aren't mesmerized by some of the more optimistic predictions made about genetically-engineered plants. The first and most important restriction involves pleiotropic genes, those that have more than one effect. For example, as mentioned earlier, a genetic change that produces a white larkspur also produces a less fertile plant. The second problem is linkage. Sometimes genes for two different traits are located so close to each other on a chromosome that they are usually inherited together.

As I have tried to show, flowers can be looked at from a variety of perspectives: as examples of genetic interactions, as successful reproductive structures and as foci for acute observation. Students can learn a great deal of biology from flowers, apart from such taxonomic considerations as the structure of the pistil or sepal number. The best possible situation would be for students to grow flowers. The elementary school science program called Life Lab involves gardening and has been used successfully in a number of schools (Fisher 1986). Though the emphasis is on growing vegetables, there is no reason why flowers could not be added to the curriculum and to the garden. It would be good for students to have the opportunity to kneel down in a garden and plant a marigold or a tulip bulb or even a rose bush, and then watch the plant's tremendous transformations through the seasons as I did in my mother's garden.

With all the concern today over where the science teachers of the future will come from, perhaps my experience gives one small answer: They literally grow in a garden. Perhaps simple experiences like my own are the best form of nourishment for future talent. I am convinced that, despite all that has been learned about cognitive psychology, we really know little about what touches children most deeply. The things I most remember from my teachers are simple things, probably not what they were most concerned about teaching me, and I think this is true for many people. Georgia O'Keefe, an artist who often took flowers as her subject, remembered a teacher who held up a plant for study and pointed out the shapes and variations in color found in it. This started O'Keefe looking more carefully at the world around her and at the rich and exciting variety of shapes and colors to be found there, especially in the world of flowers (Foshay 1984).

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February 1988

Of Chaperones and Dancing Molecules: The Power of Metaphors

Once in a while, I'll read an article on biology that makes my day. For some reason, it is so intriguing that my mind keeps returning to it. This is one of the great pleasures of being a biologist, and one that I experienced recently when I read an article on "molecular chaperones" (Ellis 1987).

Molecular chaperones are cellular proteins that ensure both the proper folding of polypeptide chains and the assembly of multi-chain or oligomeric proteins. For example, nucleoplasmin is an acidic nuclear protein required for the assembly of nucleosomes from DNA and histones. It interacts with histones so as to shield their positive charges and thus promote histone-histone interactions by reducing electrostatis repulsion between them.

Like any good chaperone, nucleoplasmin does not form part of the final relationship, but slips away to service another histone interaction. As with their human counterparts, molecular chaperones also prevent improper interactions, ones that would produce incorrect molecular structures. Some disassemble protein structures that are no longer needed or that form during stresses, such as heat shock. The heat-shock proteins hsp 70 and hsc 70 migrate to the nucleoli of heat-shocked cells. There they bind to and disrupt insoluble preribosome aggregates, thus helping recovery of normal nucleolar structure.

I'm fascinated by molecular interactions, so this article was naturally interesting to me, but it was of special interest because of the intriguing metaphor used to describe this interaction. At first glance, proteins and chaperones do not seem closely related, so the mental process that leads to seeing such a relationship is a satisfying experience of discovery.

Now "metaphor" is a topic usually associated with literature, not science. Metaphors are figures of speech that add richness to language and thought by likening two seemingly dissimilar things. But the development of a metaphor is a creative process which is as essential to science as it is to literature. Philip Gell (1983) says that:

> the use of metaphor and analogical thinking is crucial to theory building in biology, in fact possibly theory building in biology is no more than the

> development of useful metaphors–which is much more crucial than measurement. The shared use of metaphors in art and in science seems to me possibly the cement that keeps the two together.

In a discussion of literary metaphor, Max Black (1978) argues that, rather than merely formulating a similarity that already exists between two subjects, a metaphor actually creates that similarity. He develops what he calls an interaction view of metaphor. In the case of a protein being like a chaperone, the protein would be the "principal subject" and chaperone the "subsidiary subject."

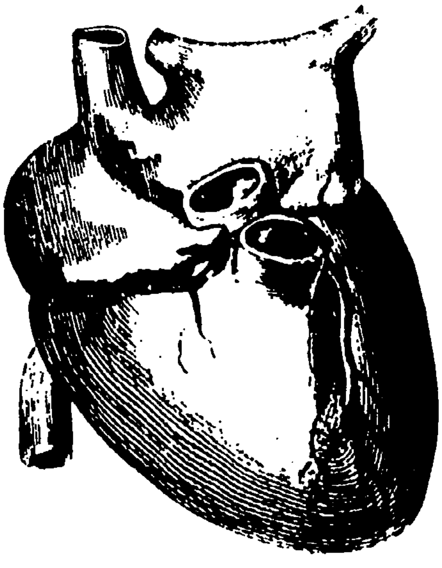
The word "chaperone" brings to mind a system of commonplace meanings. These include the idea that chaperones encourage proper interactions and curb or break up improper ones. This is similar to the function of proteins in the body. The use of this metaphor emphasizes those ideas about proteins that are similar to ideas about chaperones, while suppressing those ideas that are dissimilar.

In other words, the metaphor organizes and directs our view of protein; it acts as a filter, allowing certain aspects of proteins to come forward more clearly. This interaction can also change our view of the word "chaperone," making it perhaps a little less romantic.

Jacob Bronowski (1978) asserts that "the whole of science is shot through and through with metaphors which transfer and link one part of our experience to another, and find likenesses between the parts."

An example of this is Erwin Chargaff's (1978) description of his reaction to Avery's paper on DNA as the molecule of heredity: "I saw before me in dark contours the beginning of a grammar of biology. . . Avery gave us the first text of a new language, or rather he showed us where to look for it. I resolved to search for this text." This metaphor led him to the discovery that the DNA from every organism contains equal amounts of guanine and cytosine, and of adenine and thymine–an important clue used by Watson and Crick in working out the base pairing in DNA.

Another interesting metaphor is William Rushton's likening of the effect of light on molecules in retinal cells to the effect of music on dancers. Light causes the molecules to "rise and dance and change partners" (Stryer 1987). I find this metaphor very appealing. It makes the complexities of visual excitation seem less daunting and more interesting. It also helps me to visualize what's happening at the molecular level. Thus it illustrates the fact that some of the best scientific metaphors are both visual and based on human experience.



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Sometimes a metaphor becomes so familiar it is hardly thought of as a metaphor. This is true of the idea of the heart as a pump. Jonathan Miller (1978) contends that William Harvey would never have conceived of the heart as a pump if water pumps hadn't come into use in 16th-century mining, firefighting and civil engineering. "It seems unlikely that Harvey would have departed so radically from the traditional theory if the technological images of propulsion had not encouraged him to think along such lines."

Miller notes that while primitive societies draw their metaphors about body function from nature–tides, winds, harvests–technologically advanced societies use more mechanistic metaphors such as that of the heart as a pump.

Of course, biological metaphors do not have to be mechanistic. Howard Gruber (1978) notes the importance to Darwin of the tree as a metaphor for evolution. Tree diagrams appear often in Darwin's notebooks, and

> the image of the irregularly branching tree of nature played a pivotal role very early in his thinking about evolution. It captures many points: the fortuitousness of life, the irregularity of the panorama of nature, the explosiveness of growth and the necessity to bridle it "so as to keep number of species constant."

In another work Gruber (1981) argues that no single metaphor can illuminate all of evolution, that Darwin had to use an "ensemble of metaphors" to generate and express such a new point of view. Along with the tree metaphor, Darwin used the image of nature as a "tangled bank," with organisms interacting with each other and the environment in complex interrelationships.

Darwin also compared evolution metaphorically to human warfare and to artificial selection. Gruber says these are the two metaphors commonly referred to in discussion of Darwin's theory. They are simplifying images while the images of the tree and the tangled bank stress complexity and "dramatize the principle of vitality and the explosive, irregular living material on which selection works."

Only when all these metaphors are invoked is a true picture of evolution possible. It is George Levine's (1986) view that Darwin's use of metaphor was literary as well as scientific, and that the success of *The Origin of Species* as literature facilitated its success as science In order to make and sustain his assertions,

> Darwin had to perform some remarkable rhetorical feats, particularly feats of metaphor and analogy . . . Darwin's literary and rhetorical powers help to account in great part for the fact that evolution as an idea, in relatively little time, took hold in the scientific community and in the culture at large.

This example illustrates philosopher George Dickie's (1971) description of metaphor as "a pervasive and powerful aspect of language." Both qualities are apparent in the way we use language to describe disease.

In *Illness as Metaphor*, Susan Sontag (1978) notes that in the 18th and 19th centuries tuberculosis was associated with romantic metaphors of delicacy and sensitivity, while military metaphors in medicine "first came into wide use in the 1880s with the identification of bacteria as agents of disease. Bacteria were said to 'invade' and 'infiltrate.' But talk of siege and war to describe disease has now, with cancer, a striking literalness and authority."

In cancer, the body is "under attack" and the only treatment is to "counterattack," for example by "bombarding" a tumor with radiation. It is Sontag's contention that "illness is *not* a metaphor, and that the most truthful way of regarding illness–the healthiest way of being ill–is one most purified of, most resistant to, metaphoric thinking." But the very pervasiveness of the metaphors she describes makes this unlikely.

A metaphor can sometimes be powerful enough to bring about a paradigm shift in a science, as Donna Haraway (1976) explains in her history of 20th century embryology. Pointing out that metaphor is an important aspect of a paradigm, she presents the paradigm shift as a change from the metaphor of the embryo as a machine to that of the embryo as an organic system composed of crystals, fabrics and fields.

She notes that a metaphor can be crucial to the advancement of science because "it leads to a searching for the limits of the metaphor system and thus generates the anomalies important in paradigm change." She also says that researchers using different metaphors–for example, the embryo as mechanism or as organism–would be inclined to work on different experimental problems and to interpret the results in different language.

The importance of metaphors in biology can also be illustrated by the problems which arise when an adequate metaphor cannot be found. Stephen Jay Gould (1985) describes the case of the 18th century French savant Maupertuis. In the argument between epigeneticists and preformationists over embryonic development, Maupertuis sided with the former, but could not accept a vitalist explanation. He instead developed a rather weak explanation involving a kind of gravity. Gould asks:

> How could Maupertuis imagine the correct solution to his dilemma–programmed instructions–in a century that had no player pianos, not to mention computers? We often think, naively, that missing data are the primary impediments to intellectual progress–just find the right facts and all problems will dissipate. But barriers are often deeper and more abstract in thought. We must have access to the right metaphor, not only to the requisite information.

The fact that metaphors have such a powerful influence on thinking means that they can also mislead. Haraway (1976) cites the case of Otto Bütschli who was so influenced by the metaphor of cellular protoplasm as crystaline material that he analyzed protoplasm in terms of a geometrical space-lattice, and "belief in his paradigm led to his seeing structures that could hardly be confirmed today."

Such an error, rather than weakening the case for the importance of metaphor in biology, actually strengthens it. It shows that the influence of a metaphor can be so powerful that it can weigh more heavily in a biologist's evaluation of nature than does more concrete evidence.

According to Jonathan Miller (1978), a metaphor can be so pervasive that once it "lodges in the imagination, it can successfully eliminate or discredit any evidence which might be regarded as contradictory."

Another problem with the use of metaphors in science is that they are not always fruitful; they do not always lead to real advances in understanding. J.F. Stein (1986) describes the successive metaphors that have guided research on the functioning of the cerebellar cortex. In the early 19th century the cerebellum was thought to be like a voltaic battery, while in the early 20th century its roles in proprioception was likened to that of a telephone exchange. Then, in the 1950s, it was seen as a collection of transistor delay lines, and today as a computer.

