Dædalus

Journal of the American Academy of Arts & Sciences

Fall 2003

Inside front cover : A scientist eagerly encountering the wonders of modern chemistry : a scene from Thomas Edison's film *Frankenstein* (1910), starring Charles Ogle. "The world was to me a secret I desired to divine," declares Dr. Frankenstein in Mary Shelley's original novel (1818). See Peter Pesic on *The bell & the buzzer : on the meaning of science,* pages 35 – 44. Photograph from the book *Edison's Frankenstein* by Frederick C. Wiebel, Jr., courtesy of the author and The Fort Lee Film Commission.

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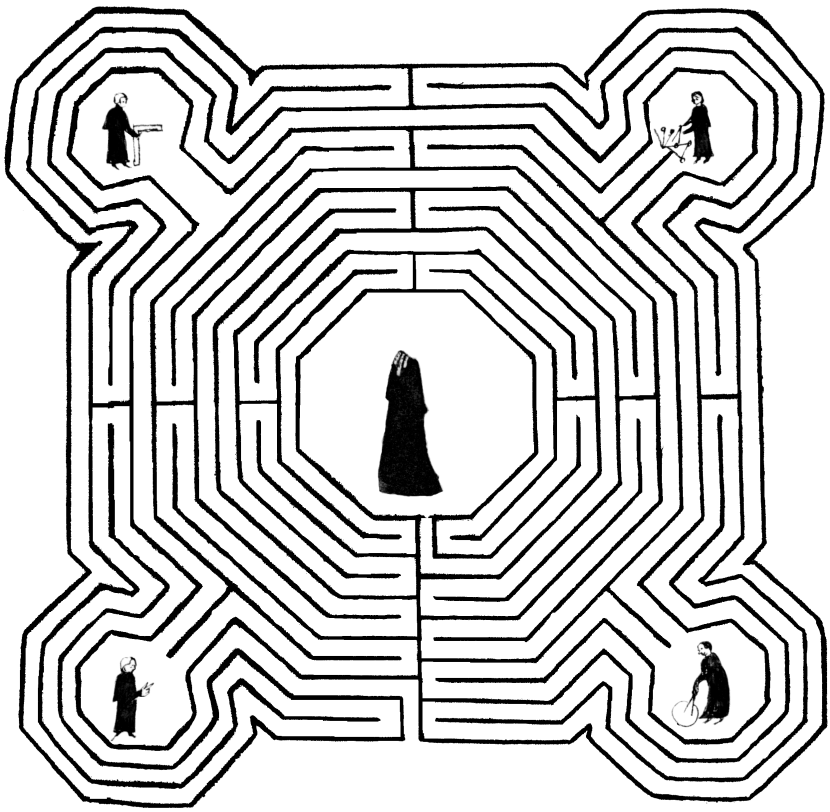

The pavement labyrinth once in the nave of Reims Cathedral (1240), in a drawing, with figures of the architects, by Jacques Cellier (c. 1550 – 1620).

Dædalus was founded in 1955 and established as a quarterly in 1958. The journal's namesake was renowned in ancient Greece as an inventor, scientist, and unriddler of riddles. Its emblem, a maze seen from above, symbolizes the aspiration of its founders to "lift each of us above his cell in the labyrinth of learning in order that he may see the entire structure as if from above, where each separate part loses its comfortable separateness."

The American Academy of Arts & Sciences, like its journal, brings together distinguished individuals from every field of human endeavor. It was chartered in 1780 as a forum "to cultivate every art and science which may tend to advance the interest, honour, dignity, and happiness of a free, independent, and virtuous people." Now in its third century, the Academy, with its more than four thousand elected members, continues to provide intellectual leadership to meet the critical challenges facing our world.

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Alan Lightman

A sense of the mysterious

Ever since I was a young boy, my passions have been divided between science and art. I was fortunate to make a life in both, as a physicist and a novelist, and even to find creative sympathies between the two, but I have had to live with a constant tension in myself and a continual rumbling in my gut.

