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Keith County Journal

On Becoming a Biologist

Second Edition

John Janovy Jr.

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taught me things that have nothing to do with living organisms and everything to do with ways to pursue intellectual endeavors. Most I respect. Their lessons, taught by example, have always taken their place within the professional context established for me by those three men characterized above. It is for this that I would like to especially thank my three great biology teachers.

ONE

Naturalists

Don't be an ornithologist if you can help it. But if you can't help it, go ahead. – Frank Chapman

I

It was that idyllic time between Little League and cars with girls. We lived on the far edge of town. In an afternoon you could set traps, marvel at the studied placement of possum tracks, and grind the iron-red Oklahoma clay into your very soul. Parents were people who drank whiskey and played cards. Their friends tried to test my manly inclinations by asking:

"What are you going to be when you grow up, Johnny?"

"A naturalist," I'd reply. They'd smile. Even then I could sense their thoughts: There's no such thing as a naturalist anymore.

Only my grandfather was sympathetic. He'd seen passenger pigeons, known the Old West, and watched Indian Territory become the forty-sixth state. His clothing and demeanor revealed a certain longing for those lost times. His house was filled with books of natural history. I remember sitting for hours staring at a color plate of men spearing a woolly mammoth. The smell of cigar smoke still takes me back to those days, those books.

"We were born a hundred years too late," he'd say. I never thought then of the nearly sixty years that separated us. We seemed of the same generation, at least in our minds.

Since those times humans have placed a biological experiment on Mars, sent the songs of whales on an odyssey outside the solar system, passed a city ordinance against gene-splicing experiments, bought stocks in companies that traffic in DNA, added terms such as "Love Canal," "Three Mile Island," genomics, and PCR to our American lexicon, and loaded up our classrooms with "information technology." The way things are going, I'd have to say my grandfather was wrong. We were born a hundred years too soon.

Developments in science since the Second World War have been stunning. There are people alive today who have seen science fiction become reality. The accelerating pace of science and its offspring, technology, has forced us into consideration of questions that in earlier times were the domain of philosophers: Who are we? Where are we going? Is there an identifiable human nature? Is our research immoral? Had I been born a hundred years earlier, my birth would have coincided with another naturalist's epic journey: Charles Darwin would have just finished his voyage on the *Beagle*. In 1837 my parents would never have accepted the idea that a young naturalist's trip could alter our vision of life on Earth. In our time, however, discoveries that assault our senses are familiar events. Yet there remains a shared awareness that confirms the implications of Darwin's worldview—namely, that our species cannot live apart from the planet upon which it evolved. We share a common bond with even the most bizarre beetle of the Peruvian rain forest. A belief in that common bond might, in fact, be the most fundamental characteristic of a biologist.

Scientific, unlike religious, belief is derived from evidence and is subject to modification. Yet belief functions in biology, and in science in general, in much the same way it functions in religion—to direct behavior and maintain values. To truly believe in a common bond with the Peruvian beetle is to hold the insect in high esteem. We respect the bug because of what it represents: life itself. The values that are upheld by a biologist's beliefs are decidedly noncommercial ones. For example, the worth of an organism is found in its contribution to our understanding of life, not necessarily in our ability to convert it into money or prestige.

Humanity as a whole does not seem to share the values of a biologist. This difference is not surprising when you consider that most biologists perceive the human species as only one of the more recent of millions that have occupied the biosphere over the last three and a half billion years and therefore have enormous interest in nonhuman components of the natural world.

This view of humanity as a late intruder—perhaps the price of becoming a biologist—is in stark contrast to the values associated with other professions. Attorneys, physicians, businessmen—all are consumed by human activities, conflicts, desires. The collective introspection that marks our species is enforced by these professions. A biologist studies "nature," however, and in doing so inevitably comes to regard humanity as the most effective competitor for the world's resources. The conclusion must be tinged with admiration: No other species' accomplishments approach humanity's accelerating cultural evolution, which in essence represents an escape from the "restrictions" of organic change. But the conclusion must also be tinged with sorrow, for no other species seems to possess the power to destroy overnight what cannot ever, anywhere in the universe, to our knowledge, be replaced. To become a biologist today is to adopt and live with this set of conflicting realizations.

Values are, of course, cultural phenomena. A great body of literature deals with the mechanisms by which cultural traits are acquired. Briefly summarized, the literature suggests that

1. there are times in early childhood when we are especially receptive to certain environmental influences;
2. early experiences often shape our later behavior;
3. it is not always possible to determine which early experiences translate into which adult behaviors;
4. once established, certain adult behaviors are exceedingly difficult to change.

Biography seeks to unravel the mystery of life choices and show us by example the effects of experience on our tracks through time. The biographies of biologists always tell of events in which nonhuman organisms are held in high regard. On her deathbed my own mother reflected on her life and talked of times that must have been among her finest. Startlingly young, with an equally young husband off to his first job, she was too broke to go anywhere in a strange land and had a child to entertain. So she did the only thing she could do for free. Every day she put me in a stroller and walked to the Audubon Park Zoo in New Orleans. Who knows what she said to me, if anything? Maybe she just let me look until I was satisfied, then moved on. It would be pure romance to attribute adult career choices to such specific early experiences. But today I cannot pass a zoo without stopping. I stand in front of cages and look until I'm satisfied, then move on. As a senior in college, I encountered a teacher who also took me for a walk, let me look at animals until I was satisfied, then moved on. In May I was to receive a bachelor's degree in mathematics. In March I decided to become a professional biologist.

That teacher was Dr. George M. Sutton, a world-renowned ornithologist who was, at the time, research professor of zoology at the University of Oklahoma. Although I will later address the relationship between teaching and research, as a biologist's life is by definition tangled up in both, for now let it stand that this holder of the highest title a university can bestow, research professor, was also a teacher who could direct career choices by example. The message was obvious to all who encountered Sutton. Here was an exceptionally articulate, broadly educated person, an artist who drew upon the poetry of Gerard Manley Hopkins as a teaching device for advanced classes, who was deadeye with a shotgun, who lived a rich and challenging life, and who was adored by the public. He destroyed any stereotyped image of "biologist." He possessed all the traits, physical and mental, we would like to give our heroes. But overriding them all was his single unshakable belief that, of all the world's resources, none had higher value than birds.

Sutton's own earliest memories included a remarkable incident. His father had taken him walking on a bridge over the Mississippi at Aitkin, Minnesota. A blackbird or grackle landed on the railing. Sutton's father lifted him up, left him standing alone on the railing above the brown and swollen river, and pointed out that the grackle, perched in a similar position, had no fear of falling. George Sutton later claimed that the experience was one of two clear and genuine

childhood memories, in that it had never been mentioned later by his parents. His other genuine memory was of a man who had a collection of bird skins, certainly a unique and impressive phenomenon for Aitkin. One is almost reminded, by these tales, of the metaphorical power of a primitive society's rites of passage. Courage and individuality became symbolized for Sutton, when he was at a very malleable age, by birds. A towering figure at the age of eighty, Sutton continued to express his own courage and individuality through his study of birds.