"But the cynic's view is that the usefulness of these theories varies inversely with their content of technical jargon." Stein contends that "despite engineering terminology," our understanding of the function of the cerebellum has hardly advanced since 1917 when Gordon Holmes described the disabilities of soldiers with cerebellar injuries. As Joel Hildebrand (1957) has noted, a metaphor "may suggest a valid hypothesis, but there is a danger that it be mistaken for evidence."

Gerald Holton (1986) warns of another problem: "Metaphors do not carry with them clear demarcations of the areas of their legitimacy." A metaphor can be pushed too far; too many comparisons–not all of them legitimate–can be made between the "principal" and "subsidiary" subjects. Then the metaphor may become confused with an identity.

According to Agnes Arber (1954), a metaphor is good and useful as long as its imperfections are kept in mind. The imperfections are the dissimilarities that exist between the principal and subsidiary subjects. Despite dangers, these imperfections are important to the functioning of metaphors because "it is their imperfection which set them in the boundary region of scientific thought where they can exercise their unique power of acting as connecting links with other worlds of experience."

It is important for teachers to realize the problems involved in using metaphors because, as William Gordon (1965) points out, "good teaching has always made ingenious use of metaphor and analogy to help students visualize the internal working of substantive material" in science courses. Holton (1986) argues that a metaphor that is useful to a scientist may be confusing and misleading, as well as useless to students. He says that a metaphor can have different functions. It can serve a scientist either in privately working out a solution to a research problem, or in explaining research to other scientists and even to the public. But a metaphor that didn't play a role in the development of the research can, nonetheless, be used by a scientist to explain research to nonscientists.

Thus scientists can reserve some types of metaphors for themselves and use other types in communicating with the public. Holton does not see this as necessarily dishonest or destructive to public understanding of science, but he does add that:

> the scientist needs above all watchfully to avoid unintended or misleading but appealing metaphors. More often than not I find so-called popularization of science shot through with the attempt to gain attention or understanding by banalized or cheapened metaphors. That is just as counterproductive with respect to scientific literacy as failing to explain the proper boundaries of the correct metaphor.

He says that a "scientist-educator is more likely to avoid such traps . . . if he or she is more conscious of an active obligation to create lively new models, analogies, and metaphors that do not sacrifice content in return for easier transmission."

I think Holton makes two points here that are important to biology teachers. First, he mentions models and analogies as well as metaphors. While many writers use the terms interchangeably, there are differences between them. In an analogy, the comparison is more direct; the two subjects compared are more similar than in a metaphor. According to W.H. Leatherdale (1974), because the comparison is simpler and clearer, analogy doesn't lead to great discoveries, though it can be useful in clarifying thinking and in teaching scientific concepts. A model is a type of analogy in which either a complex system is compared to a simpler one or one system is likened to another. With analogies and models the room for creativity is more limited because the boundaries of the comparison are more obvious than in metaphor.

Holton also speaks of the "active obligation" we have in the use of metaphor in science education. If metaphors are important in the process of science, then metaphors should be stressed more in teaching science. We often use analogies and metaphors almost unconsciously when trying to get concepts across to our students. It seems that when students are having difficulty understanding a concept, our minds work feverishly to find just the right comparison. Perhaps we should let our students in on our technique; perhaps we should actively try to make ourselves and our students aware of the part metaphor plays in both the process and teaching of science.

William Gordon (1965) goes one step further and suggests that we explore the possibility of teaching students "the conscious use of metaphor. These metaphors can lead to visual images for an intuitive, personalized grasp of science." He says that such personal metaphors make scientific concepts real to students and give them a taste for the type of mental processes that occur in doing science. But even the appreciation of others' metaphors can be rewarding because, as Agnes Arber (1954) says, humans have an "undue craving" for metaphor "because of the degree of emotional satisfaction which its use affords."

Jacob Bronowski (1956) sees the appreciation of established metaphors by students as similar to the process of developing new metaphors in science. In both cases there is a "moment of vision" when the mind performs the "act of fusion . . . In the moment of appreciation we live again and the moment when the creator saw and held the hidden likeness."

I experienced just such a moment of vision when reading about molecular chaperones. We owe it to our students to provide them with exciting moments, to guide their minds toward an appreciation for the role metaphor plays in biology. The term initially may seem strange to them coming from a science teacher rather than an English teacher, but discussion of biological metaphors may enrich our students' understanding of biology. It may also show them that the sciences are more closely linked to the world of arts and letters than they thought.

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March 1988

Communicating Biology

As NABT celebrates its 50th year, I'm celebrating my 40th. Though it's ten years older, NABT is probably holding up better than I am. An institution as vigorous as NABT is constantly being revitalized by new members and new leadership. While it can mature, it doesn't have to deteriorate with age.

That, unfortunately, is not the case with an individual. But luckily biology teachers aren't necessarily over the hill at 40. Though we may not be quite as willing as we once were to undertake an ambitious lab or an arduous field trip, we may have gained a maturity and depth of perspective that more than compensates for our lack of stamina.

Nevertheless, we must guard against complacency. Our work can become so routine that it's easy to slack off on the amount of mental, as well as physical, energy we expend. This can have the disastrous effect of making us boring, not only to our students but to ourselves.

My remedy for this is to try something new–a new topic, a new teaching technique or, the best corrective of all, a new course. Fortunately, I teach in the unit of the university responsible for career-oriented programs. This means that I get the opportunity to stay mentally young by devising courses for nonscience majors in a variety of fields.

Years ago I developed a course for criminal justice majors. It focused on the brain, psychoactive drugs, mental illness, stress and the biological side of forensic science. Then came a health course for health care administration majors and more recently, a course in exercise physiology for those in athletic administration. My latest anti-aging remedy is a biology course for communication arts and journalism students which I will be teaching next semester.

This course will be less fact-based than the others. My aim is to communicate to these students my vision of biology. Many of them come to college with an image of biology, and of science in general, that is very different from my own.

As every teacher knows, many students see science as difficult, complex and boring. Few, especially among nonscience majors, see it as interesting, illuminating and exciting. I'm not sure it's possible to appreciably change the former image to the latter in a mere semester, but I think it's important to try, particularly in teaching those who plan to go into the communications field.

Once they have finished their formal education, most people derive almost all their science information from the media. Thus, the perceptions of science held by those working for newspapers and magazines or in TV and radio play a significant role in determining the perceptions held by the rest of the population.

I plan to use the media to help me present my ideas on biology. I'll draw from TV and radio programs and from movies, as well as from newspapers and magazines. Some of the best media presentations do capture the excitement and interest and even the fascinating complexity of science.

But if I am to achieve my goal of changing perceptions, many of these presentations must be critiqued, because of their essence they give a limited view of science.

First of all, in most cases their aim is not to educate, but to inform and entertain. In newspapers and in TV or radio reports, the public expects to find out what's new. This rather obvious point means that background information, which would put that news item in perspective, is often inadequate. This may be less of a problem in a magazine article, but even here the entertainment factor comes in–too much information can bog down a story. With limited space available, keeping a story interesting means keeping it simple (Gastel 1983).

In the case of TV or radio, time is the major limiting factor. And while TV can augment the verbal material with interesting and informative visuals, there is a limit to the complexities the human mind can absorb from such a format. Everyone should be aware of these limitations, but it's particularly important for those involved in communications.

As a biology teacher, my knowledge of theory and practice in communications is minimal, so I don't intend to teach students how to communicate science. And since almost all of these students had high school biology, I won't rehash that material. I intend, instead, to communicate to them some biological concepts and some of my feelings and ideas about biology. I realize that my concept of biology is idiosyncratic at best, that every teacher has a slightly different view of what it means to be a biologist.

John Janovy (1985) has written a wonderful book, *On Becoming a Biologist*, which recently reminded me of this. While we both love the subject, we love different things about it. He sees ecology at the center of the discipline, while I look at biology from the opposite–the molecular end.

I don't plan to use a textbook in this course, but rather to give students a reading list of articles on reserve in the library. Students don't like this approach; it's a hassle to run to the library to read the needed material. But in this way students can sample a wider variety of writing than would be available in any book, and I can tailor the reading list to fit my aims. I want students to realize that science writing and textbook writing are not synonymous terms, that reading about biology can, believe it or not, be enjoyable. I also want them to have glimpses into the minds of some biologists so they can develop an inkling of how a scientist thinks about science.

Even though the aim is to create more scientifically literate communications experts, media presentations–because of the limitations mentioned earlier–cannot be the only source of material used to achieve this goal. I have found that my own appreciation of biology has been most enriched by essays, especially those written by biologists who are also literary stylists.

I have a list of favorites who are so good just thinking about their work brightens my day. I'll include several of these in my reading list which is of course subject to change during the semester as I get a feeling for how my choices are going over with the students. Are these essays conveying the ideas I intended? Are they as fascinating as I had thought, or are they something only a dyed-in-the-wool biologist could love?

I'm going to start with an essay that is directed to science teachers: Lewis Thomas's (1985) *Humanities and Science*. His argument is that science teachers approach their task in the wrong way. They fill their students with information, implying that science has achieved a fairly complete picture, a satisfactory explanation of most of the important questions in physics, biology, etc. This discourages students both because they think that they can't possibly master all these facts and because the explanations of science seem too complex to be grasped by their untrained minds. Thomas's point is that this approach is not only demoralizing to students, it presents a false picture of science. The sciences can, in fact, explain very little about the world around us. Biology, in particular, is constantly dealing with profound mysteries, not only about memory and development, but even about how the heart works and how a plant uses the sun's energy. If teachers presented biology more as a mystery tour, if they identified with their students as fellow searchers who are also baffled by these mysteries, perhaps students wouldn't feel so defeated and would begin to see science as the adventure it truly is.

Now it may seem odd to assign students an essay that's addressed to teachers, but I can't think of a better way to tell students how I perceive science, and how I would like them to perceive it.

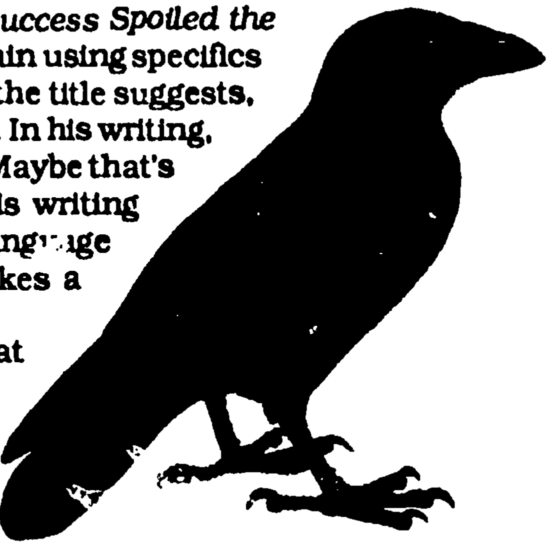
Also, Lewis Thomas is saying that there is good reason for their negative attitudes toward science, that their lack of interest and even hostility is not due to some intrinsic quality of science, but to the way it may have been presented to them. This essay, I hope, will get them thinking about how they feel about science, why they feel that way and about how science was communicated to them. It seems a good way to start the course.

In order to encourage students to see the living world as fascinating I'm going to follow a basic rule of journalism: Use specific examples to make a topic real for a reader.

I'll do this by assigning essays that beautifully describe specific organisms, even though the organisms themselves would not necessarily be described as beautiful.That is definitely the case with Howard Ensign Evans's (1968) depiction of the bedbug. While he rejoices at its demise in the Western world, he calls it a "cuddly animal," and goes on to give a witty but careful description of its habits, hosts and mating-"the male punctures a hole in the female and inserts his semen there." His tone is so conversational, his use of words so distinctive, that the facts fascinate rather than drown the reader. Yet his descriptions are detailed enough to reveal the complexity of the organism and its behavior.