In childhood, I wrote dozens of poems. I expressed in verse my questions about death, my loneliness, my admiration for a plum-colored sky, my unrequited love for fourteen-year-old girls. Overdue books of poetry and stories littered my second-floor bedroom. Reading, listening, even thinking, I was mesmerized by the sounds and the movement of words. Words could be sudden, like 'jolt,' or slow, like 'meandering.' Words could be sharp or smooth, cool, silvery, prickly to touch, blaring like a trumpet call, fluid, pitter-pattered in rhythm. And, as if by magic, words could create scenes and emotions. When my grandfather died, I buried my grief in writing a poem, which I showed to my grandmother a month later. She cradled my face with her veined hands and said, "It's beautiful," and then began weeping all over again. How could marks on a white sheet of paper contain such power and force?

Between poems, I did scientific experiments. These I conducted in the cramped little laboratory I built out of a storage closet in my house. In my homemade alchemist's den, I horded resistors and capacitors, coils of wire of various thicknesses and grades, batteries, switches, photoelectric cells, magnets, dangerous chemicals that I had secretly ordered from unsuspecting supply stores, test tubes and Petri dishes, lovely glass flasks, Bunsen burners, scales. I delighted in my equipment. I loved to build things. Around the age of thirteen, I built a remote control device that could activate the lights in various rooms of the house, amazing my three younger brothers. With a thermostat, a lightbulb, and a padded cardboard box, I constructed an incubator for the cell cultures in my biology experiments. After seeing the Frankenstein movie, I built a

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spark-generating induction coil, requiring tedious weeks upon weeks of winding a mile's length of wire around an iron core.

In some of my scientific investigations, I had a partner, John, my best high-school friend. John was a year older than I, and as skinny as a strand of number-30-gauge wire. When he thought something ironic, he would let out a high-pitched shrill laugh that sounded like a hyena. John did not share my interest in poetry and the higher arts. For him, all that was a sissyish waste of calories. John was all practicality. John wanted to seize life by the throat and cut straight to the answer.

As it turned out, he was a genius with his hands. Patching together odds and ends from his house, he could build anything from scratch. John never saved the directions that came with new parts, he never drew up detailed schematic diagrams, and his wiring wandered drunkenly around the circuit board, but he had the magic touch, and when he would sit down cross-legged on the floor of his room and begin fiddling, the transistors hummed. His inventions were not pretty, but they worked, often better than mine.

Weekends, John and I would lie around in his room or mine, bored, listening to Bob Dylan records, occasionally thinking of things to excite our imaginations. Most of our friends filled their weekends with the company of girls, who produced plenty of excitement, but John and I were socially inept. So we listened to Dylan and read back issues of *Popular Science*. Lazily, we perused diagrams for building wrought-iron furniture with rivets instead of welded joints, circuits for fluorescent lamps and voice-activated tape recorders, and one-man flying machines made from plastic beach bottles. And we undertook our ritual expedition to Clark and Fay's on Poplar Avenue, the best-stocked supply store in Memphis. There, we squandered whole Saturdays happily adrift in the aisles of copper wire, socket wrenches, diodes, and oddly shaped metallic brackets that we had no immediate use for but purchased anyway. Clark and Fay's was our home away from home. No, more like our temple. At Clark and Fay's, we spoke to each other in whispers.

Our most successful collaboration was a light-borne communication device. The heart of the thing was a mouthpiece made out of a lid of a shoe polish can, with a flat section of a balloon stretched tightly across it. Onto this rubber membrane we attached a tiny piece of silvered glass, which acted as a mirror. A light beam was focused onto the tiny mirror and reflected from it. When a person talked into the mouthpiece, the rubber vibrated. In turn, the tiny mirror quivered, and those quiverings produced shimmerings in the reflected beam, like the shimmerings of sunlight reflected from a trembling sea. Thus, the information in the speaker's voice was precisely encoded onto light, each rise and dip of uttered sound translating itself into a brightening or dimming of light. After its reflection, the fluttering beam of light traveled across John's messy bedroom to our receiver, which was built from largely off-the-shelf stuff: a photocell to convert varying intensities of light into varying intensities of electrical current, an amplifier, and a microphone to convert electrical current into sound. Finally, the original voice was reproduced at the other end. Like any project in which John was involved, our communication device looked like a snarl of spare parts from a junkyard, but the thing worked.