It's impossible in a book as brief as this to make a complete case for early experience as the crucial factor in life choices. It may also be impossible to account for the effects of a lifelong career as a biologist on the strength of childhood "memories." Especially in the case of prominent—thus in our eyes successful—people, their view of what the public wants to read may influence their choice of words for the introductory paragraphs of autobiographies. Yet again and again, biologists claim that their earliest memories are most often not of humans. Darwin's recollections of the furnishings in his dying mother's room are followed quickly by those of collecting natural items and attempting to identify plants. Charles Darwin described himself at the age of nine as "a naturalist." To support his adult work he had a habit of almost indiscriminate collecting. Writing his autobiography at the age of seventy, he obviously felt it important to convey this sense of a life spent gathering items from nature.

Biology today, of course, demonstrates how truly monumental is the legacy given to us by naturalist Darwin. Evolution is the central unifying theme of biology (see chapter 5). Molecular biologists, biochemists, cell physiologists, behaviorists, and ecologists are all able, and usually willing, to place their work in an evolutionary context. Geneticists, by the very nature of their research, are evolutionary biologists without trying to be. While the work of all these scientists may have profound implications for humanity, it is doubtful that much of it is undertaken specifically for that reason. Most of it is done instead to satisfy personal curiosity or to answer questions that just seem, at the time, to need answers.

Of special interest in this discussion of early life experiences are those of biologists who cannot, as practicing scientists, rightfully be called naturalists. Might even a "gene jockey" find his or her origins in a childhood fascination with a butterfly? Does a biologist who is captivated by the intricacies of protein structure have a certain eye for park squirrels and their acorns? Evidence suggests that they do, or at least claim they do. At the age of ten, Thomas Hunt Morgan, father of modern genetics and 1933 Nobel Prize winner, may have been, with his collection of stuffed birds, eggs, insects, and fossils, indistinguishable from the preadolescent Darwin. Jacques Monod's father, an avid reader of Darwin, instilled in young Jacques an early interest in biology. And Marshall Nirenberg, the 1968 Nobel Laureate who deciphered the genetic code, wrote his MS thesis at the University of Florida on the ecology and taxonomy of caddis flies.

Obviously not every potential biologist possesses so clear a set of values as George Sutton, Charles Darwin, and Thomas Hunt Morgan. But the models suggest that values are a legitimate tool, probably in the same category as techniques for sequencing DNA: that is, they allow you to work in areas, especially areas of thought, you would not have access to otherwise. Like other tools, they may be acquired, although one may possess them and not realize it until confronted with the fact. In retrospect, I had probably always been a biologist, but when I enrolled in George Sutton's class I was trying very hard to be something else. When people later asked why I came back to graduate school, I told them, "Sutton showed me it was all right to be a biologist, after all." What he actually showed me was that the values I held were legitimate ones. The values then asserted themselves and directed my actions.

In the years since that semester with Sutton I've encountered thousands of students, many of them majoring in biology. I could count on one hand the number who were willing or able to discuss values in the same way they could discuss the cell cycle or upstream promoter regions. Yet they all must have had some values. I wonder now if we did all those students any favors by structuring a curriculum that emphasized the latest knowledge in biology. They bought textbooks and studied someone else's summary of information that was by then at least five years old; we discussed journal

articles to present newer techniques and discoveries. Then, to teach them about why people do things, we sent them to the humanities departments. Did we expect them to integrate that knowledge to arrive at a sense of why people did biology? Yes. But did we try, or do we try today, to assist that integration by straying from the subject of someone else's latest experiments to talk about why that journal article was important to us, or might be important to them, personally? No.

So in one critical area—the *reason* biologists study living organisms their whole lives through—education is left largely to chance, and the responsibility for those lessons falls on student shoulders. The idea that science classes must, from bell to bell, deal only with observations, interpretations, and experimental design is a delusion. Original science cannot ever reveal, except in the most indirect way, why the teacher who presents it so articulately made his or her life choices. Those who ask, Should I become a biologist? or, Am I a biologist without knowing it? thus have the task of ferreting out their role models' values.

2

But what does the foregoing discussion of values mean for the person who today considers a decision to *be* a biologist? First, it suggests that such decisions may be quite different from decisions to *do* something. We begin to sense in our role models a force that in the end tells them what they are, rather than what to do. The metamorphosis from "I do . . ." to "I am . . ." is a critical one. It not only frees a mind to explore the world in a way that is not available to an intellectual larva, but it is also ultimately required for the production of original work in any area, not just biology.

Unfortunately biologists, like attorneys, must buy groceries and find shelter, and metamorphosis into a state of "I am" is strongly inhibited by concerns about employment. Inspired by uncertain economic and political climates, the entire movement urging young people to go to college in order to find a satisfying and financially rewarding job is a movement that undermines the decision-making power of a would-be biologist. To retain that power you must recognize your values for what they are—namely, the elements of identity.

A job, on the other hand, is a task you do for someone else. You can do a job without being something. But being requires an active commitment to sustain identity.

The activities that biologists use to sustain their identity often have no apparent relationship to the familiar world. But biologists do mature, find financial support somewhere, melt into the general population, and surface in the most unexpected places. Such as a local high school gym. In a fit of charity, I agree to sell tickets at a junior varsity girls' volleyball tournament. The woman who works with me fills the time between customers with casual acquaintance talk: Where do you work? . . . etcetera. Finally her eyes take on a look that I've come to see as a warning.

"I know one of the people in your department. He lives over in our neighborhood. His wife seems real nice, but he . . . ," she says.

"Oh?"

"He studies frogs in South America." There follows a considerable evaluation of people who study frogs in South America. Throughout this description of my colleague it is clear that a fascination with Neotropical amphibia is a pursuit she cannot reconcile with some image of a productive member of society. As we sit there taking money, I get my periodic look at life outside the ivory tower. It is amazing what adults will do to try to get into a junior varsity girls' volleyball tournament free. But what is more amazing is the task my colleague might face in trying to convince the world there is nothing wrong with studying Neotropical frogs. Finally the woman asks about my own research. I tell her of some studies on parasites that are capable of infecting humans. This work is clearly legitimate. I pass the test as a fellow member of the species.

But on the way home, I review my own sense of what my colleague is. First, he is an exceptionally intelligent, well-educated, and multilingual person who works exceedingly long hours at a noble profession, that of the teacher. He publishes numerous research papers every year, the result of his original study and thought. His name is known in certain circles around the world. He travels to exotic places at least once a year—the Peruvian Andes, the Amazon jungles. The animals he studies are a collection of living jewels. He can knowledgeably discuss history and philosophy and will try to discuss anything else. He loves to fish. He and his wife have contributed two bright children to our society. He lives a rich and rewarding life. He wrestles daily with the problem of conveying a sense of impending ecological disaster to the public. He wouldn't trade places with anybody. And to this gentleman, there are very few things more important than Neotropical frogs.