While Evans is a professional biologist, a professor of entomology at Colorado State University, such credentials are not necessarily a requirement for good science writing. In fact, some science journalists think the opposite is true, that a scientist is too immersed in a subject to simplify it for the nonscientist. While Evans disproves this conjecture, David Quammen (1985) shows that professional journalists can also make biology come alive. His book *Natural Acts* is filled with great essays about a variety of organisms from the octopus to the tiger.

The essay I've selected to use in class is about an animal that some may



find as annoying as the bedbug. Titled *Has Success Spoiled the Crow?*, it extols the intelligence of this bird, again using specifics to make the bird and its behavior very real. As the title suggests, this essay is written in a tongue-in-cheek style. In his writing, Quammen is a bit of a wise guy about nature. Maybe that's why this essay is particularly good-here he is writing about a wise-guy bird. But the entertaining language conveys a great deal of information and makes a valid point about evolutionary adaptation.

Yet perhaps the most important idea that Quammen conveys is that science writing can be fun to read. I plan to stress this point by assigning some articles from *The Wall Street Journal* that mix science with humor, yet make serious points about science in our society (Cantu 1987; Hays 1987). I'll also use the cartoons of Gary Larson, Roz Chast and Sidney Harris for the same reason.

Nonscientists tend to relate better to articles about animals than about plants, perhaps because the behavior of animals is so much more obvious than that of plants. But Roger Swain's essays prove that a plant can be as fascinating as any animal. Using the literary technique of making the common seem uncommon, he can make something as ordinary as a philodendron worthy of interest.

In *Earthly Pleasures* (1981), he describes the natural habitat of *Monstera deliciosa*, which we know as the splitleaf philodendron. It is native to the wet tropical forests of Central America, where it produces 10-inch long, cucumber shaped fruit and much more luxuriant foliage than when grown "at the end of the couch" in a North American living room. But *Monstera* is not just bigger and better in its natural environment. Some species of this genus display rather peculiar behavior for plants. In the early stages of growth along the forest floor, the vine seeks dark rather than light, as most self-respecting plants do. This behavior may allow the vine to find the "dark silhouette" of a tree up which to climb. Having done so, it then develops more normal light seeking behavior. This article shows that plants, as well as animals, can have interesting behavioral repertoires.

After the Swain reading, I'll lead students back to the animal kingdom with a selection from William Warner's (1976) *Beautiful Swimmers*. Subtitled *Watermen, Crabs, and the Chesapeake Bay*, this book describes how closely the well-being of all three is tied together. It also shows how much nonscientists, in this case crabbers, can know about nature, about the part of the natural world that is important to them. This may help to weaken the idea held by many students that scientists are experts about nature and nonscientists are not. It may help them realize that with nature and see what Lewis Thomas was getting at–that we are all trying to grasp the mysteries of the world around us.

To provide a more philosophical and historical slant, I've chosen an essay from Stephen Jay Gould's (1977) *Ever Since Darwin* in which he critiques the standard view that preformationists were "wrong" and rather simpleminded, while epigeneticists were "right" and rather clever in their views on embryonic development. He shows that, based on the cultural climate and the information available at the time, the preformationist view was very reasonable. I see this example as a caution to students not to think of today's science as "right," and yesterday's as "wrong."

Like those in the past, scientists today function in a particular culture and with limited information, so they too are subject to error. This is a good thing to keep in mind when reading newspaper accounts about the latest research findings or, more to the point, about the latest theory that has been overturned. The "latest" may be the best explanation of a phenomenon available at the moment, but it is always subject to change.

Just as no scientific explanation is perfect, no scientist is perfect either. Even among those for whom scientific fraud is unthinkable, personality can limit their perspective. This is not necessarily a bad thing because these limits can serve to focus their endeavors. Some researchers like to look at the broad picture, to find unifying concepts.

> *Especially in terms of biology, many writers have deepened our appreciation and perceptions of the natural world. Any number of examples are available, including whole anthologies . . .*

While physicists are particularly good at this kind of thinking, Francis Crick is a biologist with a similar bend. After his work on DNA structure, he developed a number of theories about DNA coding and, with Leslie Orgel, theories on the origin of life. In other words, Crick is a synthesizer, as opposed to the cytogeneticist Barbara McClintock, who is more comfortable with analysis, with taking a system apart and studying its components. I think it is important for students to realize that such differences in approach, in style, exist.

Scientists are not immune to very human likes and dislikes which can influence their choice of research areas as well as the strategies they use in developing their research programs. To illustrate this point, I'm using Harold Morowitz's (1979) essay *Splitters and Lumpers*, in which he looks at the equally important roles of analyzers and synthesizers in science and at the fact that some scientists, like Darwin, combine both roles successfully.

It is not uncommon for researchers to speak of "getting down into" their biological material, of thinking of themselves as part of a living system. June Goodfield (1981) quotes an unnamed researcher as saying that "you must identify with what you are doing. You must identify totally. If you really want to understand a tumor, you've got to *be* a tumor."

This is a difficult idea for students to grasp without extensive work with particular specimens or organisms that they could come to love. Perhaps they can get some small sense of what it's like by reading Primo Levi's (1984) essay *Carbon*. It is, simply, the odyssey of a carbon atom. The narrator follows the atom from its original home in limestone, where it was bonded to oxygen and calcium atoms, to its present position in the brain of the narrator. In between, it finds itself in blood, cellulose, coal, a glass of milk, etc. By the end of the essay, the reader is caught up in the atom's trials and tribulations, and identifies in some way with this tiny unit of matter much as Joshuah Lederberg has described his identification with a bacterial chromosome (Judson 1980).

Primo Levi has written both fiction and nonfiction, and this essay is a beautiful blend of the two. It is also a skillful mixture of the literary and the scientific, which is not surprising since Levi was a chemist as well as a writer. The linkage of these two modes of human expression is not as rare as is often assumed. Especially in terms of biology, many writers have deepened our appreciation and perceptions of the natural world. Any number of examples are available, including whole anthologies (Cadden & Brostowin 1964; Kiely 1966). I've chosen Walt Whitman's (1960) poem *Compost* for my class because it combines perceptive observations on the decay process with thoughts on the hopefulness of life. It takes a topic that is rather ordinary, if not repulsive ("distemper'd corpses"), and makes it extraordinary and uplifting. It makes us see life, including the life of science, a little differently.

If time permits (and usually it doesn't because like most teachers, I run out of time before I run out of ideas), I'd like to give students other poems to read. This may help balance the more fact-laden presentations they'll be reading in newspapers and magazines throughout the semester. I expect them to monitor the media closely to see how, for example, TV and radio coverage of a scientific discovery differs from print media coverage.

But I don't want to overwhelm them and give them the idea that science is all work and no fun, so I'm having them read an essay from Will Cuppy's (1941) *How to Become Extinct* to show that biology can not only be fun, but funny. Cuppy wrote these "nature" pieces for the *New Yorker* in the 1930s. His knowledge of biology is extensive, but he refuses to take science too seriously, which biology teachers are often guilty of doing. Sentences such as "Snakes are vertebrates and the vertebrates are classified as higher animals, whether you like it or not" make Cuppy a joy to read, and the joy of biology is one of the most important things I'd like to communicate to my students.

In this brief outline of the readings I've chosen, I haven't touched upon the meat of the course– the specific topics I will cover and how I will approach them. I hesitate to be too specific now. Teaching a course for the first time is, at best, a groping process. Perhaps in a future column I'll be better equipped to discuss what the course content involved.

Right now I plan to draw heavily from the sociology, history and philosophy of science. In my present outline there is little place for the social and ethical problems related to biology: environmental deterioration, genetic engineering, medical technology. This is not because I don't consider these problems important, especially for those who are going into the field of communications. On the contrary, I consider them vital issues that deserve a course of their own, a follow-up to my present effort.

After students have a better feel for biology, they might be better able to appreciate how biology relates to other human endeavors and problems. And a second advantage of yet another new course would be to slow down my mental aging for a few more years!

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May 1988

Eye on Biology

"Biology is the most visual of the sciences." This comment by Phillip Ritterbush (1968b) is almost a truism; biology is so involved with visual imagery that we tend to take this for granted. Yet it is just such imagery that initially drew many of us to the field. For example, W.I.B. Beveridge (1950) notes that "naturalists and zoologists are often attracted to study a group of animals because they find their appearance pleasing."

Of course there is more to a biologist's use of vision than just looking at the beauties of nature. Agnes Arber (1954) called her book on the philosophy of biology *The Mind and the Eye* to point out the complex relationship that exists between the two in the formation of images. And René Dubos (1961) thought one of the most creative aspects of the human mind was the ability "to create an image-more precisely, to select from the countless and amorphous facts and events which impinge upon us a few that each individual can organize into a definite pattern which is meaningful to him."

According to Howard Gruber (1978), who studied Darwin's use of imagery, images are constructed rather than chosen. They "carry the specific message the individual scientist is trying to formulate and convey," and they, in turn, "regulate the future course of that work."

What Arber, Dubos and Gruber are describing is what Rudolph Arnheim (1969) would call visual thinking, the union of perception and cognition. These have often been treated as separate mental activities, with cognition considered a "higher" function than perception. To Arnheim (1986) it is "essential to go beyond the traditional notion that pictures provide the mere raw material and that thinking begins only after the information has been received." Rather, "thinking originates in the perceptual sphere, and . . . much of the truly creative exertion of the mind in any field and at any level consists of perceptual operations" (1969).

In discussing ways to teach visual thinking, Doug Stewart (1985) says, "Images provide a rich, expressive medium for thought that complements analytical reasoning and offers quicker, more unexpected jumps and connections."

While Arnheim and Stewart stress the importance of visual thinking in all fields, it is particularly important in the sciences: "Often defying verbal classification, phenomena and functions in the world of science and mathematics depend upon visual translation" (Preusser 1965). Jacob Bronowski (1978) has noted that "science uses images, and experiments with imaginary situations, exactly as art does." He goes on to say that many people see reasoning, and therefore science, as a different activity from imaging. But for him "reasoning is constructed of movable images," and he thinks "we do great harm to children in their education when we accustom them to separate reason from imagination."

In his book *Experiences in Visual Thinking*, Robert McKim (1980) says that reading, writing and arithmetic are practiced as skills that separate children from sensory experience and that this one-sided education leads to "visual atrophy."

Richard Preusser (1965) sees this as a particular problem in the sciences because "scientific curiosity leading to discovery and invention needs the stimulus of visual as well as mental contemplation." And Robert Wolff (1965) asks: "Is not the biologist critically handicapped in his task of revealing the structure of organic life to students whose visual acuity and curiosity have never been seriously challenged by education before entering the biology lab?" This is obviously a question that we as biology teachers must consider. We have to look at how we now use images and visual thinking in the classroom and lab, and how we could use them more effectively.

Graphic Communication

We employ so many visual images in our teaching–from live animals and charts to photographs and movies–that it requires effort to step back and examine this total involvement in visual imagery. John Janovy (1985) says that biology is very dependent on graphic communication because "the world of life is, above all, the world of objects." He thinks that biologists like to see living things or, at least, "things that our minds can easily translate into living organisms. More often than not, this desire is manifested as dependence on a picture." He sees "the graphic richness of an introductory biology text" as a communication device and adds,

> all scientific publications will have graphs as well as flow diagrams, charts, tables. But in the biological journals you will find detailed anatomical drawings, graphic depictions of behavior and ecological relationships, and photographs of biological materials.

Stephen Jay Gould (1987a) agrees that illustrations are integral to scientific communication: "To a world of observation, pictorial summary assumes an especially vital role." He says that "we must never omit (though historians often do) the role played by scientific illustrations in the formation of concepts and support of arguments" (1985).

This was the case with Edward Tyson's drawings and descriptions of a pygmy chimpanzee, done in 1699 (Gould 1985). They portrayed the animal with an upright posture to enhance its human-like features and to bolster his contention that chimps filled the gap between apes and humans in the great chain of being.