It was with my rocket project that my scientific and artistic proclivities first collided. Ever since the launch of *Sputnik* in October of 1957, around my ninth birthday, I had been entranced with the idea of sending a spacecraft aloft. I imagined the blastoff, the uncoiling plume of smoke, the silvery body of the rocket lit by the sun, the huge acceleration, the beautiful arc of the trajectory in the sky. By the age of fourteen, I was experimenting with my own rocket fuels. A fuel that burned too fast would explode like a bomb; a fuel that burned too slow would smolder like a barbecue grill. What seemed to work best was a mixture of powdered charcoal and zinc, sulfur, and potassium nitrate. For the ignition, I used a flashbulb from a Brownie camera, embedded within the fuel chamber. The sudden heat from the bulb would easily start the combustion, and the bulb could be triggered by thin wires trailing from the tail of the rocket to the battery in my control center, a hundred feet away. The body of the rocket I built from an aluminum tube. The craft had red tail fins. It was beautiful. For a launch pad, I used a V-shaped steel girder, pointed skyward at the appropriate angle and anchored in a wooden Coca-Cola crate filled with concrete.

I invited my awed younger brothers and several friends from the neighborhood to attend the launch, which took place one Sunday at dawn at Ridgeway Golf Course. John, who was not the slightest romantic and didn't see anything useful about rockets, elected to stay in his bed and sleep. But even so, I had a good audience.

Because I had estimated from thrust and weight calculations that my rocket might ascend a half mile into space, some of the boys brought binoculars. From my control center, I called out the countdown. I closed the switch. Ignition. With a flash and a whoosh, the rocket shot from its pad. But after rising only a few hundred feet, it did a sickening swerve, spun out of control, and crashed. The fins had come off. With sudden clarity, I remembered that instead of riveting the fins to the rocket body as I should have, I had glued them on. To my eye, the rivets had been far too ugly. How I thought that mere glue would hold under the heat and aerodynamic force, I don't know. Evidently I had sacrificed reality for aesthetics. John would have been horrified.

Later I learned that I was not the first scientist for whom beauty had ultimately succumbed to reality. Aristotle famously proposed that as the heavens revolve about the Earth, the planets move in circles. Circles because the circle is the simplest and most perfect shape. Even when astronomers discovered that the planets changed in brightness during their orbits, showing that they couldn't remain a constant distance from Earth, scientists remained so enthralled with the circle that they decided the planets must move in little circles attached to big circles. The circle idea was lovely and appealing. But it was proved wrong by the careful observations of Brahe and Kepler in the late sixteenth and early seventeenth centuries. Planets orbit in ellipses, not circles. Equally beautiful was the idea, dating from the 1930s, that all phenomena of nature should be completely identical if right-hand and left-hand are reversed, as if reflected in a mirror. This elegant idea, called parity conservation, was proved wrong in the late 1950s by the experiments proposed by Lee and Yang, showing that some subatomic particles and reactions do not have identical mirror-image twins. Contrary to all expectations, right- and left-handedness are not equal.

When my scientific projects went awry, I could always find certain fulfillment in mathematics. I loved mathematics just as I loved science and poetry. When my math teachers assigned homework, most other students groaned and complained, but I relished the job. I would save my math problems for last, right before bedtime, like bites of chocolate cake awaiting me after a long and dutiful meal of history and Latin. Then I would devour my cake. In geometry, I loved drawing the diagrams, I loved finding the inexorable and irrefutable relations between lines, angles, and curves. In algebra, I loved the idea of abstraction, letting Xs and Ys stand for the number of nickels in a jar or the height of a building in the distance. And then solving a set of connected equations, one logical step after another. I loved the shining purity of mathematics, the logic, the precision. I loved the certainty. With mathematics, you were guaranteed an answer as clean and crisp as a new twenty-dollar bill. And when you had found that answer, you were right, unquestionably right. The area of a circle is πr^2. Period.

Mathematics contrasted strongly with the ambiguities and contradictions of people. The world of people had no certainty or logic. People confused me. My mother sometimes said cruel things to me and my brothers, even though I felt that she loved us. My aunt Jean continued to drive recklessly and at great speed, even though everyone told her that she would kill herself in an automobile. My uncle Edwin asked me to do a mathematical calculation that would help him run the family business with more efficiency, but when I showed him the result he brushed it aside with disdain. Blanche, the dear woman who worked forever for our family, deserted her husband after he abused her and then talked about him with affection for years. How does one make sense out of such actions and words?

