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Warrior

The day I started work in Dr. Becker's laboratory I felt as if I were setting sail for someplace wonderful. Many things in the lab were new to me: pieces of bone, x-rays, syringes, elaborate microscopes, surgical instruments, and specialized electronic equipment. Something else was new, although I didn't recognize it then. My life had always been completely controlled by others. Whatever distinctions my teachers had made between correct and incorrect, true and false, right and wrong, or important and unimportant, were what I had accepted. That uncritical acceptance had superimposed structure and order on what otherwise would have been for me a chaotic world, but that acceptance had also relieved me of responsibility to think for myself. It had been much the same in industry, where I drew graphs or did calculations as instructed. I had gone to graduate school because I wanted to be free to make decisions, but I had no insight into the responsibility that freedom entailed, or how difficult it was to think rather than let others do it for me.

A biologist named Fred Brown worked in the lab. The first time I saw him he was inside an electrically shielded cage making voltage measurements on a small cube of human bone. Wires connected it to a rack of measuring equipment and a chart-recorder. From time to time the needles on the meters slammed into the stops at the end of their allotted ranges, plainly indicating that he was doing something wrong. I thought to myself that he needed help. Later in the day, as he talked about working at the hospital, he happened to say something about a urine test on a patient. I said, "You mean they analyzed his urine to see if he was sick?" He nodded, so I said, "That's the last place I would think of looking," to which he replied, "That's because you don't know anything about biology."

Dr. Becker didn't tell me to do anything specific so I began reading his published papers in the hope of getting a hint about what to do. In his first publication he had described the similarity between the neuroanatomy of salamanders and the pattern of voltages that he measured on their skin. His next paper had reported on experiments in which he amputated salamanders' limbs and measured the voltage at the amputation sites; there was a big change immediately after he cut off the limb, but the voltage returned to normal as the limbs regrew. For comparison purposes, he had also amputated the limbs of frogs, which don't regenerate their limbs, and found that the pattern of voltage change was quite different from that in the salamander. He had concluded that the nervous system of the salamander somehow regulated limb regeneration, and that the frog didn't regenerate because its nervous system couldn't make the proper electrical signal.

In a paper published in *Science,* he had presented evidence that a flow of electrons in nerves gave rise to the voltage that controlled the regeneration. In a paper in *Nature* he had concluded that the brain was like a battery and the nerves were like wires; some types of nerve cells carried the current away from the brain and other types formed a return path to the brain. In a second paper in *Science,* written with an orthopaedic surgeon at Columbia named Andrew Bassett, he reported that bone emitted electrical signals when it was bent or squeezed. How the signal arose and what its purpose was remained a mystery.

In a book chapter he had described studies by scientists who experimented with the effects of magnetic fields on people and animals, and he concluded that living things could somehow detect magnetic fields. The same year the chapter had appeared he had also published the results of a study of the pattern of admissions to psychiatric hospitals; he found that its monthly changes matched the pattern of changes in the earth's magnetic field, suggesting that the changing field might be associated with psychiatric disorders.

In an article that described what made bone grow, he wrote that bone was made up of millions of microscopic transistors formed by the arrangement of tiny crystals of bone mineral on a protein matrix. When mechanical forces were applied to bone, as in walking, the transistors generated an electrical signal that regulated the activity of bone cells and made them build new bone. Among other things, that explained why prolonged bed rest resulted in osteoporotic deterioration of the skeleton. In another paper, he and Bassett had apparently proved the theory that electricity could make bone grow. They built small battery-powered electric circuits and implanted them in the legs of dogs; after twenty-one days, a large amount of new bone had grown at exactly the point where the electricity exited from the circuit into the tissue.

Dr. Becker's research accomplishments were awesome, and each new publication had added to his stature. He had been awarded research grants by the Veterans Administration and the National Institutes of Health, his work had been featured in national magazines, and he had received the Veterans Administration's highest honor for medical research. He lived in a beautiful house that had a studio where he did oil paintings, and another room where he made sculptures out of pecan wood that he had shipped in from Louisiana. He and his wife had a greenhouse where they grew orchids.