But of what value to society is his work? Will additional knowledge of the Leptodactylidae provide a cure for cancer, eliminate pollution, end the threat of terrorist attack? No. What it will do is contribute to our overall picture of the planet upon which we live. In recent times, it has been shown that the tropics are the repository for the bulk of the genetic information that spells life on Earth. Current research brings into harsh focus the speed with which tropical forests are being cleared and the frightening long-term implications of such clearing. Fifty years ago we didn't equate the clearing of tropical forests with elimination of life itself. Molecular biology had not given us the vision of strange species' genes as common property in which we all had an interest. But today the work of naturalists such as my colleague is beginning to show us just how much of this genetic information exists. Through tropical studies, the world has been shown to be far richer, and more complex and fragile, than we imagined it to be. My fellow scientist's research helps form the fundamental concepts that should shape our decisions about the kind of relationship we must have with the planet. And he surrounds himself with frogs.

The decision to become a biologist demands an attachment to the world of living organisms. There may be several million species of plants, animals, fungi, protists, and microbes. The vast majority of them are insufficiently studied. They are all distinct in some way and thus reflect several million different relationships with Earth. They all have evolutionary histories and relatives. Most have been here longer than humans. Their relationships with one another add a level of complexity above that of their own specific structure and history. One of the major accomplishments of biology has been to demonstrate how little we actually know about all these organisms and, by implication, our own life support system. Organisms are, or are constructed from, cells. The complexity of cells is at least as great as that of ecosystems. Thus, whether we look beyond ourselves or within ourselves, we still see a world that we are only beginning to understand. There is much to be done by biologists. The exotic lives of people like my herpetologist friend are waiting to be repeated over and over again by succeeding generations. But they are not likely to be repeated by people whose values are focused only on humans.

3

What do biologists actually see? How do these scientists perceive the world? These questions need to be answered if only because all professions are characterized by their typical world visions. Individuals whose perceptions are inconsistent with these accepted visions are outcasts. Such people can become miserable and ineffective burn-out cases, or else they foment rebellions that redefine the typical worldview.

Perceptions that are shared among professionals are used as the basis for defining accepted areas of inquiry within a profession and to determine legitimate problems and their solutions. This general phenomenon is the subject of Thomas Kuhn's classic work *The Structure of Scientific Revolutions*. Kuhn begins his discussion by presenting the concept of the paradigm. Paradigms are intellectual environments, frameworks within which we work. The nature of a particular environment is determined by leaders, or those with reputation, by the state of knowledge, and by available technological tools. These factors all operate to establish the limits of investigation and define valid and important problems. For example, the problem of how to clone a gene was not a recognized one prior to the rediscovery of Mendel's laws of inheritance. In 1880 you could have asked the question, By what mechanism is DNA synthesis regulated? and no one would have cared. In fact, people might have thought you were crazy. Professional biologists of the time had neither the understanding nor the equipment to consider such a question. Instead their knowledge and technology would have established an environment—that is, a paradigm—in which other questions were important. An apprentice's paradigm is generally consistent with the worldview of professionals. A beginner is taught what the professionals know, feel is important, and think can be studied. Thus paradigms both direct and limit intellectual development.

Scientific revolutions occur when paradigms are overthrown and new questions become valid, important, and potentially answerable. Scientists are in the business of trying to make discoveries that will change our working environment—that is, our paradigms and worldview. It is for this reason that Kuhn is virtually required reading for anyone who would be something defined by intellectual activity—for example, a biologist.

Of course no one has asked a broad and extensive cross section of biologists how they see the world. An individual's sense of the common vision is a result of years of contact with other people who have claimed to be biologists, who have made life decisions to become biologists, or who are biologists without knowing it. One day I found myself sitting at a corner table over beer and pizza with two people. One of them was an exceptionally bright first-year graduate student, a person I always mentioned when predicting success and fame. The other was a young woman who would soon be entering graduate school. Neither was worried about a job. Both had done some research, taught laboratories, attended scientific meetings. I asked what they see when they walk across campus.

The graduate student, a young man, says "birds," but then goes on to explain how he's always either watching the ground or the sky, which I translate into "robins" or "gulls." He concedes that between the ground and the sky, he averages straight ahead. The young woman sees processes. She always knew there was a beginning and an end, but now she sees "what goes on in between." Her big course this semester is cell biology. Both recognize some essential differences between themselves and their fellow students. Both see their environment in terms of their identity. Both already consider themselves biologists.

Differences between worldviews become glaringly apparent when a biologist, as teacher, walks into a university classroom of nonmajors. For months, often years, before this happens, departmental committees have asked, What should we try to teach these people? "These people" are typically a collection of up to several hundred eighteen-to-twenty-year-olds who have already, perhaps on the advice of a high school counselor, made what they believe are life decisions. Few if any of them hold values that include a place for the leptodactylid frogs. When asked at the beginning of the semester to describe what the world is like, the vast majority will respond that it is filled with war, politics, education, and money. If questioned about their choice of majors, most will give an answer that translates into money. Few see the living world so obvious to my two companions over pizza and beer; while walking across campus, most look for their friends, or dig around in their packs for cell phones, instead of searching their environment for robins or gulls.

So with what equipment should a biologist approach this mob? Obviously among the list of intellectual weapons should be the profession's worldview. If it is not expressed, then the biologist will not bring to society his or her essential contribution: one version of the truth. We will then produce another generation of leaders with biology on their transcripts but not much that passes for biology on their minds. Such a group will have little potential for making rational decisions on major issues involving the life of our species. If a student leaves biology class with information, but without the vision to see beyond the surface and into structure, process, complexity, and dependency, then we have not actually taught biology. Ideally a teacher should convert students into at least partial biologists.

Contemplating the responsibilities of an instructor is a useful exercise for any serious student considering his or her role in society as a biologist. The task of teaching a subject brings into focus a person's own thoughts about what is significant enough to be passed on to succeeding generations. Deciding what is to be taught by a biologist as opposed to, say, a chemist or linguist helps us choose what we feel is of fundamental importance to us in our specific role. Sooner or later, directly or indirectly, every professional will address the matters of role, responsibility, and identity. Biologists are not immune to this experience.