A long time later, after I became a novelist, I realized that the ambiguities and complexities of the human mind are what give fiction and perhaps all art their power. A good novel gets under our skin, provokes us and haunts us long after the first reading, because we never fully understand the characters. We sweep through the narrative over and over again, searching for meaning. Good characters must retain a certain mystery and unfathomable depth, even for the author. Once we see to the bottom of their hearts, the novel is dead for us.

Eventually, I learned to appreciate both certainty and uncertainty. Both are necessary in the world. Both are part of being human.

In college, I made two important decisions about my career. First, I would put my writing on the back burner until I became well established in science. I knew of a few scientists who later became writers, like C. P. Snow and Rachel Carson, but no writers who later in life became scientists. For some reason, science – at least the creative, research side of science – is a young person's game. In my own field, physics, I found that the average age at which Nobel Prize winners did their prize-winning work was only thirty-six. Perhaps it has something to do with the focus and isolation of the subject. A handiness for visualizing in six dimensions or for abstracting the motion of a pendulum favors an agility of mind but apparently has little to do with anything else. By contrast, the arts and humanities require experience with life and the awkward contradictions of people – experience that accumulates and deepens with age.

Second, I realized that I was better suited to be a theorist than an experimentalist. Although I loved to build things, I simply did not have the hands-on dexterity and practical talents of the best students. My junior-year electronics project caught fire when I plugged it in. My senior thesis project, a gorgeous apparatus of brass fittings and mylar windows designed to measure the half-life of certain radioactive atoms, was sidelined on the lab bench instead of being installed in the cyclotron for a real experiment. I never did believe the thing would actually work. And apparently neither did my professor, who kindly gave me high marks for my endless drawings of top views and side views and calculations of solid angles and efficiencies. By graduation, I knew that I was destined to be a theorist, a scientist who worked with abstractions about the physical world, ideas, mathematics. My equipment would be paper and pencil.

A year or two later, I had my first true experience with original research. It was an experience that I can compare only to my first love affair. At the time, I was twenty-two years old, a graduate student in physics at the California Institute of Technology. My thesis advisor at Caltech was Kip Thorne, only thirty himself but already a full professor. Kip had grown up in Mormon Utah but had completely acclimatized to the hip zone of California in the early 1970s. He sported long red hair, starting to thin, a red beard, sandals, loose kaftan-like shirts splotched with colors, sometimes a gold chain around his neck. Freckled, lean-limbed, wiry. And brilliant. His specialty was the study of general relativity, Einstein's theory of gravity. In fact, there was at this time a renaissance of interest in Einstein's arcane theory because astronomers had recently discovered new objects in space, such as neutron stars, that had enormous gravity and would require general relativity for a proper understanding.

One of Kip's programs was to compare general relativity to other modern theories of gravity. And it was in that program that he assigned me my first research problem. I was supposed to show, by mathematical calculation, whether a particular experimental result required that gravity be geometrical. The known experimental result was that all objects fall under gravity with the same acceleration. Drop a book and a cannonball from the same height and they will hit the floor at the same time, if air resistance is small. By 'geometrical,' Kip meant that gravity could be described completely as a warping of space. In such a picture, a mass like the sun acts as if it were a heavy weight sitting on a stretched rubber sheet, and orbiting planets follow along the sagging surface of the sheet. In the early 1970s, some modern theories of gravity, such as Einstein's general relativity, were geometrical. Some were not. To be 'geometrical,' to be equivalent to a bending of space, a theory had to have a particular mathematical form. So my project amounted to writing down on a piece of paper the equations representing a giant umbrella theory of gravity, a theory of theories that encompassed many different possible theories, next imposing the restriction that all objects fall with the same acceleration, and then finding out whether that restriction were sufficiently powerful to rule out all nongeometrical theories.

I was both thrilled and terrified by my assignment. Until this point of my academic life, my theoretical adventures had consisted mainly of solving homework problems. With homework problems, the answer was known. If you couldn't solve the problem yourself, you could look up the answer in the back of the book or ask a smarter student for help. But this research problem with gravity was different. The answer wasn't known. And even though I understood that my problem was inconsequential in the grand sweep of science, it was still original research. No one would know the answer until I found it. Or failed to find it.