The janitors, electricians, and elevator operators who worked at the hospital idolized Dr. Becker. They often came to his office to talk about their aches and pains. The people in the hospital administration, however, had a quite different attitude. They thought he was too independent, and derisively called him "the cowboy" because of the hat and boots he wore and the pick-up truck he drove.

Soon after I had begun work in the lab I asked him how he got started in research. He told me that when he was in medical school he had wondered why some animals could grow a new limb and others couldn't. "After all," he said, "the limb of a salamander is as anatomically complex as yours or mine. It has the same bones, muscles, and nerves as those in a human being; they're just smaller. It occurred to me that the only thing missing in people might be a special signal that turned on the cells and instructed them to build a new limb. I knew from experiments done in the 1940s and 1950s that nerves were somehow involved in the ability of the salamander to regenerate a limb, but I didn't know how. I decided I would do experiments after I finished my medical training, and that's why I took this job at the Veterans Administration."

"Why here?" I asked.

"The Veterans Administration has a program that funds its doctors to do some research. If it didn't offer this perk nobody would work here because it's a crappy job for a doctor."

I began thinking of Dr. Becker's project as my own. No other kind of work that I knew about even came close to providing the feeling of importance that I got when I pictured myself doing what he was doing. But this identification of my "interest" heightened my angst because I didn't know if I had what it took to come up with ideas, like him. I thought about how awful failure would be, and about how Ensor's advice wouldn't work if I did fail.

I wanted to know what Dr. Becker's formula was, so I asked him, "How did you get the idea that magnetic fields and electricity have anything to do with nerves and bone?"

"The thing that impressed me most," he said, "was that the body knew how to heal itself." He stopped, puffed on his pipe as if he were drawing the story out of its bowl, and continued. "But nobody knew how that happened, and nobody was even studying it. What the biochemists did was cut out tissue, dissolve it, and then study the chemicals it contained. They didn't seem to realize that they had destroyed the organization of the tissue, which was something really important. Human limb regeneration seemed so impossible that everyone considered it unscientific to even discuss the subject. Then, the year I finished my residency the Russians launched Sputnik. Do you remember Sputnik, about 10 years ago?"

"I sure do."

"Well, after Sputnik suddenly there was a lot of money available for science. One of the things the government did was to start translating Russian science journals. One day a truck drove up here and deposited a load of them at our library. I came across an article that described the use of electricity to make tomato plants grow faster. That started me thinking about electricity and life."

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I began smoking a pipe, using Balkan Sobranie No. 3 tobacco, which was Dr. Becker's brand. The laboratory was full of modern equipment, but I really didn't know what kind of research I should pursue, like having a Corvette and no place to go. Dr. Becker taught residents how to do orthopaedic surgery, but he wasn't teaching me how to do bioelectrical research, and I began to recognize that I would have to get the job done by myself.

I didn't know anything about experimenting with animals, but making electrical measurements on bone looked like something I could do. The first bone samples I prepared by myself came from the left tibia of a young woman whose leg Dr. Becker had amputated because of cancer; the bone arrived in the lab in a metal pan covered with a saline-soaked rag. I tried not to think about her as I put the bone in a vise and cut away a few inches that were bulbous and irregular because of the tumor. I passed a rod down the central canal to push out the marrow, and I treated the bone with acetone for a week to dissolve the remaining marrow. I used a chisel to remove the fibrous layer on the outside of the bone and smoothed the surface with sandpaper. I cut off ring-shaped sections about 1/2 inch thick, from which I cut small cubes. They were as white as sawn ivory.

I tried to detect the bone transistors Dr. Becker had written about but I couldn't find any. Then I tried to repeat Bassett's measurements that had shown bone made an electrical signal when it was squeezed, but I had many problems. The results were erratic because it was hard to apply a force to the bone in the exact same way over and over again, and any small differences affected the results. In addition, if the humidity in the room changed, then the signal I measured would change. I just couldn't get the same results that he had published, at least not consistently.

Dr. Becker knew that bone picked up water from the humidity in the air, and he had purchased an apparatus that could measure the dielectric constant of bone which he believed showed how much water was in bone. He asked me to make the measurements; that was one of the few times he ever asked me to do anything.