There is a mental exercise that I sometimes use to help people either acquire a biologist's worldview or to recognize it in themselves. If done honestly, it forces them not only to look at their surroundings differently but also to combine seemingly unrelated ideas. It generally works like a charm. The task is to discuss the biological content of the magazine *Art in America*. (Although virtually any reasonably sophisticated art magazine will do, this particular publication is both heavily illustrated and of high production quality.) What one discovers is the use of plant and animal subjects by nonbiologists, and although the usage is symbolic, it often extracts some essence of the organisms portrayed that would escape an unromantic person. For example, one typical issue illustrated, among other biological subjects, a botanical garden as backdrop to a Miró sculpture; Giacometti's *Dining Table with Gilded Leaves, Frogs, and Sparrows*; Alexander Hogue's *Desert Mesa in the Big Bend*, which could have substituted for any photograph of the desert biome in any freshman textbook; Jack Thompson's *La Rosa del Cardinal* (voluptuous torso with head of a cardinal); an André Masson abstract with identifiable fish; Rudy Fernández's surreal *Courting Disaster*, with a perfectly executed trout; a veritable bestiary in Harry Koursaros's *Pandora*; and Gallery Hirondelle's advertisement of the sculptor Mihail's "spiritual safari to free the Elephant from the shackles of Man's dominating ambitions" and the casting of his first of eleven life-sized bronze elephants. Once they've been asked to look, and told where to look for it, most students can generate pages of discussion on this kind of material.

This kind of exercise is beneficial in that it generates an unexpected amount of biological awareness. First, for a biologist to ask a student to read an art magazine is an affront to the student's sense of order. Second, the assignment clearly has nothing to do with biology as the subject is perceived by the student. At this point the student's perception of biology is simply narrow. But just by being forced to look beyond a familiar context, the student acquires a measure of sensitivity to biological content in unexpected places and thus makes some progress toward acquiring a worldview similar to that of my young companions above. Obviously, if you exercise this kind of sensitivity easily and naturally, on your own, you have one of the common properties of people who would be nothing other than biologists.

4

To this point we have considered the values, visions, or worldviews that biologists, as opposed to other professionals, hold. These values and visions will not necessarily guarantee a successful career in biology, but they will validate a career decision long after a student has left formal academic training, at a late time in a person's life when careers often need validation. It is a common experience among all professionals, not just biologists, to wake up one day and ask, Is being a . . . really what I want to do with my remaining years? At such times values and visions will prove their worth, for they provide the best foundation for serious consideration of one's contributions and potentials. At the end of his career will my herpetologist friend renounce the Leptodactylidae as worthless and obscure? Did Sutton on his deathbed decry a life wasted on birds when he could have been an equally articulate attorney? No.

Values and visions also have another significant role—namely, that of recognition of oneself. A certain value set allows you to see yourself as a biologist, and not as an attorney, banker, or used-car salesman. Such self-recognition can be the factor that turns a searching student into a professional with a mission, allows an older person to add richness to a wandering life, and helps anyone to place disappointments and frustrations into their proper perspective. I think that self-recognition is what I developed in Sutton's ornithology class. The fact that I am not now an ornithologist is testimony to the good judgment of some other teachers as well as to the diversity of intellectual opportunities for biologists. But I do consider myself a biologist. And I have never looked back on that decision, made without a great deal of thought one day in March.

I did have an opportunity, however, in the six years after that decision, to be closely associated with a number of people whose naturalist values were, like Sutton's, virtually nonnegotiable. In every case they pursued their intellectual work as if it were of monumental importance and in so doing validated every day my decision to become a biologist. Harley Brown (see Acknowledgments) seemed

at the time to be able to identify every organism—from the nearly microscopic to distant soaring hawks—that we encountered on field trips to southeastern Oklahoma. Furthermore he became excited over most of them, even though I had the feeling that he'd seen them all dozens of times on previous expeditions. He was the first grown man I'd observed who simply waded into a stream in his field clothes and began turning over rocks, exclaiming his discoveries in a voice that compelled a student to take note. By the end of my first field day with Dr. Brown, a sense of the earthly richness a naturalist's eye could discern had started to take shape in my mind. To Sutton's birds, Brown added the rest of the animal kingdom, although his emphasis was on the free-living forms.

J. T. Self, with his group of students, showed me the parasites. Two graduate students in particular played a key role in my decision to study parasites—Dan Harlow and Jerry Esch. Both had been in the ornithology class in which I'd decided to become a biologist instead of a mathematician. By the time I returned from the army, they were well into their graduate studies. Dan was asking a grand question: Do pectoral sandpipers transport parasitic worms from one continent to another on their migrations? Jerry's research was, at the time, a model for physiological studies that were done within the context of a species' life in nature. His question was a rather sophisticated one: Do larval and adult tapeworms utilize glucose according to the same metabolic pathways? Dan's work took him to the field to collect sandpipers; Jerry's involved jackrabbits and dogs. Both spent long hours in the lab processing their materials, but they never forgot that the worms lived in, and had come from, nature. Dr. Self seemed to enjoy sitting back and watching both of these young men struggle with their research.

Dan used to come over to our little rented cottage two or three nights a week to sit around and talk about science and scientists. Jerry was enrolled with me in Brown's advanced invertebrate zoology course. In the middle of lab, we'd take a break, go up to Jerry's office, drink terrible instant coffee, and review the structure of worms. With this kind of exposure to the naturalist's values, and recognition of myself as a person who was, down deep, a biologist, there was no question that I would accept Self's offer of a research assistantship on a large project involving the intercontinental movements of viruses and parasites.

The project was based on the assumption that organisms that migrated from one continent to another could carry parasites, including viruses of medical and veterinary importance, and in the process serve as a source of potential pathogens for resident animals. In practice, however, the work required that I commute from Norman, Oklahoma, to the marshes at Great Bend, Kansas, where the bulk of the Central Plains field work was to be done. My home away from home was a small building put together by a multitalented gentleman, H. A. "Steve" Stephens, the project's resident collector and the last of the old-time naturalists. Whatever doubts I may have had about the worth of the naturalist tradition in biology Steve laid to rest. His personal residence was a camper on the back of a pickup truck. Inside there was a pet prairie dog, ample reading material, a desk where he did his writing, and a small kitchen. Steve was working on a book about the woody plants of Kansas. His reasons for living in a camper seemed obvious: When a particular shrub is about to bloom, and one needs to draw a picture of the flower, it helps to be able to simply drive up to the plant and wait for the blossoms to appear.

Over the course of the next three years, I was to become completely immersed in an attempt not only to do project work but also to answer my own thesis question: How does the life of a host affect its interactions with a parasite? My studies concentrated on two species of birds and a single species of parasite, *Plasmodium hexamerium*, which each host contracted from mosquitoes. The two birds, meadowlarks and starlings, lived under very different circumstances—the starlings were tree-hole nesters, the meadowlarks stayed in the open fields. I had embarked upon a journey of discovery that led eventually to the tops of rotted cottonwood trees, the inner stillness of a prairie marsh, the flooded Kansas pastures with mosquitoes so thick one could hardly breathe, and the Gulf Coast of Texas. In the end, I did learn something about the transmission of bird malarias, but not nearly as much as I had expected in the beginning. More important, I discovered I was in the company of naturalists all parading as professional biologists.