To Gould, scientific illustrations are not frills–"they are foci for modes of thought" (1987b). He illustrates this point with the paleontologist Othniel Marsh's chart depicting the evolution of the horse as a ladder proceeding from the small eohippus to the much larger modern horse. This diagram gave the impression of an orderly progression through an unbranching lineage, while in fact the geneology of the horse can be more accurately portrayed as a branching bush. There were many lineages that branched from eohippus and led to evolutionary dead ends, with only one leading to the modern horse.

In a discussion of anatomical drawings, Ludwig Fleck (1979) argues that images not only influence thought, but also reflect what he calls the "thought style" of the science of the time. He uses drawings of the rib cage to describe the "particular intellectual mood in present-day anatomical illustration." The stripping of the ribs and the arrangement of the ribs and plexus stress the resemblance to a cage. This "underscores the symbolism of a mechanical apparatus" and emphasizes the idea that the "skeletal system is regarded as a supporting frame." The illustrations Fleck uses to make his point seem very ordinary to us because we are so immersed in the thought style of our time. We are as unaware of it as of the ocean of air that surrounds us. To illustrate a different thought style, Fleck uses Vesalius' drawings of skeletons that clearly show the rib cage. Rather than portraying the skeleton as a mechanical apparatus, these drawings present the skeletons as symbols of death, with one showing grief and the other contemplating a death's-head. To us such symbolism seems out of place in anatomical drawings, but that is precisely because our thought style has changed so radically from Vesalius's time.

In another analysis of anatomical drawings, Jonathan Miller (1978) blames illustrations for giving "the misleading impression that everything in the chest is immediately distinguishable." In these drawings the aorta is red, the veins "sky-blue," the nerves green or yellow and the heart "artificially distinguished from its vessels by a bold graphic outline and sometimes a special color." Also, the colors are laid out on a digital "all-or-none principle," with no natural shading.

These rather lurid pictures in no way prepare a student for dissection:

> The unsuspecting student plunges into the laboratory carcase expecting to find these neat arrangements repeated in nature, and the blurred confusion which he actually meets often produces a sense of despair. The heart is not nearly so clearly distinguishable from its vessels as the textbook implies, and at first sight the vessels are practically indistinguishable from one another.

Perhaps if we gave a little more thought to what illustrations really portray we would be more sensitive to our students' disorientation during dissections. Then we could prepare them for the difficulties in extrapolating from pictures to real tissue.

Problems with relating what we see in drawings to what we see in specimens should not lead us to condemn the work of illustrators. They have a real problem–they must make their work not only accurate, but understandable. Arnheim (1969) has said that "unless an image is organized in forms so simple and so clearly related to each other that the mind can grasp them, it remains an incomprehensible, particular case." In her book *Presenting Science to the Public*, Barbara Gastel (1983) mentions the experience of a scientific illustrator who realized he did his most effective work when he was rushed, because he then left out extraneous details.

Gastel also discusses how to use illustrations effectively. This advice for communicating science to a lay audience is relevant to teachers who are in essence doing the same thing. As an example, she discusses a presentation on coronary artery bypass surgery. Illustrations would obviously be useful, but only if appropriate. An X-ray is too difficult to interpret and a drawing from an anatomy text is too detailed. A simple line drawing including only the structures under discussion–the coronary arteries–would be most effective.

Views of the Lab

I recently asked my students which of their high school biology lab exercises was most memorable. Some were evening students who had finished high school some time ago, so the labs they remembered obviously must have made a deep impression on them–for good or ill!

No one mentioned measuring the rate of photosynthesis or analyzing the chemical composition of food. In fact, few mentioned experiments at all. The common answer was a dissection; regardless of whether or not they enjoyed it, they found it [to be] memorable. The other common reply was microscope work–to actually see the unseen, to see things that had been talked about and pictured in books, to see that things like blood cells do exist–was memorable to many.

I am not suggesting that we eliminate experimental labs and merely present our students, week after week, with feasts of visually exciting biological specimens, but I do think we should be more conscious of the visual excitement that such specimens can generate. The colors seen under the microscope, for example, both in live material and in stained and preserved specimens, are so rich, so visually pleasing, that we should give our students an opportunity to enjoy these experiences.

Gerald Holton (1965) has written that "there must be time enough to gaze at some of the visually fascinating or aesthetically satisfying things of science for their own sake." *Volvox*, for example, is a beautiful creature. Of course, it's also a good illustration of the beginnings of multicellularity, but in lab perhaps we should dwell just a little longer on the visual impression it makes. When given a chance to see *Volvox* as an aesthetic object as well as a scientific one, students might be more interested in learning about it.

E.O. Wilson (1986) says that there is an aspect of beauty found in living things that is absent from art work, namely that a work of art is beautiful at only one visual level. In other words, a painting loses its meaning when viewed under microscope.

In contrast, living things are beautiful at a variety of levels. A leaf, for example, is beautiful to the naked eye. That beauty doesn't disappear when the same leaf is viewed under a light microscope, and still another exciting dimension is revealed when the leaf's cells are examined with an electron microscope. He illustrates his point with beautiful photomicrographs of autumn leaves in which:

> we see them in a very different way. They have been invaded by millions of bacteria and fungi, and these microscopic organisms proliferate into new patterns as rich as the ones on which they feed.

But appreciation of such sights requires visual education. As any biology lab instructor knows, some students see little through a microscope. Frederick Grinnell (1987) says that, at first, even "the average medical student often is unable to distinguish between cells and cell nuclei."

One solution to this problem is to force students to take a long and concentrated look, or many looks, at a specimen. The "force" here would not be in the form of physical torture (though some students view all labs that way), but in making a visual record of what's seen. John Janovy (1985) says that:

> it is perfectly appropriate for a lab instructor to ask a student to draw what is seen in the dissecting pan or through the lenses of a microscope. In a complex but tangible world, understanding often comes from combining observation of what is new with the physical act of graphic representation.

In fact, Philip Ritterbush (1968) quotes the botanist Julius von Sachs as saying, "What has not been drawn has not been seen."

Drawing cannot only make for more careful observation, it can also make students aware of biology's links to other disciplines. A biologist is not a one-dimensional being, but one who has a variety of very human interests. In the 19th and 20th centuries, before photographers and scientific illustrators took over the task of visual expression in biology, many great biologists were accomplished artists. In describing the work of the neuroanatomist Santiago Ramon y Cajal, Peter Knudtson (1985) says that "by mentally creating a single, sharply focused neuron from many microscope views, Cajal the artist communicated visions of neurons that no photographer could possibly equal." These drawings were crucial to the acceptance of his work.

Sometimes, however, the artist can get the better of the scientist, as was the case with Ernst Haeckel (1904), whose *Art Forms in Nature* contains drawings that are beautiful, "though a bit short on accuracy, since Haeckel often added a touch of heightened symmetry for artistic effect" (Gould 1985). Haeckel's inaccuracy is a good example to use in cautioning students about the problems of observation. Since, as Arnheim says, vision involves thinking as well as perception, our preconceptions can distort what we see. For example, the 19th century biologist Christian Ehrenberg was convinced of an ideal unity of plan in morphology in which lower animals had all the organs of higher animals. As a consequence, he misinterpreted intracellular complexity completely and thought he saw miniature organs–heart, stomach, etc.–even in protozoa. Ritterbush (1968a) explains how Ehrenberg's misconception arose: "The bodies of protozoa contain inclusions of various kinds just indistinct enough when seen through a microscope to allow scope to the imagination in their interpretation."

New Images

Today, cells can be seen through a variety of microscopes. While the light and electron microscopes are most familiar, NMR imaging of single cells is now possible and a new scanning X-ray microscope has been developed (Robinson 1987). The pictures produced by these new technologies are computer-generated and seem very artificial, but they can reveal structures that are inapparent by other methods. For example, the scanning X-ray microscope has revealed the internal structure of zymogen granules from pancreatic cells. Using such images in class is a good way to improve students' visual literacy, to make them aware of the different ways images are produced and of the limitations and distortions created by imaging techniques.

Computer graphics are also being used effectively to display macromolecular structure. M. Lemonick (1987) describes computer models of viruses that can be manipulated so all sides can be viewed. There are also models of molecules interacting, such as DNA with a repressor. More than 30 years ago Gyorgy Kepes (1956), an artist who was interested in science, wrote rather prophetically of new imaging technologies:

> This new range of perception will bring us more than factual information, it will bring us new sensory experiences, enriching our vision . . . helping us to dissipate old ways of seeing by lifting the visual barrier between inside and outside.

In this column I've concentrated on the visual aspects of biology, but where does that leave visually-impaired students? Is vision so necessary to this science that they are excluded from participation in it? Obviously not. Fortunately, biology is, to paraphrase Ritterbush, the most sensuous of the sciences. Living things possess an exquisite variety of textures and shapes to be experienced tactilely. Also, a great many animals use sound for communication and many use odor. So the human ear and nose can be amply gratified–or alarmed! And many biological specimens are rather tasty–I can remember happily devouring the specimens used in a botany lab on fruits. So biology can be very rewarding, even for those who are deprived of its visual aspect.

But for the average student, stressing the visual excitement of biological material is a terrific way to explore nature. It's probably how most of us became interested in science. As children we collected pretty shells, precipitated colorful crystals, watched beautiful birds, gathered insects (which are attractive to some people).

No matter at what level we teach, from kindergarten to university, I think we have to keep reminding ourselves of these childhood attractions. We liked science because it was a way for us to explore the beauty we delighted in. For many of us, it was an excuse for spending time with such beautiful creatures. Why should our students be different from ourselves?

Unfortunately, in many cases their attraction to nature is not as well developed as our own. It's something we have to cultivate, though it is unlikely we will succeed if we merely inundate them with facts about the organisms we cherish. We have to give them a chance to experience nature, to appreciate its beauty, to love it, to form meaningful images of it in their minds. Only then will our teaching become truly meaningful to them.

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Loving Biology–It's About Time

It's a good idea for a teacher to be a student. Of course, all teachers are students in the sense that they are always learning something new about their field. But I'm referring to being a real student–going to class, taking notes, sitting at a small desk while someone else stands in front of the blackboard. This is probably the best way to improve a teacher's teaching, not because of the subject matter presented, but because of the effects of role reversal.

As you can probably guess, I am still going to school. After years of procrastination, I'm working toward a Ph.D. in science education. I now think like a teacher during the day and like a student in the evening. I complain about "ambiguous" questions on exams, take furtive glances at my watch to see how close we are to being "released" and worry about how my final grade will be calculated.

It is amazing how rapid and complete this transformation can be–at 2 p.m. I can be firmly stating that an exam will not be postponed; at 5 p.m. I can be asking for just such a postponement from my professor. While I try to look at the situation objectively and think as a teacher while I'm a student, it just doesn't work; the roles are too different.

Going back to school has also made me more tolerant of my teachers. In my college days, sitting in the cafeteria critiquing a professor's dress, speech patterns and grasp of the subject was a favorite indoor sport. Now I can appreciate what it takes to hold a class's interest for two hours, what ability is involved in conducting a lively discussion and how difficult it is to make abstract concepts come alive for students.

I am also more tolerant when things don't go well–when the projector doesn't work or when the lecture is tedious. As a born-again student, I am fully aware that tedious classes are unavoidable. Though I'm more than willing to blame the professor for being boring, I now have enough perspective to see that, just as beauty can be in the eye of the beholder, boringness can be in the mind of the listener. We all find some topics more interesting than others.

This problem points up a basic asymmetry that often exists between teacher and student: the teacher loves the subject and the student may not. Just as two people who are in love enjoy being together as much as possible, teachers love to think about, talk about, teach about their chosen subject.