The apparatus consisted of a variable Wheatstone bridge, a null detector, and an adjustable capacitor that held the bone samples. I built equipment to control the humidity at which the bone was stored and measured. At a particular humidity, each bone sample adsorbed a certain amount of water from the air, and then no more. For a particular sample, the dielectric constant was a maximum after equilibration with 100% humidity, and a minimum after the sample was heated which caused all of its water to evaporate. I could measure how much water was adsorbed at a given humidity by weighing the sample after it stopped picking up water at that humidity, heating the sample, and then weighing it again.

I worked out all the details by myself, and at the end of the project I could draw a graph of dielectric constant versus amount of adsorbed water. The graph started off as a slowly increasing straight line and then it registered an amount of adsorbed water at which the slope of the graph increased steeply. I interpreted the change in slope to mean that there were *two* compartments for water in bone, one consisting of water adsorbed directly onto bone and the second that consisted of water that was adsorbed onto the water that was already in the bone. I got that idea from an article about how salt crystals pick up water from the air.

The values I found for where this transition occurred were different for each bone sample, whether or not it came from the same person. I measured ten bone samples and found that the average transition point was 37.2 milligrams of water per gram of bone, which I took to be the correct value because, like everybody else, I assumed that the average of a set of measurements was always closer to the truth than any of the individual measurements. I truly became a scientist when I realized that assumption was not always valid, but fifteen years would pass before that happened.

When I made the measurements of the water compartments in bone my point of view was entirely conventional in another sense. Once in Trashcan Trischka's class I was measuring the wavelength of an electromagnetic field by the method of locating the nodes of a standing wave produced by current in a wire, and I couldn't get what my text said was the correct value. Then I noticed that the ends of the meter sticks I was using had been worn away, so when I placed them end to end they gave an overall length that was shorter than it should have been. That's the way I thought of a measurement — that there was always just one correct value. It didn't depend on who made the measurement; if there were no people on earth, the wavelength would still have the same value. There was really nothing of me in the result. I didn't write, "I measured the wavelength and I observed that it was X" but rather, "The wavelength was X," as if the measurement had been done by a machine. I thought of the bone measurements the same way, as if there was a "right" answer, and I just assumed that everything in science was like that. The possibility that there could be many different right answers to some scientific questions hadn't dawned on me.

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Dr. Becker bought an electron spin resonance spectrometer because he understood that it could detect electrons, which were key to his bioelectrical theories. Except for the physics department, no one else in Syracuse had such an instrument. It worked by means of microwaves and magnetic fields, and had a built-in oscilloscope and an array of gauges and knobs that reminded me of the cockpit of the lunar excursion module. Dr. Becker was never comfortable operating the spectrometer and one day he turned it over to me. He had been in the middle of some measurements which he asked me to complete. I could hardly believe my luck.

The purpose was to measure the signal from bone and compare it with those from bone mineral and bone collagen. I never knew exactly why, I just did as I was asked. The bone samples had to be in the form of a powder, which I made by scraping bone with a glass slide. I prepared samples of bone mineral by treating the powder with a strong organic solvent that dissolved collagen, which was the protein that formed bone's matrix. The solvent left a yellow residue which I decided to remove by washing the mineral in running tap water for 24 hours. I made samples of bone collagen by treating bone powder with formic acid, which dissolved the mineral. When I examined the samples in the spectrometer, bone and bone collagen gave similar results, but those from the bone mineral were quite different. Dr. Becker published the results in *Nature* and listed me as an author. It was my first paper.

Soon afterwards, I told Dr. Becker that I had an idea about why the signal from bone mineral was so different. If bone really were made up of millions of tiny transistors formed by bonds between mineral and collagen, as he thought, then the organic solvent should have created new surfaces on the mineral at those places where it had previously been bonded to the collagen. Suppose that the electrons responsible for the signal I had measured in the mineral were in atoms that came from the tap water and stuck to the new surface of the bone mineral. That idea could support the transistor theory and *also* explain why we got the signal from bone mineral. Evidence in favor of my idea would be measurements showing that I didn't get the bone-mineral signal when I washed bone powder in tap water and that I did find it when I washed bone collagen. That's what happened. Dr. Becker was happy, and I felt as if I were really helping him. This time I wrote the paper.