Dr. Self probably had the most perspective on a scholar's life of any of my teachers. He was a very practical man, a no-nonsense problem solver and decision maker. His stint as department chairman had eliminated any fear he may have had of campus politicians; his contacts with people outside the department helped him to appreciate the philosophers; his exposure to faculty from other universities inspired him to send his doctoral students on to postdoctoral training in the programs of renowned scientists; and his sense of wonder at nature kept him working and publishing well into his seventies. But of all his experiences I think one stood out as a beacon. His first graduate student was a boy named Bob Kuntz, a kid who loved snakes and was a collector in the Darwinian tradition. Self spoke often, and somewhat smugly, of the difficulties Kuntz had in getting admitted to graduate school. I could see why my teacher had such special feelings about his first student. By the time I encountered J. T. Self, he was near retirement and Bob Kuntz was one of the most widely published and well-known figures in his field.

Among those who were fellow biology graduate students during my years at OU can now be counted college presidents, deans, department chairpersons, taxonomists, ecologists, behaviorists, biochemists, businessmen, real (not campus) politicians, teachers, wildlife artists, and photographers. None of them trained specifically for these various roles in society, although they may have emphasized particular areas of study by taking selected courses. Instead I prefer to think they all evolved, intellectually, as a result of their fascination with organisms. A dozen years after leaving OU, I found myself in need of the lessons I'd learned from these people outside the classroom. Campus wheels had turned at my institution; machinery and reductionism seemed to be replacing the curiosity about nature that I knew should characterize the profession; and in our rush to become modern we'd thrown away our respect for plants, animals, and microbes. What values must one hold in the technological age? I asked myself, desperately needing an answer at the time. This answer came as a book I wrote entitled *Yellowlegs*, a quasi-biographical piece of vision-quest literature that celebrated the naturalist tradition among those people who guided my attempts to become a biologist.

5

Is a decision to become a biologist one faced only by a college student? Is it necessary to become a professional in order to be a biologist? In both cases the answer is no. There is a wealth of opportunity for serious and rewarding study by "amateurs." While nonprofessionals are usually limited by lack of technical training and sophisticated equipment, and by the incredible expense of some types of biological research, they have access to almost unimagined resources in the world of nature. There are so many kinds of organisms that can be studied with a magnifying glass, so many known only by their structure and not their habits, so many whose lives are more easily analyzed by the ingenious mind than by a sequencing machine, that biology should not be restricted to professionals. But ultimately a middle-aged widow's decision to become a biologist will rest on the same questions as a college freshman's: Do I have, or can I accept, the values and visions that open up this rich and complex world?

Of course the concept of an appropriate vision is also relevant for the professional engaged in more formal—that is, scheduled—research, where one sees not only problems to be solved but also questions to be posed. A skillful scientist is one who first asks the right questions, who can "see" such questions in the surrounding biosphere. Right questions tend to be those that can be answered using known or devised techniques, that serve as case studies, analogs, or metaphors for larger questions, and that generate additional questions with similar characteristics.

A fundamental property of a mind that asks the right questions is that it not only sees complexity of structure and function within organisms but also sees how this complexity is superimposed on uniformity. The uniformity is that of cell structure and function, the structure of DNA, the processes of gene expression and evolution, the phenomenon of interdependency. For the biologist, complexity reveals itself in the specific manifestations of life processes. This vision is easily demonstrated with simple examples: There are at least three hundred thousand known ways to express the concept "beetle," ten thousand ways to express "grass," and nearly twenty thousand expressions of "orchid." A true biologist walks through town and sees complexity upon uniformity in the sparrows digging through last night's garbage, reads the paper while the words "tiger . . . lizard . . . lily" leap out from the comic page as if they were the real thing, and sits in a crowded restaurant and watches *Australopithecus*, *Pongo*, and *Pan*.

The world of a true biologist is also filled with potential investigations. This person goes home in the evening and despairs for only seconds over the bindweed strangling his tomato plants, for in that bindweed he recognizes a lifetime of experiments. He may pick an underground stem and take it into his laboratory for no other reason than to think for a few days about how this material can be converted into an understanding of the processes that govern plant growth and development. Perhaps a "right question" will come into his mind. For example: What biochemical events occur when a white stem is stimulated to produce a green leaf upon exposure to sunlight?

And finally, in this matter of vision, a biologist sees interdependency. The possible relationships that can exist between organisms are often summarized by introductory textbooks as (1) prey-predator, (2) competitive, and (3) symbiotic. These categories imply that organisms either eat one another, compete for various resources, or live in some (often) obligate relationship in which one species depends directly on another at the individual level. But prey-predator relationships also involve dependency, that of the predator upon the prey. Since competition can drive evolution, competitors may depend on one another, in an almost metaphysical sense, for their identity. The relationships that are established within a community of organisms therefore provide organization and structure, regulate populations, and give a community a "life" of its own.

Relationships also dictate the specific paths by which energy and materials flow within a community and ecosystem. It is a fundamental principle of life on Earth that energy has a net flow in only one direction, while chemical elements are recycled. Thus life as we know it depends on a continuous supply of energy from the sun and the availability of materials which may have already been used in living organisms. Although the statistical chances are minuscule, this principle allows that a carbon molecule in your body today may have been incorporated into the DNA of some lumbering dinosaur. The energy that powered the beast, however, is not available now, nor will it ever be again.

The extent to which biologists are aware of these fundamental principles of their science is the extent to which they are aware of interrelationships, potential and otherwise, in their daily lives. My two pizza-eating friends saw not only robins, gulls, and metabolic pathways along the campus walks, but potential interactions among them. Robins eat worms, which are converted into CO_2 by Krebs cycle reactions; the CO_2 is incorporated into leaves of campus plants which give off oxygen that is breathed by a gull to help power it to the Gulf of Mexico. Nothing in that sentence, from its implications to its almost cell-like complexity, is strange to a biologist.

Finally, the combination of dependency and complexity gives rise, in a biologist's mind, to diversity. In a walk through town or woods, a biologist observes the kinds of organisms, be they cultivated or wild, and notes their relative numbers and the niches they seem to occupy. From block to block the diversity may change: A vacant lot offers a mini-course in ecological succession; a garden easily reveals the unstable nature of monoculture; trees tell the age of a neighborhood as easily as they tell the year a southern farm was abandoned.

Today's biologist will also extend his or her analysis to the dominant species: Are there niches for humans, do societies obey the same principles as the organisms with which they surround themselves? New York is structurally complex, a virtual, albeit synthetic, equivalent of a tropical rain forest, populated with layered communities, guilds, and a diversity of intellectual species occupying their own niches. Such niches are not necessarily present in the "deserts" of our society, but a biologist strolling down Madison Avenue knows there are thriving, adapted communities in the savannas, the alpine tundras, and the taigas of our culture as well. These are not the metaphors that occupy the minds of attorneys, bankers, engineers.

Or, if they are, we have some biologists chafing within common disguises.