But just as I can't understand what my cousin sees in her husband (I certainly don't love him!), students may find it hard to fathom what we find so exciting about biology. This is a serious problem that warrants attention. This "love gap" between teacher and student is an abyss, an abyss so deep it can't be filled. We cannot expect to make all our students love our subject, but perhaps we should teach as if that were our goal. We may not be able to fill the abyss, but we may be able to bridge it, to allow our students some access to our object of love.

A first step in this direction is to allow our love to show through, to not be afraid to show our enthusiasm for our subject. I took a course in research methods with a professor who reveled in the mechanics of writing a dissertation. Footnotes were endlessly fascinating to him. He could go on for hours about the intricacies of bibliographic citations. As far as I'm concerned, the thought of teaching such a course is about as exciting as a coma. I will never love "idem" and "op. cit.," but I looked forward to that class every week, and I remember and use what I was taught there because the professor enjoyed what he was doing and wasn't afraid to make that obvious.

An editorial in *Nature* some time ago made the point that science teachers seem less willing than other teachers to show their enthusiasm, perhaps because it would make their subject seem less serious and important. This reticence contributes to students' negative attitude toward science ("Understanding Begins at Home" 1985). Cyril Stanley Smith (1981) also believes the joy that scientists and science teachers experience in their subject is "invisible to a student" (p. 234). Ronald Hoffmann (1987), a Nobel prize winner in chemistry, poses a question that could be asked of biology as well as chemistry: "Can we really expect young people to enter our profession given the authoritarian, dulling nature of many introductory courses?" (p. 418). He says we have to talk about what lures us to science if we expect people to appreciate it.

As far as inducing our students to appreciate biology, we may have an advantage that those teaching the other sciences don't have. According to Edward O. Wilson (1984), humans have an innate attraction to other living things. He calls this biophilia, "the innate tendency to focus on life and life-like processes" (p. 1). It is the "urge to affiliate with other forms of life" (p. 85).

Wilson is one of the major proponents of sociobiology. He has been critiqued for his over-enthusiasm in attributing a genetic basis to many aspects of human behavior, and he uses biophilia as an example of such behavior. But while he doesn't have a great deal of evidence to support his hypothesis, it is hardly unsubstantiated. He cites the work of Gordon Orians (1980) and Yi-Fu Tuan (1974) in indicating that humans have an innate attraction to a savanna-like environment, probably because the species had its origins in such a habitat. He says that people "are responding to a deep genetic memory of mankind's optimal environment . . . [when] confined to crowded cities or featureless land, they go to considerable lengths to create an intermediate terrain, something that can tentatively be called the savabba gestalt" (p. 111). Frederick Turner (1988) sees the "passionate zeal" of those working to restore prairie lands as an indication of a deep urge to expunge "ecological guilt" for destroying lands we are so attracted to aesthetically (p. 54).

Joseph Wood Krutch (1929) also thought our attraction to the beauty of nature is inborn. He saw it as a relationship with other living things. He argued that this shared life made us more responsive to the beauty of organisms than to the beauty of the inorganic world. More recently, Alexander Skutch (1985), a botanist and naturalist, has taken a similar view. He sees an aesthetic sense existing in animals which allows them to appreciate their own existence and their participation in the life of the earth. Humans also have this sense, but in a more fully developed form: "We seem made to contemplate beauty; in the natural world we see it everywhere, from the creatures that, through a microscope, we watch swimming in a drop of water to the most stately trees" (p. 140). He says that "we seem to have been created to enjoy beauty" (p. 145).

Both Wilson (1984) and Skutch (1985) see this innate aesthetic attraction to natural beauty as adaptive; that's why it has become such an integral part of human nature. Skutch explains how a sense of beauty could be important to animal survival:

> If blue sky and green land were as depressing to an animal as certain drab colors can be to us, its vital processes and its will to live might be adversely affected, so that in the struggle for existence it would be less successful than some related animal who, instead of being depressed was pleasantly excited by these colors. (p. 147)

Wilson calls the "naturalist's trance" adaptive (p. 101). The human response to snakes--a mixture of horror and fascination--is an example of this type of trance. The response reveals "the complexity of our relation to nature and the fascination and beauty inherent in all forms of organisms. Even the deadliest and most repugnant creatures bring an endowment of magic to the human mind" (p. 84). For early humans a vivid response to nature was important, he says, because

> snakes mattered. The smell of water, the hum of a bee, the directional bend of a plant stalk mattered . . .The glimpse of one small animal hidden in the grass could make the difference between eating and going hungry in the evening. And a sweet sense of horror, the shivery fascination with monsters and creeping forms that so delights us today even in the sterile hearts of the cities, could see you through to the next morning. (p. 101)

Other observers do not see the human response to nature's beauty as genetically determined. They see it as a product of culture. David R. Wallace (1986) says that because of its particular culture, "Japan has perhaps come closer than any other nation to making nature the center of its aesthetic" (p. 79). In the United States, however, only some forms of natural beauty are appreciated. In this country, Wallace says, flatlands are not considered beautiful. But this prejudice can hardly have a genetic basis since a hundred years ago, before urbanization, such a prejudice did not exist. But while Skutch and Wilson's view may be overly idealistic, it seems to be a useful idea for biology teachers to keep in mind. Any natural tendency toward a love of nature and nature's beauty should be nurtured fully rather than ignored. While this is hardly the only solution to the problems of biology education, it is definitely an avenue worth exploring.

But love of living things, like any kind of love, cannot be forced. There must be time and opportunity for it to develop. The more I think about it, the more I realize that, in terms of teaching resources, the one that is in shortest supply is not laboratory equipment or audio-visual materials, but time. I'm reading a book by Bob Samples (1976) in which he writes that our culture is ruled by the concept of linear time–time cut up into little pieces and apportioned for various activities, time as a progression leading somewhere. The opposite view of time–as a cycle, as rhythmic and constantly returning–is less important in our culture. Thus we see time as something to spend, to use up. George Lakoff and Mark Johnson (1980) argue that the metaphor "time is money" illustrates the value we put on time and indicates our attitude toward it. Time is a commodity that shouldn't be wasted; we should get the most for our money by packing as much as possible into a period of time.

I live in New York City, the time-is-money capital of the world, so this observation makes sense to me, but Americans in general seem to take this approach to time. A trip to almost any foreign country, however, will show that this attitude is far from universal. My parents were from Ireland, and on several visits "home" we stayed with relatives who couldn't understand why we were rushing around. To them time was cyclical; if the job wasn't finished today, the dawn would be returning soon to signal a new day. If dinner wasn't ready "on time," so what? The hour hand on the clock would return to its upright position soon and we'd have a whole new hour to work with.

But most of us are teaching in a culture with a far less luxurious attitude toward time. Yes, lab time will roll around again soon, but another exercise is scheduled. There is not enough time for the lab to be rerun, rehashed, or reconsidered, no matter how valuable the experience might be. Most teachers must follow syllabi that are overloaded, to say the least. And if we feel pressed, it is inevitable that our students will also feel the pressure. These are hardly ideal conditions for the development of a love affair.

One of my favorite quotes from science education literature is from Arnold Arons (1983):

> I think it is essential to back off, to slow up, cover less, and give students a chance to follow and absorb the development of a small number of major scientific ideas, at a volume and pace that make their knowledge operative rather than declarative. (p. 97)

By declarative knowledge Arons means "knowing facts" while operative knowledge involves "understanding the source of such declarative knowledge."

He argues "there is increasing evidence that our secondary schools and colleges are not doing a very good job of cultivating operative knowledge" (p. 94). "Cultivating" is a good word to use here; it illustrates my point. Cultivation can be defined as the fostering of growth–in this case the growth of a love and understanding of living things. Any cultivation, any growth, is a slow process and cannot be rushed. Arons' argument is persuasive, but it has yet to affect policy makers who could mandate syllabus changes.

Students need time. They need time to think, to absorb the information we pour over them, to develop operative knowledge. They also need time in the laboratory to savor the biological materials they work with. Love is a pleasurable experience; it involves enjoyment of the object of love. It is unlikely to develop when there is no time for enjoyment, when students are pressured to do the required exercises, record the results and clean up. In the lab, time may not literally be money, but it is still treated as a commodity in short supply. Love involves an intimacy that is inhibited under such conditions.

Yet, such intimacy is an essential part of the process of science. If students are to have any feel for science in general, let alone for biology, they should have ample opportunities for such experiences because, as Michael Polanyi (1962) has said, "a detached manner of observing life would dissolve altogether our knowledge of life" (p. 373). Robert Root-Bernstein (1988) agrees: "A scientist is wise to know intimately, even to identify with, the things or creatures he studies" (p. 33). The reward for such internalization is intuition, or what Stephen Jay Gould (1987) calls an "integrative insight" (p. 165). Jacob Bronowski (1978) has said that it is this personal engagement in the object of study that separates the scientist from the technician. Devoting several laboratory periods to studying the same organism, stressing the need for close observation, or just giving students time to "get to know" some specimen are all ways to encourage such personal engagement. Even if the syllabus doesn't allow for much intimacy with the things of nature, just being aware of the problem should make us more open to those opportunities which are available.

Besides time restraints that inhibit a student's romance with biology, textbooks don't help much either. The writing in most texts is dry, fact-laden and unlikely to inspire awe or a love of nature. Although texts have become more visually attractive over the years and diagrams have become more frequent, clearer and more illuminating, the written word is still what students must study for exams, and this prose is enough to quench any but the most raging fires of interest. The best writing on living things, the writing most likely to fan the fires of ardor for nature, is that done by naturalists. According to David R. Wallace (1986), himself a gifted observer of nature, naturalists create "appreciative responses to a scientific view of nature" (p. 112). He says that naturalists, and especially nature writers, are a special breed who can translate information into feelings and visions. His description of "A Dunk in the Eel" River is one such translation:

> Being attacked by a school of minnows is a curious experience. It tickles, which can be enjoyable or annoying according to one's mood. Like all expert ticklers, minnows go for the toes, although I don't suppose they intend to inflict torment; and they nibble at other exposed parts of the body as well. The bites of even the largest–three or four inches long–don't even begin to break the skin. Apparently, what the minnows are after is the film of dead cells that constantly sloughs off the human epidermis. (p. 59)

Wallace's combination of vivid imagery and information makes the reader want to experience nature in a personal way. It emphasizes the affinity with other living things that Wilson and Skutch stress. But such acute observation requires time. Someone taking a quick dip in the Eel River would never have an experience like the one Wallace describes. You have to be willing to lazily float around for awhile, to let nature happen to you, rather than to try to go after nature. And then you have to take the time to translate that experience into words. According to Bob Samples (1976), poetry comes from the part of the mind that sees time as rhythmic and cyclical, not the part–so well-developed in our culture–that looks at time as linear. Poetry, beautiful imagery, cannot be rushed.

And so we are back to the issue of time. Perhaps it is not a coincidence that the naturalists who have made the most careful observations and who have given us the most luminous accounts of those observations are people who could see time as rhythmic rather than linear, who were not concerned with the constant ticking of the clock. They were willing to make the necessary sacrifices for love, perhaps because their love of nature was so deep.They were willing to go against the tide of culture and view time as something to be experienced rather than spent. In the *Outermost House*, Henry Beston (1928) chronicled a year spent in a bungalow on a Cape Cod beach. Using telling imagery, he provides a great deal of information on flora, fauna and weather conditions, as well as vivid impressions of his experiences with nature. Beston devoted a year to this project. He took time off from his job in New York as a magazine editor and spent it in the presence of nature, the object of his love. Thoreau (1966) isolated himself at Walden Pond, and Gilbert White (1949), one of the first nature writers, settled at Selbourne and led a quiet life observing nature.