The next thing I tried to do was identify what it was in the tap water that contained the electrons, and ultimately I was able to show it was copper. When we published that paper we emphasized how the results had helped us to understand the structure of bone. We downplayed the fact that we had never intended that something from the tap water would stick to the bone mineral, and that we were only trying to get rid of the residue of the solvent.

I published additional papers based on data I got using the spectrometer. But as I continued the work I began to sense that I wasn't going anywhere because the results weren't really summing up to anything. Dr. Becker was satisfied, however, and I was publishing papers in *Nature* which, according to him, was the world's most prestigious journal in experimental biology. I thought that I was doing well, especially considering that I still didn't know anything about biology.

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Andrew Bassett was a handsome man, particularly when he was wearing his white lab coat. His long wavy hair sat perfectly on his head, like a hat. He had sixty scientific publications, each of which was a gossamer web of arguments, data, and citations to the work of others that was so well organized it made his conclusion seem more than plausible, almost necessary. I most admired the fluidity of his transitions; he used many different words and phrases as vehicles to move smoothly from paragraph to paragraph or idea to idea. I began incorporating his transitions into my writing.

He and Dr. Becker were cordial to one another but they disagreed about many things, one of which was the origin of the electrical signal from bone. Bassett said it was piezoelectricity and Dr. Becker said it came from the transistors that he thought were present in bone. I found an article that described a clever way to measure piezoelectricity and I told Dr. Becker I wanted to use it to study bone. He did not receive my suggestion warmly, and when I thought about it I realized why. I was really proposing to look for evidence supporting Bassett's theory, because no possible result from my proposed experiment could support Dr. Becker. The only direct test of his theory would be to make bone that was exactly the same in all respects as normal bone but had no junctions of the type he said formed transistors, which was impossible.

I did the experiment and found that bone was piezoelectric. More than that, it was robustly piezoelectric. One of the hospital residents had been a Peace Corps physician in Chile, and had brought back bones from a burial ground of a civilization that had disappeared more than 800 years ago. Even that bone was piezoelectric. I worried that Dr. Becker might think me disloyal, but he agreed to be a coauthor on the paper.

Bassett and Dr. Becker had worked together on an experiment in which Bassett passed a weak electric current through a solution of collagen in a dish and observed the formation of fibers that precipitated at right angles to the flow of the current. They interpreted the results as evidence that the electrical signal from bone made collagen fibers line up parallel to the axis of the bone so that they could become mineralized to form new bone. The story seemed like a great scientific advance because it connected an electrical property of bone and the effect that applied electricity had on its growth, and when I duplicated the experiment I got the same results. Nevertheless I was troubled because no one knew how the bands formed in the dish. If the responsible process occurred only in dishes and not in the body, then the story would fall apart.

I read about the chemistry of collagen and learned that it would precipitate from solution if the pH was about 8; otherwise it stayed in solution. I measured the pH of the solution in the dish after electricity had been passed through it and I got drastically different results depending on exactly where in the dish I made the measurement. I soon realized that the pH changed from its initial uniform value of about 6.5 because the voltage I had used caused water molecules to break down. Oxygen formed at one electrode and hydrogen at the other. On the hydrogen side the pH became 12 and on the oxygen side dropped to about 2; in between it had intermediary values and where it was 8 was exactly where I saw the bands. I did the experiment many times and the result was always the same. Unfortunately, pH changes just couldn't happen in the body because the fluid environment of bone was so well buffered that any tendency to change pH would immediately be opposed by substances dissolved in the fluid. It was clear to me, therefore, that even though the phenomenon of band formation in dishes was real, it was not evidence in support of how currents promoted bone growth.

I told Dr. Becker what I had found and he suggested that I write and tell Bassett, and invite him to be a coauthor on a paper describing my results and their implications. He said, "We could say 'we previously showed that collagen precipitated from solution in response to the passage of weak currents, and we interpreted the result as support for the theory that stress-generated electrical signals in bone are part of the growth-control system for bone. Further studies, however, have shown etc., etc.' We need a graceful way out."