6

The field of biology that a student encounters today is stunningly different from the one Darwin experienced. A hundred and fifty years ago science wrestled with not only the mysteries that have confronted humans at all times, but also with a philosophical climate in which religion was a powerful and ever-present force. Although scientists proclaim intellectual neutrality, social climates can never be eliminated as an influence on the practice of a profession. Thus while Darwin's contemporaries did science in an era when religion influenced the interpretation of data, yours do science in an overpopulated, weapons- and health-obsessed society that acts as if the world has an unlimited supply of fossil fuel. The times affect science as much as they influence the art, music, and literature a culture consumes. During the decades following World War II, two inescapable factors cast their shadows on every scientist's work: (1) monumental problems to be solved if our species is to remain extant, and (2) technological tools of such power that the public equates their use with science. The former, the problems of *Homo sapiens* (mainly overpopulation), I will consider later. The technological tools need to be dealt with now, for they have a bearing on the image I have been drawing of a "naturalist."

What specifically are these tools? First, they are machines, pieces of equipment. Your familiarity with their names is as sure an indicator of the times as your calendar: scanning electron microscope, transmission electron microscope, amino acid analyzer, gas chromatograph, scintillation counter . . . personal computer, main frame . . . laminar flow hood, ultra centrifuge, PCR machine, sequencer. Second, they are standard analytical approaches that allow machinery to be incorporated into biological investigations; examples are techniques such as cell fractionation, nucleic acid and protein purification, *in vitro* methods for everything from enzyme assays to cell-free protein synthesis, cell culture, and hormone assays. Third, they are the mathematical equations and statistical methods that allow scientists to convert raw observations—that is, numbers—into tests of hypotheses. Finally, they are the massively sophisticated software that allows the data-mining that characterizes fields such as genomics, proteomics, and molecular phylogeny. As with any set of tools, it matters less that you possess them than that you use them well.

Because the public today tends to view science in terms of its tools, there is a subtle danger that biology students (who, after all, emerge from the public) will find it easy to confuse technology with science. Given the proper equipment and training, it is not difficult to make monoclonal antibodies or sequence a piece of DNA. What is infinitely harder is to walk through the woods and decide, on the basis of your observations, against which antigen you should make monoclonal antibodies and which pieces of DNA to sequence. Until you are able to make this decision, or perhaps more important, until you are willing to try, you will remain a technician instead of a biologist. To make the transition, however, you must acquire the mind-set of a naturalist. If you are successful in doing so, your apprenticeship is likely to end, for you will begin to apply your tools to the raw material of organisms' lives to develop understanding.

It is important for every practicing biologist to ask: What effect do these tools have on the way I approach organisms, biology, and science in general? At the most obvious level they influence thinking itself, if for no other reason than by their constant reminder of what can be analyzed. The ever-growing range of available tools should also serve as a reminder of not only what training it will take to become a certain kind of biologist but also what may happen to you after having made a commitment to a line of study built around a certain tool. This may be a critical consideration for students. Advanced math, chemistry, and physics, which are almost essential today for minimal technological expertise, are not easily acquired by an established professional, so that a decision to become a biologist almost obliges one to a certain minimum exposure to math and physical sciences at an early age. Yet there are only so many hours in a day, and using them in the acquisition of tools inevitably takes time away from the study of organisms. In the end you may find that

formal education has provided you with the biologist's tools but not the naturalist's values and worldview. This would not be so bad if the history of science did not show that tools grow dull quickly. High-tech biology compounds the dilemma by its adoration of vogue.

We should, then, soberly address the question: What has high technology done for and to biology? The answer is: Plenty. It has expanded, and is continuing almost daily to expand, our understanding. We see in organisms things we never saw a generation ago. Today a parasitic worm such as *Schistosoma mansoni* is viewed in terms of its specific ultrastructure, metabolic pathways, fatty acid composition, and the antigens that it uses to cover its own unique proteins and thus "hide" from its human host. Or a single species of nematode, *Caenorhabditis elegans*, is viewed as something that will finally help us discover the principles by which embryonic development is regulated.

Furthermore our knowledge now enables us to recognize interrelationships among observations. We look at a plant and see a spectrum of secondary compounds. A generation ago we didn't understand the role these molecules played in plant-animal interactions. Today we see plants defending themselves against herbivory, using secondary compounds as repellents, and we wonder if the gene splicers can put the ability to manufacture certain secondary compounds into food plants, thus eliminating our need for commercial insecticides. At this point the flippancy of the phrase "high-tech vogue" disintegrates.

The above example is worthy of closer examination. What exactly would it take to provide humankind with a strain of corn that would repel, through its own secondary products, the insects that now compete effectively with us for food? What would the payoff be? The second question is fairly easily answered. An enormous financial burden would be lifted from agriculture and a major source of environmental toxins—that is, pesticides—could be eliminated. And we can speculate on the answer to the first. It would require identification of those compounds that actually function as insect repellents in plants (organic chemistry), demonstration that some of these compounds are effective specifically against corn pests (experimental design, statistical analysis), identification and description of the metabolic pathways by which the compounds are produced in nature (biochemistry), identification and isolation of the genes responsible for the pathways' enzymes (molecular biology), successful insertion of the required genes into the corn genome (genetic engineering), and production of the seed grain itself (agronomy).

Given the nature of biological science today, this potential accomplishment does not seem outlandish; the basic elements of this scenario are fairly familiar to us, even from the popular press. There is very little in the above paragraph that has not already been demonstrated to be possible. But professional biologists, especially those with modern research experience, would be less sanguine than the public regarding the actual likelihood that biology could soon eliminate our need for insecticides. Conversely, professional biologists might be much more sanguine, or at least realistic, about the positive benefits of genetically modified organisms in our food chain than is the average citizen. Basically what remains is to accomplish the feat of combining parts of organisms or, more precisely, combining specific parts of specific organisms. Other successful combinations are already generating commercially useful products.

Ecology and ethology are the modern and mature versions of natural history. Ecologists and behaviorists have thus tended to acquire tools that help them understand the activities of whole organisms, rather than single genes, proteins, or metabolic pathways. These tools are primarily mathematical ones. Math, probably more than chemistry or physics, influences the thinking of those who employ it. Mathematics provides one with highly structured processes that can be used in an almost infinite number of ways. Having used math, however, and appreciated its powers, one is reluctant to retreat into a weaker mode of communication and instead steps forward to open another intellectual door. In the next chamber lies abstraction, the representation of process by marks on paper and a stairway to places where the purest thinkers live. Not many biologists climb the stairs. But all are familiar with math's utilitarian cousin, statistics.

Today, because calculations and statistics are done largely by computer, it is imperative that a student whose curiosity leads to ecology

and behavior become computer-literate. "Student," in this case, does not apply only to the college junior. One of the most powerful experiences I have had in my own career is that of watching my colleagues wrestle with computer literacy. We are talking here about tenured senior faculty members who suddenly see the future staring them in the face.