In an introduction to White's *The Natural History of Selborne*, R.M. Lockley (1949) says that White "seems to find beauty everywhere, but especially in those objects nearest to him. He loved the Sussex Downs. He thought he saw new beauties every time he traversed them. These downs and the neighboring forest wastes were the limit of his wanderings." He did not need more to satisfy his love of nature. Present-day naturalists may be principally writers, like Wallace (1986), or researchers, like Bernd Heinrich (1984) and Jane Goodall (1971), but they, and many others, have all made love of nature their life's work. They have structured their work so they can spend many hours in the field, oftentimes alone, observing the organisms they are studying.

Niko Tinbergen (1958) says that he finds "studying the behavior of animals in their natural surroundings fascinating. It allows one to live out of doors and in beautiful scenery; it gives free scope to one's urge to observe and to reflect, and it leads to discoveries . . . [which] cause intense delight" (p. 285). "Free scope" means that there is ample time to observe animals at their own pace. There is also time "to reflect," to allow the mind to work on what is observed. Thus, linear time loses its meaning. Human time is replaced by the more cyclical animal time.

Such a change in time perception allows an opportunity for the "intense delight" of discovery. June Goodfield (1981) likens such a moment of discovery to the moment of fulfillment in a human relationship; it is a moment of love. In fact, Michael Polanyi (1962) argues that at all levels of biological investigation, researchers are sustained in their work by a love for the organisms they are studying.

Which brings us back to biophilia. Wilson (1984) contends that "to the extent that each person can feel like a naturalist, the old excitement of the untrammeled world will be regained" (p. 139). He sees the widespread development of such feeling as the starting point for a deep conservation ethic; appreciation will lead to concern. If people were given the opportunity–and time–to explore the "mysterious and little known organisms which live within walking distance of where you sit" (p. 139), their innate reverence for life would develop into a feeling of stewardship for living things.

Such a desire to "affiliate with other organisms" will lead to a desire to know more about them, and "as biological knowledge grows the ethic will shift fundamentally so that everywhere, for reasons that have to do with the very fiber of the brain, the fauna and flora of a country will be thought part of the national heritage" (p. 154). Skutch (1985) argues that if we followed our innate tendencies, we would view the earth not as a farm to be exploited but as a garden "that is cherished, not because it yields food or wealth, but because it uplifts the spirit with its loveliness" (p. 25).

Wilson and Skutch are obviously idealistic, but there is no better place to try out these ideas than in a biology course. Last spring, I told my class to observe the changes in nature at that time of year and write an essay about them. Some of the essays were beautiful. In one, a student described spending time watching a spider build a web at the bottom of a flower pot. She became fascinated with this creature as she took time to observe its work, to be with this organism. I'm not sure that such an experience will make her a conservationist, but I do think it made her a little more sensitive to the organisms she could find "within walking distance." I think it made her feel a little more positive about biology. Perhaps she could appreciate a bit more why I love the subject.

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April 1989

*Human Biology**

I've been putting off writing this column for several months. I didn't want to work on it because I knew it would be difficult to write, and because I'm not sure it's appropriate to a department called "Biology Today." Yet I felt a need to do it. The topic I want to discuss is the biology teacher as human being. This seems too obvious a matter to even mention, but that's just the point; we often take for granted the fact that both we and our students are human beings involved in a human relationship. More attention to this relationship might make the learning experience more rewarding for us all.

One reason for the inclination to ignore the more human aspects of our endeavor is that those involved in science tend to be more personally detached and withdrawn than those in other fields. Anne Roe (1952) noted this in her study on the psychology of scientists. She found physicists and biologists tended to be "quite shy." Many were uneasy about personal relationships and were apt to keep their distance from others. This inclination was deep-seated: "From early on, they found their satisfactions and interests away from personal relationships." Many biologists spoke of an early interest in nature–in birds, insects and butterflies–and of their enjoyment of solitary study of these organisms. Of course, there are exceptions. Some biologists are the most gregarious of human beings, but on the whole they tend to be withdrawn, and this tendency extends to many biology teachers as well. In many cases, biology teachers are biologists who teach, and they fit the biologist's personality profile.

This presents a problem because teaching is the most social of endeavors. Most of teachers' days are spent with a great number of other human beings, involved in a very human undertaking. Humans are thinking animals; many observers consider thought our "highest" function. In teaching, this function should, ideally, be used to the utmost degree. Good teaching requires constant, exhausting thought, and it is ineffective if it doesn't require such activity from students as well. But according to many philosophers and psychologists,

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**Recipient of the 1990 Washington Education Press Association's Excellence in Print Award for a column.*

thought is not divorced from the emotions. Learning involves feeling as well as reasoning. Michael Polanyi (1962) says that there is a passionate quality to learning. And Rudolf Arnheim (1969) contends that ideas tend to remain associated in our minds with the emotions that were aroused at the time the ideas were learned.

If this is so, then biology teachers are in a difficult position. The emotions must be taken into consideration in teaching, yet dealing with emotions doesn't come easily to many biology teachers. This is the dilemma I find myself grappling with. As a human being, I don't feel comfortable ignoring the human element in biology teaching, but I don't feel completely comfortable dealing with it either. This becomes a particular problem in teaching human biology. Everyone in the classroom has years of experience dealing with their own human bodies, both physically and emotionally. Here, our own experiences are inextricably linked to the subject matter, especially in teaching health-related topics.

Last summer I was, as usual, teaching "Topics in Health." As usual, we covered nutrition, exercise, heart disease and infectious disease; then we got to cancer. I have taught this section many times, though never in the same way twice. There are always new discoveries about therapy and about oncogenes, so I always have to revise the material. But this time the human element of the topic had also changed. In March, my mother had died of colon cancer. Though other members of my family had died of cancer, it had never hit so close to home.

. . . there are more and more cases where cancer is not fatal, where a cure is possible or where treatment, while it cannot cure, can greatly prolong life. Our society's attitude toward cancer creates tremendous burdens for people with it . . .

Frankly, I'm better at dealing with atherosclerosis! As an Irish-American, I come from a culture where the major component of the diet is saturated fat–butter on bread and potatoes, gravy on meat, beef at least three times a week. It is not surprising, therefore, that my grandmother died of a stroke, my uncle of a heart attack. By the time I was 14, not only had these loved ones passed on, but my father had had his first heart attack. So from an early age atherosclerosis was almost second nature to me, but cancer wasn't. Mentally, I was better able to deal with sudden death than with expected death.

In fact, I fully expected my mother to die of atherosclerosis, too. Over a period of 16 years, she had had several strokes that had impaired her mental capacities more than her physical ones. One of these "CVAs" seemed to have destroyed the nasty part of her brain! Though she had been a stubborn Irish woman who made perfectly clear what she thought of her daughters, their activities and their husbands, she became a sweet little old lady. But with her continued mental deterioration, and after two broken hips, she was cared for in a nursing home. I expected, and dreaded, the day when I would visit her and she would no longer recognize me. But it never came to that. She was diagnosed as having cancer, and though extensive testing showed no spread, an operation revealed uncontrollable metastases. She died a few weeks later, recognizing her children almost to the last moment.

After this experience, teaching about cancer took on a new dimension, a personal dimension. It was no longer a topic of purely academic interest, yet I tried to handle it that way. We discussed causes of cancer, characteristics of cancer cells, types of cancer, but it just wasn't right. The presentation kept sticking; the image of my mother kept coming to mind. Finally, I had to say something. At the beginning of the next class, I apologized for my less-than-brilliant performance the day before. I explained simply that my mother had recently died of cancer. Such exposure to my private life made me uncomfortable, but it was worth it. The problem was no longer silently nagging at me; it was out in the open. Later, when we discussed diagnostic techniques, I expressed my frustration that the most up-to-date of scanners, the best testing methods, failed to detect the extent of my mother's cancer. At this point, the personal and the factual blended beautifully, at least as far as this topic was concerned. I no longer felt a conflict between my intellect and my emotions, between the "cognitive" and "affective" aspects of the subject.

I think putting myself out on an emotional limb like this is an important, though difficult, thing to do. It is almost a truism that people are more interested in what affects them directly. The human aspect of any subject makes that subject come alive. My husband read me a statistic last night: 64 percent of household fires in the Soviet Union are caused by faulty TV sets. That tells the average American student more about the quality of Soviet consumer products than an hour's lecture on factory management and production techniques. The same principle applies in biology and in human biology; the teacher as human being is a rich source of stories that can make biology–and the teacher–seem more human and interesting.

I am certainly not advocating a daily gabfest in which the teacher recounts the minutiae of her or his life. Such stories are like strong spices; they must be used sparingly to be most effective. Also, they don't have to be as emotionally demanding and depressing as the one I've just mentioned. My best stories are about my sister and her family; in these she comes across as the Gracie Allen of Waterbury, Connecticut. Her faddish interest in vitamins helps me make a point about the need for moderation and balance in vitamin use. Her efforts to lose weight using starch blockers, liquid diets, kelp tablets, etc. are useful in a discussion of how not to diet. And when it comes to talking about the skeletal system, I'd be lost without her! Her jawbone dislocates easily, and students love the story about the night she was *very* tired, yawned *very* wide and got her jaw stuck in that position. Her adventures in the emergency room are not only amusing; they illustrate both the need for medical expertise in dealing with a dislocation and the problem of getting ligaments back into shape after such an episode.

My sister's most dramatic excursion into the world of orthopedics began with a tumble down her basement stairs. She ended up with a compound fracture of the lower end of her right femur. Students love the goriness of a compound fracture (a picture of such a break is the only thing I remember from elementary school science), and giving it a personal perspective makes it even more interesting to them. It is not just a fracture, it is somebody's fracture. But this isn't just a good story. It brings up the subject of bone healing, and the need for pins (13 in this case) and other devices to hold the bone fragments together,

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and the problem of bone infections which can arise when bone pierces the skin. It can also lead to a discussion of the need for calcium and vitamin D in the diet, and of what these nutrients can and cannot do in preventing osteoporosis. A fracture that involves a joint–in this case the knee–can also lead to a discussion of arthritis, of how injuries can hasten joint deterioration. So you can see, I'm really lucky to have my sister; she's better than a "textbook" case.

But I don't have to rely solely on her for illustrations. Her daughter's prematurely closing soft spot in the skull points up the extent of brain growth after birth and the need to allow space for that growth. On my husband's side of the family, my thrifty brother-in-law buys everything by the case and what is bought must be used, even if the product proves unsatisfactory. His case of contraceptive foam–and his three children–illustrate the efficacy of this method of birth control.

Revelation of the personal by a teacher is a tricky business. It can easily be carried too far.

On a more serious note, my father-in-law serves as an example of someone who has been cured of cancer. I use his history to illustrate the very important point that cancer is not one disease, that when different cell types become abnormal they do not all behave in the same way. Even cells of the same type can behave differently because, as current research shows, there can be different types of changes in the cells' DNA. Added to this variability are differences in the extent of the disease at the time of diagnosis.

With such diversity, it's not surprising that there are vast differences in the outcomes of cancers. Yet, we don't perceive cancer that way. Most of us automatically equate cancer with death. This idea is ingrained in us; it is part of our culture. In *Illness as Metaphor*, Susan Sontag (1978) has written of the language we use to talk about cancer. She says this language is metaphorical and that "the controlling metaphors in descriptions of cancers are, in fact, drawn . . . from the language of warfare: every physician and every attentive patient is familiar with, if perhaps inured to, this military terminology." Thus, cancer cells do not simply multiply; they are "invasive." These "aggressive" cells must be stopped, and treatment involves "bombarding" the cells with "lethal" radiation.

Such language indicates a deep-seated fear of cancer. As Sontag says, "cancer was never viewed other than as a scourge; it was, metaphorically, the barbarian within." Such fear is difficult to allay; it involves feelings that are often much stronger than rational thought. For years I've been discussing this problem in health classes. I make the point that cancer is not one disease, that different cancers have very different prognoses, that early detection and better treatment methods have rendered invalid the equation of cancer with death.