I did as he asked and Bassett wrote back saying that he wanted to do further experiments before he made a decision regarding my offer. Months went by, and I didn't hear from him. I sent him a second and then a third letter, but received no reply. Finally, I gave up and we published the paper without Bassett.

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Dr. Becker respected Bassett and found it expedient to cooperate with him, but he didn't trust Bassett. I first understood why after he told me a story. "Just after Bassett joined the faculty at Columbia, Bernard Baruch went to the dean and told him about rumors of a doctor somewhere on a mountaintop in Switzerland who had developed a treatment for restoring youth. Konrad Adenauer and Pope Pius XII had received the treatment, and Baruch wanted someone to go to Switzerland and investigate whether it actually worked. The dean picked Andy Bassett and sent him to Switzerland. After he came back I asked him whether the treatment worked. He said he couldn't tell, but that he had told the dean it didn't work. The dean passed on the information to Baruch who wrote a check to Columbia and then promptly departed. I asked Andy why he told the dean the treatment didn't work if he couldn't tell one way or the other. He told me that his career at Columbia would have been over if he had said that he didn't know, or if he had said it worked and Baruch went to Switzerland and got the treatment and then still looked and felt like an old man. On the other hand, Andy said if he told the dean it didn't work, he would be extremely unlikely to send somebody else to make another investigation."

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Dr. Becker thought his ideas would lead to important improvements in science and medicine, and he was pure and selfless regarding these fruits. He never thought in terms of owning the knowledge he produced, or of using it to start a business. But he wanted to be recognized for his contributions, which was something he felt didn't often happen to pioneers. The story that best illustrated his fears was one that he frequently told about a Hungarian physician named Ignaz Semmelweiss. "Semmelweiss worked in a maternity ward in a hospital in Vienna in the 1840s. The death rate from infection in the public ward was almost zero, but there was a high death rate among both the mothers and the babies in the private ward, which was where all the rich people went and where the treatment was supposed to be much better. One day Semmelweiss noticed that the medical students routinely went to the private wards after they had dissected cadavers in the gross anatomy laboratory, and that their visits to the public ward always occurred prior to dissecting the cadavers. It occurred to Semmelweiss that whatever caused the infection was being carried by the students from the anatomy laboratory into the private ward, and he urged that the students be required to wash their hands before they examined the patients. He even did an experiment in which he got some of the medical students to wash their hands, and the infection rate in those beds on the private wards dropped to zero. The experts of the day, however, thought that his suggestion was absurd, and he died in disgrace in an insane asylum." Dr. Becker typically paused at this point and fiddled with his pipe before delivering the point of the story. "Fifteen years after he died, Pasteur discovered that bacteria cause infection."

Perhaps because of his sensitivity regarding the issue of credit, Dr. Becker was always careful to explicitly recognize the importance of specific ideas of others in the development of his theories. In his articles he said that he got the idea about applying electrical currents from experiments with tomato plants by Sinyukhin, the idea about currents in nerves from Zhirmunskii, the idea about the role of nerves in regeneration from Polezhev and Rose and Singer and, most important of all, the idea about the flow of electrons from a Nobel-Prize-winning Hungarian biochemist named Albert Szent-Gyorgyi. Still, Dr. Becker feared that others would not treat him the same way. "They will steal my ideas," he would say, "I know it."

One morning Dr. Becker picked up his copy of *Scientific American* and saw an article entitled "Electrical Effects in Bone," written by Bassett. It described the work they had done together, but Bassett had taken all the credit and never even mentioned Dr. Becker's contribution. "I knew it," Dr. Becker said as he went into his office and slammed the door.

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Paul Dirac came to the physics department to give a lecture. The graduate students jockeyed for seats farthest from the blackboards to minimize the possibility that he might call on one of us. When a speaker introduced Dirac as the Lucasian Professor of Mathematics at Cambridge and said that the position had once been held by Newton, a jolt went through the room. Dirac had divined an equation that predicted the existence of a subatomic particle that no one had ever seen, and then someone saw it. To a physicist, Dirac's achievement was something sublime.