After an initial period of study and work, I succeeded in writing down all the equations I thought relevant. Then I hit a wall. I knew something was amiss, because a simple result at an early stage of the calculation was not coming out right. But I could not find my error. And I didn't even know what kind of error. Perhaps one of the equations was wrong. Or maybe the equations were right but I was making a silly arithmetic mistake. Or perhaps the conjecture was false but would require an especially devious counterexample to disprove it. Day after day, I checked each equation, I paced back and forth in my little windowless office, but I didn't know what I was doing wrong. This confusion and failure went on for months. For months, I ate, drank, and slept my research problem. I began keeping cans of tuna fish in the lower drawer of my desk and eating meals in my office.

Then one morning, I remember that it was a Sunday morning, I woke up about 5 A.M. and couldn't sleep. I felt terribly excited. Something strange was happening in my mind. I was thinking about my research problem, and I was seeing deeply into it. I was seeing it in ways I never had before. The physical sensation was that my head was lifting off my shoulders. I felt weightless. And I had absolutely no sense of my self. It was an experience completely without ego, without any thought about consequences or approval or fame. I didn't know who I was or where I was. I was simply spirit, in a state of pure exhilaration.

The best analogy I've been able to find for that intense feeling of the creative moment is sailing a round-bottomed boat in strong wind. Normally, the hull stays down in the water, with the frictional drag greatly limiting the speed of the boat. But in high wind, every once in a while the hull lifts out of the water and the drag goes instantly to near zero. It feels like a great hand has suddenly grabbed hold and flung you across the surface like a skimming stone. It's called planing.

So I woke up at five to find myself planing. Although I had no sense of my ego, I did have a feeling of rightness. I had a strong sensation of seeing deeply into this problem and understanding it and knowing that I was right – a certain kind of inevitability. With these sensations surging through me, I tiptoed out of my bedroom, almost reverently, afraid to disturb whatever strange magic was going on in my head, and I went to the kitchen. There, I sat down at my ramshackle table. I got out the pages of my calculations, by now curling and stained. A tiny bit of daylight was starting to seep through the window. Although I was oblivious to myself, my body, and everything around me, the fact is that I was completely alone. I don't think any other person in the world would have been able to help me at that moment. And I didn't want any help. I had all of these sensations and revelations going on in my head, and being alone with all that was an essential part of it.

Somehow, I had reconceptualized the project, spotting my error of thinking, and began anew. I'm not sure how this rethinking happened, but it wasn't by going from one equation to the next. After a while at the kitchen table, I solved my research problem. I had proved that the conjecture was true. The equal acceleration of the book and the cannonball does indeed require that gravity be geometrical. I strode out of the kitchen, feeling stunned and powerful. Suddenly I heard a noise and looked up at the clock on the wall and saw that it was two o'clock in the afternoon.

I was to experience this creative moment again, with other scientific projects. But this was my first time. As a novelist, I've experienced the same sensation. I've read the accounts of other writers, musicians, and actors, and I think the sensation and process are almost identical in all creative activities. The pattern seems universal: The study and hard work. The prepared mind. The being stuck. The sudden shift. The letting go of control. The letting go of self.

I learned many things about science from Kip. One of the most important was the concept of the 'well-posed problem.' A well-posed problem is a problem that can be stated with enough clarity and definiteness that it is guaranteed a solution. Such a solution might require ten years, or a hundred, but there should be a definite solution. Such a solution may be arrived at by a variety of different approaches – such as Schrödinger's wave equation versus Heisenberg's matrix formulation of quantum mechanics – and these different expressions may involve very different mental pictures and interpretations and even psychological force. But they are mathematically and logically equivalent, and they all lead to the same numerical answers. They are all tools in the service of the well-posed problem. While it is true that science is constantly revising itself to respond to new information and ideas, at any moment in time scientists are working on well-posed problems.

I often think of Kip's idea of the well-posed problem as closely related to Karl Popper's notion of what makes a scientific proposition. According to Popper, who was an important early-twentieth-century British philosopher of science, a scientific proposition is a statement that can in principle be proved false. Unlike with mathematics, which exists completely within its own world of logical abstraction, you can never prove a scientific proposition or theory true because you can never be sure that tomorrow you might not find a counterexample in nature. Scientific theories are just simplified models of nature. Such a model might be mathematically correct but its beginning premises may not be in sufficient accord with physical reality. But you can certainly prove any scientific theory false. You can find a counterexample, an experiment that disagrees with the theory. And, according to Popper, unless you can at least *imagine* an experiment that might falsify the theory, that theory or statement is not scientific.