Here I am not speaking so much as a biologist, but as a human being whose background in biology has made her aware of the problems of our approach to cancer. I feel strongly about this because there are more and more cases where cancer is not fatal, where a cure is possible or where treatment, while it cannot cure, can greatly prolong life. Our society's attitude toward cancer creates tremendous burdens for people with it, people like my father-in-law. Because cancer is seen as fatal, they have difficulty getting jobs, mortgages, leases–anything involving a long-term commitment. People just assume they will not be around to fulfill those commitments.

There is also another, and I think more serious, problem. Growing evidence indicates that mental attitude can influence the course of cancer; a strong will to live makes successful treatment more likely than does an attitude of passive acceptance. More and more links are being found between the immune and nervous systems, and such links could explain how mental attitude, by affecting immune-system functioning, could affect the body's own ability to control the cancer cells. If this is the case, then our culture is militating against these natural defenses. It is very difficult to have a positive attitude when all your loved ones are sitting around crying and wondering how they will manage without you.

Usually when I make this point in class, it elicits many responses from students; they are involved in this problem as human beings. Some argue that cancer has to be viewed as a fatal disease: their aunt, grandfather, or mother has succumbed to it. Others, however, disagree; they have loved ones who have survived cancer. But when the discussion is over, I'm afraid I've done little to change their attitude toward cancer–the fear is just too deeply embedded in their psyches. In fact, I end my discussion by illustrating this point with another family story, this one about myself. At a routine checkup a couple of years ago the doctor found a lump in my breast. I was surprised and scared. I had planned to go clothes shopping with a friend the next day, but I thought to myself, "Why bother? I'm not going to be around to wear these clothes." No sooner had this thought gone through my mind than I stopped myself and said, "You jerk. This is just the attitude you've been fighting against in class all these years." Obviously either my powers of persuasion are very poor, or I am up against the terribly powerful deep-seated ideas of our culture.

Revelation of the personal by a teacher is a tricky business. It can easily be carried too far. While I let my students know some things about my personal life, such discussions hardly take up a whole class period. They are usually short allusions used to make a point about the topic under consideration; an example that becomes too extensive takes on a life of its own and is no longer effective in illustrating the point. When talking about others, I only use examples that would not be embarrassing to them. My sister loves being talked about; she even tried to get her orthopedist to give me X-rays of her fracture. Some people remain anonymous in my stories, and I never talk about my husband. He works in the same college, so we have some students in common, and I want to protect his privacy. This doesn't mean there's no interclass communication. Right now the students are arguing over which one of us is funnier (I'm not sure winning this contest reflects well on teaching biology!).

Being human in the biology classroom is a two-way street; it applies to students as well as to teachers. This seems an obvious point; we do try to treat our students as individuals, to get to know them as more than names on a roster. But the student-teacher relationship deserves closer examination. I have often been tempted to write a column entitled "The Biology Teacher as Stepparent." As a member of both species, I can see that they have much in common. Being a stepparent involves the most ambiguous of relationships. I am called a mother, but with a qualification to remind me of the peculiarity of my position. My stepsons have a mother, so I can hardly replace her, yet when they live with us

I play the role of mother-cooking their meals, yelling at them to clean up their things, listening to their problems. After eight years of such a relationship I've learned that while I can develop a closeness with my stepsons, there is certain territory where I cannot tread, that is off limits to anyone who hasn't shared in their nurturing from birth.

While a biology teacher isn't expected, or encouraged, to develop a relationship with a student comparable to that of a stepparent, there are parallels. Students often crave a relationship to compensate for deficiencies in their home life. I think science teachers are more likely than others to be sought out in this regard because of what I call the "kitchen phenomenon." Several years ago Mimi Sheraton, who was then a food editor for *The New York Times*, wrote an article about the benefits of working in the kitchen with children. It came out at the time I was trying to grapple with the complexities of stepparenting, so it made a particular impression on me, though I can't remember the date of the article. Sheraton's main point was that you can become particularly close to children in the kitchen. You are both engaged in a mutually satisfying task-children may not love to cook, but they definitely love to eat. A child can experience a feeling of accomplishment by preparing food, so they can feel good about themselves in this setting. And the point that struck me most strongly is that, since you are both working while talking, you don't have to look at each other. If something awkward comes up, if the child wants to discuss a difficult matter-or you do-it's much easier if you don't have to make eye contact.

All these characteristics of kitchen work also apply to lab work, especially in preparing for a lab or cleaning up afterward. There will usually be a student or two who likes to help, and often these are the students we get closest to. They are engaged with us in a mutually satisfying task from which they can experience a feeling of accomplishment, and they can talk more freely because they're not facing us directly. Even during a regular lab period we can get to know students, see sides of them that aren't apparent in a conventional classroom. In the lab we experience each other during physical as well as mental work. This is an experience which is really not open to history, English, or social studies teachers. Mind and body are more totally involved, so it's not surprising that this makes biology a more personal experience.

This may not be the way we usually look at lab work. We see it primarily as a way to teach students about the workings of biology, as a way to teach process skills and to allow students to experience living material firsthand. While this is all true, the lab also has another dimension. It is a place where teacher and student can be more human, can reveal more facets of their personalities. This aspect of lab work deserves further attention. A great deal of educational research shows that science teaching in general neglects the affective domain. There is little concern for the attitudes toward the subject that students are developing in our classes. Perhaps that's why so many of our students leave us with negative attitudes toward science. The lab seems to be a good place to begin to correct this problem because here we can interact with students more closely; we have more one-to-one contact with them.

Besides lab work, there is still another aspect of being a biology teacher/stepparent. In teaching about human biology, and especially in teaching a health course, we touch upon topics that will often strike chords with our students. After all, they all have bodies and often they are concerned about them in ways that are difficult to discuss with parents. Sometimes it's the parents' health they are concerned about–a mother with cancer, a father with heart disease, but more often it's questions about contraception, pregnancy, or drugs. At times the concerns are more exotic. If students ask questions about pernicious anemia, Grave's disease, or melanoma–when their concerns are so specific–it usually means that they or family members have had experience with the disease. For me, such questions involve one of the trickiest problems for the teacher/stepparent. I try to answer questions thoroughly and correctly, but I don't think it's my place to give too much information. It is rather, to guide them to the proper sources. I am not a doctor. As I remind my students, it is illegal for me to practice medicine without a license. My knowledge of something like Grave's disease is very limited. I know it's an autoimmune disease resulting in hyperthyroidism. But that's about it. When a student's father has the disease, that student–but no one else in the class–wants more information. I try to find out what I can, but I'm careful to give only a general description. I am not a parent, therefore I don't want to give more information than the parent may want the student to have. Also, as in my role of at-home stepparent, there are emotional boundaries I cannot cross, and these are obviously much more confining in the student/teacher relationship. I can listen, I may even be able to say something that will help, but being a "human" biology teacher does not mean being intimately involved in students' personal lives. It does, however, mean being aware that the personal life–of both the teacher and the student–cannot, and should not, be totally divorced from classroom life.

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Telling About the Lure of Science

Two Nobel Prize winners have given me much food for thought recently. It is not only their research, but their descriptions of why they do research that I find interesting. They have both written beautiful pieces about what attracts them to their work, about why they do science. Arthur Kornberg (1989), a Nobel laureate in physiology and medicine, has done this in his scientific memoir, *For the Love of Enzymes*, and the Nobelist in chemistry Ronald Hoffmann in a series of articles on molecular beauty. They have both fulfilled what Hoffmann sees as an essential obligation of scientists:

> We have to tell people (not the least among them being our parents and spouses) what it is that lures us back to work nights and Sundays, why it's thrilling to open a new issue of the *Journal of the American Chemical Society*.

Molecular Beauty

Hoffmann's quote is from a 1987 article; it seems to have haunted him and precipitated the 1988-1989 series of pieces on "Molecular Beauty." In the first of these (1988a), he describes the conversation that prompted him to write them. It happened while Hoffmann was working on a manuscript during a plane trip with his wife. When she asked what the manuscript was about, he replied, "A beautiful molecule." She then wanted to know, "What is it that makes some molecules beautiful to you?" To answer her, Hoffmann decided to practice what he had preached in 1987, to explain the "lure" of this and other molecules. He refused to accept the idea that only chemists can appreciate the beauty of chemistry, that "outsiders are excluded."

The substance that spurred this work is an inorganic compound, $NaNb_3O_6$. Hoffmann admits its beauty might not be readily apparent, then patiently describes the crystal's layered structure, the entrapment of niobium (Nb) atoms in octahedra of oxygen atoms and the interplay of symmetry and asymmetry which gives this compound its appeal.

Like an art critic analyzing a painting, he moves step by step, describing each facet of this compound's rather complex structure. His writing is patient;

he doesn't try to hurry the reader along. Hoffmann really is explaining this molecule to his wife or to anyone unfamiliar with chemical bonds and three-dimensional chemical structures. He ends, as any good critic would, by coming back to the whole picture and explaining that this molecule's:

> beauty is in its structure, which is at once symmetrical and unsymmetrical. The beauty is in the incredible interplay of dimensionality. Think of it: two-dimensional slabs are assembled from infinite one-dimensional chains of edge-sharing octahedra around niobiums, which in turn share vertices. These two-dimensional slabs interlink to the full three-dimensional needles of niobium and sodium.

Hoffmann uses such careful analysis in each of his articles. In the second (1988b), he discusses a molecule that seems to be "plain." He refuses to call it "ugly." Describing himself as a "most prejudiced chemist," he claims that "there are no ugly molecules." The molecule in question is an intermediate in the synthesis of a catenane, two interlocking rings of carbon atoms in which the rings are not chemically combined, but are held together like the links of a chain. Here the beauty is not the "static" kind of $NaNb_3O_6$, but that of dynamism, movement, change. Making such a molecule is difficult and its "beautifully conceived synthesis" requires several steps.

Though the entire synthesis is "elegant," Hoffmann sees the molecule in the middle of the scheme–the one he cites at the beginning of the article–as most beautiful because it is most complicated relative to the starting materials and the goal, the molecule "most disguised, yet the one bearing in it, obvious to its conceiver but to few others, the surprise, the essence of what is to come."

Beautiful Pasta

The excitement Hoffmann feels for chemical synthesis comes through clearly here. He is indeed describing what lures him to the lab, why he can't wait to read the latest chemical journals.

In his third article (1989a), he continues to share with the unanointed his fascination with chemistry. This time his subject, at first glance, "looks like a clump of pasta congealed from primordial soup." This rather unappealing description turns out to be about hemoglobin! Hoffmann finds its attraction in its "richness," its intricacy and in the fact that its "bizarre sculpted folding has a purpose: It allows for the reversible binding of oxygen." In the process, as oxygen binds to the iron at the center of the heme group, the iron atom, the heme and the protein all shift position slightly, allowing for easier binding of the next oxygen molecule. This carefully orchestrated dynamism is "dazzling" and stems from the "enabling complexity . . . of every bend, fold, or twist."

Hoffmann thus makes clear to a nonscientist why this "pasta" of a molecule is beautiful. But his description sheds new light for even a biologist familiar with hemoglobin. One's appreciation is deepened as it is for a familiar art masterpiece when analyzed by a perceptive critic.

By the time Hoffmann's fourth article (1989b) appeared, I was ready for his series to go on indefinitely. After all, there are more than 7 million known chemicals, so he couldn't possibly run out of material. And in this installment, he tackles a totally different class of molecules: metal carbonyl clusters. In these molecules, carbon, which 'always" forms four bonds, instead forms six. Here, the attraction is novelty, surprise, even:

> shock-the full impact of which should hit every maker of carbon compounds. It makes these carbonyl clusters... beautiful. They are new, interesting, and lovely.

The appeal comes from the fact that scientists "are addicted to new knowledge."