He filled the blackboard with equations about the deepest properties of electrons and atoms. After his lecture someone asked him how he had decided which equations were correct, and he said that "mathematical beauty" was the ultimate criterion. "Suppose the mathematics were ugly," someone asked, "but gave good agreement with experiments?" Without any hesitation Dirac replied, "Just because the results happen to be in agreement with observation does not prove that one's theory is correct." I had a hot flash because I thought the great man had contradicted himself. If truth was beauty, how could physics be objective?

On my way from the lecture hall to the reception where the graduate students would have an opportunity to meet Dirac personally, one of them said to me, "That's physics, Marino, not the crap you do with bone. You are going to wind up like Rachel Carson." I just gave him the finger, and waited for my turn to talk to Dirac. I considered asking him to explain his comment about "truth" and "beauty." I thought it might have something to do with why Hegel didn't like physicists; maybe he thought we were hypocrites.

Finally I was face to face with Dirac.

"Hello sir, I am Andrew Marino."

"What kind of work do you do, Andrew?"

"Well … I … I work with bone."

"And what do you do with bone?"

"I try to understand what makes it grow."

"That's very interesting, Andrew," he said. "Erwin wrote a book about biological matters. Have you read it?"

"No sir, but I will," I said.

When I left the reception I walked down the broad creaky stairway that led to the large wooden front doors of the physics building, exited, turned left and headed back to my lab. A stiff intermittent breeze blew in my face as I thought, Erwin? … Erwin? … Jesus Christ! He must mean Schrodinger!

All the books on quantum mechanics started with something like "The wave equation, which was first formulated by Erwin Schrodinger in 1926, is given in equation 1…", and would then go on to use the equation to calculate energy levels in atoms. I had sweated over those kinds of calculations for three semesters in my courses in quantum mechanics, but I had never thought about the human being who had created "Schrodinger's equation."

There was not much about him in the library. He had gotten the Nobel Prize for his equation but hadn't done much after that, except for a book entitled "What Is Life?" in 1945. The copy in the physics library had been checked out only once, for two days in 1953.

Now, *there* was a question. Equations governed radar and lasers and moon rockets, but what about cells and people? Where were the equations that governed cells? Either the behavior of living things was governed by the laws of physics, or it wasn't. Considering that people behaved in more or less reliable ways, I figured something had to account for that. Was there an equation that could tell you who you should marry or who would make the best President? Was there an equation that governed who would get the flu this year or who would get cancer next year? Was there an equation that could tell you when you will die? Even in principle, was it possible to discover such equations?

I had met a graduate student who believed that God was directly responsible for everything, as if life were a puppet on a string. I saw some merit in her perspective because it dealt with the big picture, not with just a few of the parts like gravity, electricity, and atoms. But science had certain rules, foremost of which was that whatever happened in the world was assumed to happen for earth-based, non-transcendent reasons that could be learned by analyzing observations. So if you claimed what you were doing was science, there were only three possible stories for explaining anything. You could tell everyone exactly how the laws of physics governed the observation, you could argue that the explanation for the observation was latent in the laws and would be found someday, or you could claim that the observation was governed by a law that hadn't yet been discovered. You couldn't say "God did it" because that was simply breaking the rules. There was no *scientific* alternative to the conclusion that laws of some kind somehow govern everything.

Schrodinger couldn't explain life on the basis of the laws of physics and he didn't think that there were undiscovered laws, so the only story open to him was that some super-smart physicist would someday show how life was governed by known laws. I didn't think there was anything wrong with that belief, but it obviously wasn't scientific because there were no observations or analyses that warranted it. It was simply philosophy, which was still another perspective on the world, and from all I knew, the least credible. I saw that the sense in which physics "explained" life was simply not helpful because the "explanation" had no predictive power.