In direct and indirect ways, Kip emphasized to his students that we should not waste time on problems that weren't well posed. I have since come to understand that there are many interesting problems that are not well posed in the Popper or Thorne sense. For example: Does God exist? Or, What is love? Or, Would we be happier if we lived a thousand years? These questions are terribly interesting, but they lie outside the domain of science. Never will a physics student receive his or her degree working on such a question. One cannot falsify the statement that God exists (or doesn't exist). One cannot falsify the statement that we would be happier (or not happier) if we lived longer. Yet these are still fascinating questions, questions that provoke us and bring forth all kinds of creative thought and invention. For many artists and humanists, the question is more important than the answer. One of my favorite passages from Rilke's *Letters to a Young Poet*: "We should try to love the questions themselves, like locked rooms and like books that are written in a very foreign tongue." Science is powerful, but it has limitations. Just as the world needs both certainty and uncertainty, the world needs questions with answers and questions without answers.

Another thing I learned from Kip, more a matter of personal style, was generosity. Kip bent over backwards to give credit first to his students. He would put his name last on joint papers, he would heap praise on his students at public lectures. Kip was well aware of his strengths, but he was modest at the same time, and he was deeply generous in his heart. I believe that he inherited these virtues from his own thesis advisor at Princeton, John Wheeler. Wheeler, in turn, absorbed much of his personal style from his mentor, the great atomic physicist Niels Bohr in Copenhagen. In a sense, I was a great-grandstudent of Bohr.

Three Caltech professors served on my thesis committee, charged with examining me at my final thesis defense. Richard Feynman was one of the three. For some years, Feynman had taken an interest in Kip's students and, every couple of months, would go to lunch with us and pepper us with questions about the latest findings in gravitational waves or black holes or some other topic in general relativity. At my thesis defense, I stood at a blackboard in a small room while these guys sat comfortably and asked me questions. Feynman asked the first two questions. His first question was rather easy, and I answered it without too much trouble. His second question was just a little beyond my reach. I struggled with it, I went sideways and backwards, I circled around. Finally, after about twenty minutes of fumbling at the blackboard, I managed an answer. Feynman asked no more questions. Later, I realized that with his two questions he had precisely bracketed my ability. He had launched two artillery shells at me, one falling short, one long, and he knew exactly where I was in the intellectual landscape of physics.

I vividly remember a scene from sometime in 1975. It takes place during my two years as a postdoctoral fellow at Cornell. I am sitting on a couch in Edwin Salpeter's house. Ed, suffering from one of his recurring back problems, lies on the floor. From that low vantage, he is helping me think through a problem involving stars being ripped apart and consumed by a giant black hole. It is a theoretical problem of course.

At this time, Ed would have been about fifty years old. He was widely regarded as one of the two or three greatest theoretical astrophysicists in the world. His most famous work, done in the 1950s, involved the theoretical recipe for how helium atoms in stars can combine to make carbon and then heavier elements beyond that. It is believed that all of the chemical elements in the universe heavier than the two lightest, hydrogen and helium, were forged at the centers of stars. Ed and his colleagues showed how that process was possible. Among some of his other accomplishments, he calculated how many stars should be created in each range of mass – a sort of birth weight chart for newborn stars.

When I first arrived at Cornell, in the fall of 1974, Ed immediately dragged me out to the tennis court to find out what I was made of. I was a fair tennis player myself. After a number of exhausting matches over the season, we were approximately tied, but Ed could not refrain from quietly gloating whenever he beat me. And I could see that same gentlemanly but competitive edge in his science. He didn't like to lose.

On and off the tennis court, Ed dressed in tattered short-sleeve sports shirts. These, combined with his loafers and stylishly long hair and faint Austrian accent, gave him an air of casual elegance. But Ed was enormously serious about his physics. When he was talking about a physics problem, he would sometimes stop, turn his head, and just stare off into space for a few moments, and you knew that he was delving into deeper layers of thought.