The Aesthetic of Chemistry

Just when Hoffmann has whetted the appetite for still more molecular beauty, he writes, "Perhaps it's time to stop here and take a different tack." He ends by summarizing his aesthetic of chemistry and comparing it with philosophers' descriptions of the aesthetic of art. He agrees with Monroe Beardsley (1981) that intensity is an aesthetic quality. Some molecules seem to possess a large number of interesting attributes, and this makes them especially attractive. He gives as an example an organometallic molecule:

> in which one and the same tungsten atom forms a single tungsten-carbon bond, a double one, and a triple one. And two bonds to phosphorus, for good measure.

Hoffman also agrees with the aesthetic philosophy of Nelson Goodman (1968), who sees both science and art as cognitive processes. Hoffmann notes that:

> we *feel* that these molecules are beautiful, that they express essences. We feel it emotionally, let no one doubt that. But the main predisposition that allows the emotion-here psychological satisfaction-to act is one of knowing, of seeing relationships.

What Hoffmann has done is to let the nonchemist in on this knowledge, to point out relationships between symmetry and asymmetry, between structure and function, between old ideas and new ones. He has done this patiently, giving sufficient background explanations so we know enough to appreciate the beauty. June Goodfield (1981) has said that science is like modern music or art: Its beauty is not obvious; a perceptive critic is needed to guide one to understanding and hence to appreciation. Hoffmann is one such guide, and he provides more than a lesson in the beauty of chemistry. His is also a lesson in good teaching. He makes his points clearly, using many illustrations. He guides the reader through unfamiliar territory by starting with basics and carefully introducing all the necessary points in his argument. Teachers can learn much from his approach. He has the patience most of us lack; he seems to always remember his purpose-to reveal the beauty in his subject-and does nothing to make the reader bridle and give up because the explanation becomes too complex or the argument too turgid.

It might seem odd that in a journal devoted to biology teaching I've spent so much time discussing the writings of a chemist. But I've done so for two reasons. First, Hoffmann's explanations of molecular beauty are relevant to biology teachers because most introductory biology texts begin with a discussion of the molecular basis of life. If we could incorporate his approach into our lessons we might make this topic, one of the most difficult, more interesting to students. It might also give them a better understanding of molecular dynamics and of the importance of the molecular level to the higher levels of biological organization.

Loving Enzymes

The other reason for discussing Hoffmann is that I love molecules! I am a biochemist at heart. While the intricacies of ecosystems fascinate me and the adaptations of organisms astound me, it is with the molecular level of biological organization that I feel most comfortable. Among molecules, my favorites are the enzymes, and that's why the work of the other Nobelist I mentioned, Arthur Kornberg, interests me so much.

Kornberg has spent most of his scientific career studying enzymes–more than 30 of them–and while Hoffmann considers no molecule "ugly," Kornberg claims he has:

> never met a dull enzyme. From the humble hydrolase that uses a molecule of water to split NAD to the glamorous polymerase that assembles vast DNA chains of genes and chromosomes, the feats of enzymes are all awesome.

A statement like this would definitely predispose me to like his memoirs, *For the Love of Enzymes*, but, in fact, I bought the book solely on the basis of its title–it had to be good!

But even less prejudiced readers than myself have found the book fascinating (Racker 1989). Why this is the case is not readily apparent. Kornberg simply seems to be describing his research, telling about the twists and turns it took over the years from his early work on vitamins to his present interest in viral replication systems. He does not reveal much personal background in the process. He wants to tell the story of his science rather than that of his life:

> I wished to use the chronology of my career only to organize the narrative and introduce personal elements where they might leaven and humanize the science.

And they do just that. They are what make this book so rewarding. They make it the most personal of books because through them Kornberg reveals why he loves his work. He does what many scientists are loathe to do, he tells what attracts him as a human being, as well as a scientist, to the study of science and to the study of enzymes in particular. Early in the book he says that, after several years of work in nutrition, he found enzymology "intoxicating," because "the momentum of experimental work was breathtaking." Instead of waiting days or weeks for the results of dietary assays, enzyme assays could be completed in minutes, so "many ideas could be tested and discarded in the course of a day." Kornberg is a man in a hurry. He even admits to being impatient. When a research assistant broke a tube of sample and said it didn't matter because he had more, Kornberg replied that "the hour lost can never be recovered."

The Rewards of Enzymology

But it isn't just the pace of enzyme research that attracts Kornberg; he says that:

> **purifying an enzyme is rewarding all the way, from first starting to free it from the mob of proteins in a broken cell to having it finally in splendid isolation.**

Enzymes have a level of complexity that "suits" him. He feels "ill at ease grappling with the operations of a cell, let alone those of a multicellular creature." He also feels "inadequate" in studying the chemistry of small molecules. For him, "becoming familiar with the personality of an enzyme performing in a major synthetic pathway is just right."

His language is very revealing. Kornberg thinks of enzymes as having "personality"; to study one, he must separate it from the "mob" of proteins in the cell. He describes one of the enzymes he discovered as being more "novel and glamorous" than another. As far as enzymes are concerned, he admits to feeling "like a parent concerned for a child's whereabouts and safety." He can't leave the lab at night without knowing in what state of purification the enzyme has been left.

This anthropomorphic language reveals Kornberg's level of intimacy with his objects of study. In a sense, they have become part of him. This is not an uncommon experience for a scientist, or indeed for those who enjoy their work and the things they work with. What makes Kornberg unusual is how articulate he is about his feelings. He does precisely what Hoffmann prescribes: he tells us what lures him back to the lab at night. It is very refreshing to read a scientific memoir with statements like "Holy Toledo! This fraction had the bulk of the enzyme activity," or "Wow! The reaction was explosive, hundreds of times greater than before. The radioactivity counter went wild–one of those rare moments in a scientific lifetime." These are very simple, direct statements, yet they clearly convey that science can be a great source of joy.

Hunters in Medical Science

But this volume is more than a compilation of personal comments. These are, as Kornberg promises, the "leaven" for the science which fills the book. He not only describes his research, particularly the work with DNA polymerase which won him the Nobel Prize, but also historical background which puts his work in perspective. Kornberg sees 20th century medical science as a series of hunting expeditions. He takes his cue from Paul de Kruif's classic history of bacteriology, *The Microbe Hunters*. These researchers dominated the field in the first two decades of the century and were followed by the "vitamin hunters." In the 1950s, it was the "enzyme hunters" who were at the fore, and they have been superceded more recently by the "gene hunters."

Though Kornberg would, of course, identify himself as an enzyme hunter, he could be considered a member of all these groups. His first research was on vitamins, particularly folic acid. It was the role of many vitamins as coenzymes that led him to enzymology. He studied the synthesis of NADP (nicotinamide adenine dinucleotide phosphate), which contains the vitamin niacin as well as most of an ATP molecule. His work with ATP led him to the study of nucleotide synthesis. Since others were pursuing purine–adenine and guanine–synthesis, he investigated pyrimidine–uracil, cytosine and thymine–production. Though he originally used liver, kidney and potato extracts, he eventually discovered the advantages of working with microorganisms. He could even be called a microbe hunter, because he searched for and found soil bacteria that thrive on pyrimidines and could be used in the study of pyrimidine biochemistry.

In a beautiful example of how research interests develop and evolve, Kornberg's work on nucleotide synthesis led quite naturally to studies on how nucleotides are joined to form nucleic acid. Again, the work of others determined the direction of his research. Severo Ochoa and his colleagues had just discovered the enzyme responsible for RNA synthesis, so Kornberg hunted for a similar enzyme in DNA production. The result was DNA polymerase. In 1959, he and Ochoa jointly received the Nobel Prize for their work, but this milestone did not end Kornberg's work on DNA synthesis. He later discovered that his polymerase was more an enzyme of repair than synthesis, and it was his son, Tom, who as a fledgling biochemistry student discovered two of the major DNA polymerases.

Kornberg's later research has been in identifying and explaining the workings of the many enzymes involved in DNA synthesis. The DNA polymerase III holoenzyme is a complex of 10 proteins, each with a specific function. The alpha unit is the actual polymerase, the tau unit clamps the polymerase to the template, the epsilon unit has a proofreading function–deleting an improperly paired nucleotide–and other units improve the efficiency of these primary activities. Besides this elaborate polymerase, there is also a helicase to unwind the DNA and a topoisomerase to do the untwisting required for the unwinding. Kornberg sees these and a number of other enzymes as joining to form a replisome, a structure–an elaborate factory–which combines all the functions.

Gene & Enzyme Hunting

Both because of its size and the disruptive forces needed to open a cell, Kornberg has yet to take the replisome "alive," but his research so far points to the plausibility of its existence. In pursuing this work, Kornberg has become something of a gene hunter. He identified a 245 base-pair DNA sequence that is the origin for chromosome replication in *E. coli* and then cloned this sequence in a plasmid. Analysis of this sequence shows it is remarkably conserved in widely-divergent bacterial species and that specific sequences have particular functions in initiating replication. This work with gene sequences is almost inevitable today for anyone working with proteins, particularly with proteins that bind to DNA.

But Kornberg has not been converted from an enzyme hunter into a gene hunter. Enzymes are his first and last love. He criticizes biologists for being dazzled by the power of recombinant DNA technology. Though he admits that "analyzing and rearranging DNA has produced astonishing results," he claims that "attention to the enzymes that actually make and operate the cell has not kept pace." To him:

> DNA and RNA provide the script, but the enzymes do the acting. Without knowing and respecting enzymes, better still loving them, answers to the most basic questions of growth, development, and disease will remain beyond reach.

In this quote and in the whole book, Kornberg comes across as a man consumed by a love of enzymes and a love of research. But these are hardly his only loves. His book is dedicated to the memory of his late wife, Sylvy, whom he calls "my greatest discovery." (Being an incurable romantic, this sold me on the book before I had read a single word of text!) She too was a biochemist and worked in the lab with him while raising three sons. These boys played in the lab as children and early on learned laboratory techniques. Kornberg took them with him when he traveled. He didn't allow science to separate him from his family, instead making it a family activity. The result is that the older two, Roger and Tom, now are noted biochemists themselves. While the youngest, Ken, did not pursue a career in science-he became an architect-he specializes in the design of laboratories and research buildings.

Scientists are often portrayed as cold, rather unfeeling individuals incapable of close personal relationships. Kornberg's life reveals the fallacy of this facile characterization. And in a new melding of the scientific and personal, Kornberg had his second wife, Charlene, do the illustrations for this book. Her diagrams of complex molecules such as FAD and NAD are particularly good because they indicate, through different colors, the origins of different parts of the molecules.

A Lesson for Teachers

I hope that I've conveyed the idea that *For the Love of Enzymes* is a wonderful book. It is one that almost any biologist would enjoy, and it carries a particular lesson for biology teachers. Kornberg, like Hoffmann, shows that science can be made to have a human face, that revealing why scientists like science is not an impossible task. At one point, he describes a conversation he overheard between two students leaving a lecture he gave on DNA polymerase. One said to the other: "How dull it must be to purify enzymes." This comment "saddened" Kornberg. (It reminded me of my first semester teaching nonscience majors, when I discovered that they did not find protein synthesis nearly as fascinating as I did.) He thought that "perhaps I should have tried the mountain-climbing metaphor." This refers to a metaphor he uses earlier in the book. I think quoting from it here is an appropriate way to end this column. I don't know if it would convince students how exciting enzymology is, but it gives a good indication of how Kornberg feels-as a scientist and as a human being-about his work:

> Enzyme purification . . . often seemed like the ascent of an uncharted mountain: the logistics resembled supplying successively higher base camps; protein fatalities and confusing contaminants resembled the adventure of unexpected storms and hardships. Gratifying views along the way fed the anticipation of what would be seen from the top. The ultimate reward of a pure enzyme was tantamount to the unobstructed and commanding view from the summit. Beyond the grand vista and thrill of being there first, there was no need for descent, but rather the prospect of even more inviting mountains, each with the promise of even grander views.

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