I found much about Rachel Carson in the library. To her, life was a beautiful kind of relationship among plants and animals and people and the air and the water and the land; it was the process by which everything was perpetually renewed. In sad and delicate prose, she said that we were inadvertently destroying nature as a consequence of our use of pesticides, insecticides, and chemical fertilizers. I found a long series of attacks against her by the chemical companies, and by the man who won the Nobel Prize for his work in developing new strains of wheat. He called her work "half-science, half-fiction," and blamed it for "instigating a vicious, hysterical propaganda campaign against the use of agricultural chemicals."

What was the difference between Schrodinger and Carson?

Obviously, one dealt in precise facts, and one didn't.

Wait. Homer, Aeschylus, the Bible, Shakespeare, and Goethe are still read today, and that wouldn't be the case if they didn't tell us something about ourselves, some timeless facts.

Perhaps, but they would be esthetic rather than observational facts.

That makes no sense. Can you imagine someone writing about or understanding anything in the absence of observations?

Science enables us to explain and predict phenomena.

Yes, as do the understandings that we can distill from our great books.

Science is certain.

Not all parts of it. Not biology!

Wouldn't it be wonderful if people like Rachel Carson and Erwin Schrodinger talked to one another about the science of living systems. What is the truth? How will we know it when we see it? Unfortunately, such people didn't talk to one another. I saw that most clearly in a dream. I was sitting across the room from Albert Einstein, who was slumped in his desk chair, holding a pipe. His long white hair was rumpled and pressed backwards so that it framed his face and emphasized his high, lined forehead. The two top lines went from one side to the other, and the lowest was interrupted just above his nose.

"What do you want to talk about, Andrew?"

"About science. I want to know what it is."

"What do you think it is?"

"I don't know. There is the world of equations, where everything happens the way it must happen, and there is the world of bone and blood and nerves, where there are no equations to predict what will happen. It's as if there were different worlds."

A sense of sadness seemed to come over him and he said, "The community of the intellect that once united the world of knowledge seekers is dead. Men of learning have become representatives of narrow traditions, each with their own methods and goals. The sense of an intellectual commonwealth has been lost. Nowadays we are faced with the dismaying fact that there are no exponents of general ideas."

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I earned my Ph.D. in 1968. At my commencement Walter Cronkite said, "There are a lot of things wrong with this world we've made: poverty, ugliness, corruption, intolerance, waste of our resources, pollution of our air and water, urban sprawl, inefficient transportation, outmoded concepts of national sovereignty, the secret society of the establishment elite, the power of the military-industrial complex, the atomic arms race, the population explosion, war." As I listened to him it struck me that science had made all those things possible.

When I had begun studying physics I thought it was mankind's most noble undertaking. Over the years that attitude had faded, like a bright color exposed too long to the sun. The whole enterprise had come to seem elitist, something that benefited only some human beings. When Galileo had studied the earth and the sun he hadn't been trying to make money. When Roentgen had discovered x-rays, he refused to apply for a patent because he believed that the knowledge belonged to all humanity. Einstein was a humble man; self-aggrandizement seemed to be the furthest thing from his mind. There didn't seem to be any men like them, at least that I knew about, except Dr. Becker.

The president of the National Academy of Sciences had said that physicists were an elite corps of disinterested experts who were better than everybody else because of the knowledge they had produced. But that knowledge had also caused great pain. It seemed to me that if you weighed the pluses and minuses, perhaps physicists weren't even as good as everybody else. They argued over and over that knowledge generated by atom-smashers would benefit all humanity – absurd. Meanwhile, detergents fouled the water, insecticides poisoned the land, automobile exhaust created smog, and physicists wouldn't acknowledge the impossibility of continuing to exploit nature with impunity, even though anyone with common sense could see it.

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It was hard to get a job the year I graduated, and those that were available had starting salaries below what I was making in Dr. Becker's lab. He never really asked me to stay, but he never told me to go. I had all the equipment and supplies I needed, and I could do any kind of experiment I wanted. Moreover, he had told me about new experiments that would "revolutionize" regeneration research, and I wanted to be there when the results came in. So I decided to stay in his lab and continue to try to find some kind of research pathway that would be meaningful. I hadn't been able to generate the kind of ideas that he did, but I thought that perhaps if I hung around longer, it would happen. I kept looking for a way to tie into his purpose and help him carry the load.