The University of Nebraska operates a summer field program at a place called Cedar Point Biological Station. One summer, I believe it was in 1980, a new faculty member borrowed from the city campus, for a period of five weeks, one Apple II personal computer, and set it up in the main laboratory. The college students were reluctant users. Unable to write their own programs, they felt embarrassed. Confrontation with a new language and its characteristic grammar and syntax was not anticipated to be a part of a course entitled Vertebrate Zoology.

The students' embarrassment, however, was nothing compared to that of the teachers. A twelve-year-old faculty child with a short elementary school course in computers sat down at the machine and produced wonders: graphics, original games, records of his kitchen employment. By the end of that summer, we knew we had no choice but to come to terms with what we had witnessed. Some of us immediately bought personal computers from out of our own pockets. Others began immediately writing grants. The next summer every course used faculty-written software, and there were four personal computers in camp. I've just described a mini-drama in which a group of professionals and students were shown what it takes to be a naturalist in today's intellectual climate. Nowadays university students at this same field station bring their laptops to lab, however, and we old-timers are more worried about their dissection and identification skills than about their access to hardware. But few if any write code.

Chemistry, physics, and math are clearly, in their own right, discrete areas of intellectual endeavor. But they are also ones that the complex science of biology has borrowed from in order to answer questions about organisms. Historically human progress has been characterized by a blurring of the lines between disciplines, not only in the so-called hard sciences but also in the social sciences, arts, and humanities. In most cases, however, the overlaps involve technical contributions rather than values and visions. Artists may choose space-age materials, but these materials are then used to present an artist's, not a scientist's, worldview. The same can be said of the relationships between a biologist and chemistry, physics, and math. A molecular biologist may have to convince reviewers that a research paper's chemical and statistical techniques have been done correctly, but the published paper is usually much more interesting to biologists than to chemists.

Interactions between fields can be thought of as occurring through a filter of values and visions. That these interactions occur is an element of your daily working environment as well as a fact of history. Not only will you have to deal with them in order to become a biologist, they will influence the kind of biologist you become. The most successful biologists, however, tend to keep the filter intact. For example, it is easy to become vitally interested in problems of enzyme regulation because they must be solved before you can explain the manner in which an organism deals with environmental change. On the other hand, in order to study enzyme regulation you may have to become as skilled in chemical techniques as a professional chemist. Research problems can consume decades of intense work. If, after those years of research, you are more interested in the enzyme than in your original question about physiological adaptation, then your values and worldview will be those of a chemist instead of a biologist.

7

When complementary fields exchange values and visions instead of simply techniques, intellectual communities tend to respond with controversy. An excellent historical example of this phenomenon can be found in the original reaction to sociobiology. Sociobiologists interpret human behavior within the context of the broad field of ethology, seeing in humans general behavioral patterns that are common to the "lower" animals. Familiarity with this field is important to a potential biologist because E. O. Wilson, the founder of

sociobiology, made biology a direct human concern in a way even the layman can appreciate.

For example, in sociobiology literature humans are described as "mildly polygynous," a primate social characteristic that is predicted by differences in body weights between males and females. "Mildly" implies that the human male, on the average, consorts with three to five females, instead of twenty or thirty, as might the males of some other mammalian species. Culture, however, directs the specific manifestation, but not the fact, of this trait. It is not unusual for a male to have two wives and be helped by three secretaries over the course of a career in business in this country. A sociobiologist would interpret this situation as a rather natural one—that is, having a biological basis. If you are a female reader, you can easily see from this one example how the findings of sociobiology can generate controversy. Wilson does not state that social structures that have a biological basis should necessarily be maintained. What he does imply, in essence, is that a biologist has as much to say about the human condition as the politicians.

Let us imagine that "biologist" is the cultural equivalent of a family or genus, that your specific interest is the equivalent of a species, and that your individual approach to that interest is a variant within the species definition. Society therefore becomes the environment that will select for or against your cultural phenotype—that is, the form your individual education and skills will take. If like most students, you are interested in employment, you will try to discover those cultural phenotypes for which society is selecting. If you are interested only in perpetrating your original ideas regardless of your state of physical and financial well-being, then you will probably try to discover cultural niches where your mutant ideas are not selected against. If the sociobiologists are correct, in either of the above cases you as a job seeker will be forced to take into account the extent to which *Homo sapiens* is a social species, for social behavior dictates the structure of much of our working environment.

As a result, you will conduct your career in a world in which group attitudes determine the fate of individual ideas. No matter what your contributions, you will eventually have to find employment. Whether you get a paying job in government, business, or academia, you are still likely to encounter dominance hierarchies, lingering sexism, cultural conservatism, religion or equivalent belief systems, and intergroup rivalries. I hope that in the next few paragraphs we can deal with this situation in a serious, uncynical manner. Humanity will not change its basic nature before you receive a PhD. Or for that matter before you retire. It is best to look at ourselves objectively and plan accordingly.

A close look at group behavior reveals that social forces foster opportunities as well as inhibitions. If you understand the mechanisms by which these forces work, then career hurdles that seem difficult can suddenly become easy. If you are planning to teach, then recognize that a classroom is fundamentally a social unit and your teaching will become significantly more satisfying. For example, you may have to establish a dominance hierarchy with yourself at the top in order to counter dominance behavior, by a very few class members, which keeps a bright but shy student from making a significant intellectual statement. You may also have to devise ways to thwart group judgment in order to preserve a student's sense of self-worth so that he or she can progress. Thus when you understand social behavior, teaching becomes a challenging and rewarding contest between your own problem-solving powers and a social order that might otherwise appear fixed.

Similarly in research, you will find that social forces tend to determine which problems are "good ones" and which solutions "will work." We are back to Thomas Kuhn (*The Structure of Scientific Revolutions*). As a beginning biologist, if you attempt to step outside your paradigm, then expect resistance every inch of the way. Negative criticism about technique can be answered with ingenuity. But you should also be prepared for the apparently damning, Why are you asking *that* kind of question? I'm not dissuading you from trying to step outside your paradigm. I am saying that you should not expect it to be done easily. If you accomplish it, you'll be history's hero.

Social behavior will also influence your career through the funding of research. For example, it should be obvious that an agency with the name National Institutes of Health will have certain missions and vested interests. Virtually every source of money society will provide to support your intellectual activities will have some stated or practiced policy that can be thought of as a group identity. To receive funding, you will either bend your thoughts to the source's mission, or convince the source its vested interests are served by your work, or do without. Alternatives tend to fall in a writer's world: marry for money.

In the long run, the social sciences can thus be considered in the same light as chemistry, physics, and math—namely, as disciplines that influence the way you do biology. And in a very real sense, the social sciences can and should also be thought of as tools. Like the physical sciences and math, they enlarge our vision of what can be analyzed, opening up areas of study, stimulating the investigation of new questions, and redefining the word *biologist*. Unfortunately most universities have not yet come to this realization. Rarely, for example, will a semester of psychology substitute for a semester of physics in a biological sciences curriculum, even though the former might well be more beneficial than the latter, over the course of a career. So it may be largely up to you to educate yourself in the social sciences, to choose courses in history, political theory, and group behavior, and the faculty members who teach them, with the same seriousness and care with which you choose your physics, chemistry, and math.

8

Among the items I inherited from my father, a petroleum geologist, was his introductory zoology notebook. He had taken the course in the early 1930s from a Dr. Richards, who, it turned out, was the major professor of Dr. J. Teague Self, the teacher who directed my own doctoral work. I always knew my father had graphic skills. His maps were works of perfection. He could do things with drawing instruments that were beyond belief, I thought even as a college student. So it came as no surprise when, not long after his death, I opened his zoology notebook to discover some pencil drawings. By this time I was a professional biologist. It was obvious from certain anatomical details, irregularities of placement of certain invertebrate organs, that the drawings had been made directly from specimens. They were also stunning works of art.

My father had been following a tradition that goes back hundreds of years: A biologist must be observant. The world of nature is complex, and generations of biologists have tried to make sense of this complexity by recording their experiences in drawings. There may be something in the profession that brings out the artist. Art has played an exceedingly strong role in the naturalist tradition. Exquisite botanical drawings dating back hundreds of years had a very practical purpose at the time they were executed—namely, as an aid in identification of medicinal, edible, and poisonous plants. Leeuwenhoek's introduction of the microscope as a valid research tool in biology was accomplished to a major extent by his drawings of things that had simply not been seen before the late 1600s. The same statement, substituting appropriate respective dates and the word *photographs* for *drawings*, could be made about transmission and scanning electron microscopists. George Sutton's watercolors served, whether he intended them to or not, as a window through which the general public saw into the workings of a scientist's mind. His Arctic field sketches and Mexican paintings, exhibited in the university's art museum, drew shoulder-to-shoulder crowds. Louis Agassiz Fuertes, Sutton's mentor, produced paintings of such biological strength and artistic beauty that they remain unsurpassed today. *Audubon* is a household word.

The strongest evidence for the significance of art to a biologist today can be seen in professional journals. A comparison of any dozen biological journals with their counterparts in chemistry, physics, or math will reveal the extent to which biology relies on graphic communication. All scientific publications will have graphs as well as flow diagrams, charts, and tables. But in the biological journals you will find detailed anatomical drawings, graphic depictions of behavior and ecological relationships, and photographs of biological materials. Electron microscopists are especially proud of their work; most are intensely competitive about the quality of photographs that appear under their names. They may be dealing with the intricacies

of subcellular anatomy, but they communicate in the same manner as did Sutton and Fuertes.

The world of life is, above all, the world of objects. Although biology is certainly not devoid of theory, our fundamental interest in organisms always has the greatest influence on our thinking. While we endure abstractions, we prefer to see things that are alive. Failing that, we like to see things that our minds can easily translate into living organisms. More often than not, this desire is manifested as dependence on a picture. The graphic richness of an introductory biology text, in comparison to a text in math or the physical sciences, is further testimony to our reliance on art, in all its forms, as a communication device. So 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 a very real sense, art is a tool. But the full breadth of art—including, for example, abstract expressionism, photo-realism, and historical trends in architecture—is often less accessible to a potential biologist than are physics, chemistry, and math. Somehow the physical sciences seem legitimate adjuncts to a biologist's education, while art tends to fall into that nondescript category of "humanities electives." Furthermore, public schools tend to encourage an early separation of the arts and the sciences. Students who excel in one while struggling in the other will take appropriate refuge. The result is often an early commitment to courses of study, even in the public schools, in which those "interested in science" avoid painting, drawing, and ceramics like some intellectual plague. All this comes home to roost about the time you have to design and produce the plates for your first paper.

Thus the following suggestion is not too far out of line: Study art, fairly seriously. Begin with any good book on cave art and read the modern interpretations—speculations—on what these first naturalists were trying to convey. Note the context in which this art occurs, the evidence that the artists possessed detailed anatomical knowledge, and the values suggested by what is and is not represented. Visit art museums whenever you get the chance. Study the different ways single themes are presented down through the ages, in different media, in different social contexts. Give abstract art an honest try; ask what might have been in the artist's mind when the piece was conceived, how the work might have been modified by environmental forces during its ontogeny. Then budget some time to wonder what a freshman biology student does with "abstractions" such as transcription and translation.

What you will be doing with this activity is addressing the question: In what ways do humans express their perceptions of reality? *Reality* in this case is a complex and often misinterpreted word that includes everything from images out of the depths of the artist's mind to the most seemingly mundane street scenes. The value of this exercise to a biologist is fairly obvious. At some time in your career you will ask: How do I best express the reality of my observations and interpretations, which may range from the depths of cellular processes to the seemingly mundane regulation of group behavior? With any luck, at this point, the investment of time spent in museums will pay off.

9

In the course of this chapter I have tried to comment on the naturalist tradition in biology, the values and worldview that biologists hold, and the tools that allow us to explore a complex and interacting world of organisms. I don't intend to imply that one cannot be a biologist without having attained the values and acquired the tools mentioned. There are professionals, in fact, who might take offense at the suggestion that they are part of a naturalist tradition. Some cell and molecular biologists fall into this category. Similarly field men often treat the pursuits of molecular biologists with disdain. There is little to be gained from such provincialism, except perhaps some short-term benefits that accrue to those who dabble in academic politics.

There is, however, much to be gained from a broad and tolerant view of a chosen field. The most valuable advantage is one analogous to that held by the genetically variable species: In the long term, a catholic approach allows exploitation of numerous opportunities. Biology today is an exceptionally wide field of endeavor, almost as varied as the subject matter that supports it. Try as you might, you will not be able to keep up with all the latest advances and techniques outside your immediate areas of interest. A wide view, however, of what, in your own mind, is legitimate biology will help. Furthermore it will enable you to see applications for your own discoveries that may not be obvious to a more narrowly focused person. The converse is also true; breadth will allow you to see how contributions in other areas can apply to problems that you may not currently be able to solve.

At one time or another, in order to see yourself as a biologist, you will have to make some kind of original observations of nature and meld them into a synthesis of understanding. The increasing diversity of biological subject matter, coupled with growing interconnections between physics, chemistry, math, and the social sciences, provide many opportunities that were never dreamed of a generation ago. It is unlikely that this trend will be reversed. It will, of course, be difficult for you to maintain a generalist's approach to biology, if for no other reason than that modern science puts a premium on the specialist. But an extensive literature on careers and life tracks, ranging from serious investigations to pop psychology or sociology, suggests that if you choose narrow and early specialization, then in later years you will become vulnerable to role extinction. Scientists today are caught in an intellectual paradox: To operate at the professional level they must confine their practice, while the field itself demands that they enlarge their visions. One of your greatest challenges will be to resolve this paradox for yourself. One of the surest ways to meet the challenge is never to lose the naturalist's sense of wonder at the world of organisms.