What I found most brilliant about Ed was his physical intuition. He could visualize a physical problem and almost feel his way to the core of it, all in his head. This ability arose from his vast knowledge of physics and astronomy and his talent for making analogies from one subject to another. Many of the greatest scientists have had this talent for analogies. Planck compared the inside surface of a container to a collection of springs with different oscillation frequencies. Bohr compared the nucleus of an atom to a drop of liquid.

So we're in Ed's living room, me on the couch, Ed on his back on the floor, some kind of classical music floating in from the next room, and Ed draws an analogy between stars being swallowed by the big black hole and a drunk wandering on a street with an uncovered sewer hole. If a star comes too close to the black hole it will be destroyed, just as if the drunk stumbles to the sewer hole he will fall in. Each star, in each orbit around the central black hole, is given a random jostle by the gravity of the other stars, just as the drunk takes a random step every minute. Such random steps can lead a star, or a drunk, to fall into the hole. The star bumps about in two-dimensional 'angular-momentum space,' just as the drunk wanders around on a two-dimensional street. The critical question, Ed announces from the floor, is whether each random step of the drunk is bigger or smaller than the diameter of the hole. With this insight, I and the other postdoctoral fellow collaborating with me on the problem can now work out the details. The result will be a prediction for the Hubble Space Telescope, more than a decade away. Ed asks if I would please bring him a cup of tea. He has other things to think about this morning.

Some months later, I had a severe emotional upheaval with a different scientific project. I was working on the arrangement of stars in a globular cluster. A globular cluster is a congregation of about a hundred thousand stars, all orbiting each other under their mutual gravitational attraction. There are about a hundred globular clusters in our galaxy. Through the telescope, a globular cluster appears as a beautiful, shining ball of light. Imagine: a hundred thousand stars all concentrated together in a tight ball, whizzing about like angry bees in a bees' nest.

Since about 1970, astrophysicists had begun to simulate the structure and evolution of globular clusters on a computer. You feed the computer the initial position of a lot of points, each representing a star or group of stars, you put in the effects of gravity, each point gravitationally attracting all the others, and you let the computer tell you what happens in time. In a sense, the computer is doing an experiment for you. Each minute of computer time might represent a million years for the globular cluster. One of the findings of these 'experiments' was that the simulated globular clusters begin collapsing. The inner stars lose energy and move closer to the center, while the outer stars gain energy and move farther from the center. For extra gratification, there were even observations of actual globular clusters in space, observations suggesting that some globular clusters may indeed have undergone such collapse.

Many of the computer simulations had been done with the simplification that all stars have the same mass. I wanted to investigate what happens under the more realistic assumption that there is a range of masses of stars. But instead of doing a computer simulation, which is extremely time-consuming to set up and costly to run, I found an approximate way to attack the problem using only pencil and paper. As I suspected, having a range of masses of stars made the cluster collapse even sooner and faster.

While in the final stages of writing up my results for publication, I strolled into the astronomy library to complete my list of references to previous work. And there, to my horror, I discovered a brand new issue of *Astrophysics and Space Science* in which two Japanese scientists had solved the same problem. With my pulse racing, I checked their results against mine. Our figures and graphs agreed to within three decimal places. I had been scooped! Of course, most people get scooped at various times of their lives if they're working on anything at all interesting. But this was the first time for me.

I experienced a complex set of reactions. I was embarrassed. I was humiliated. I grieved the loss of several months of my time. I worried whether the wasted effort would compromise my chances for an assistant professorship. But then, another emotion began working its way through my body. Amazement. I was utterly amazed that people on the other side of the planet, with no correspondence between us, no comparing of notes, had decided to solve the same problem and had gotten the same answer to three decimal places. There was something wonderful and thrilling about that. Here was powerful evidence of a thing – part science, part mathematics – that exists outside of our own heads. Presumably, Martians would have also gotten the same answer to three decimal places. There was a terrible precision in the world.

After this feeling of awe at the terrible precision and exactness of the world, I began to experience another emotion: irrelevancy. If the physical universe is reducible to precise equations with precise answers to three decimal places (and more), then why was I, as a particular person, needed to find those answers? For the globular cluster problem with multiple masses, Saito and Yoshizawa had found the answer before me. If neither they nor I had found the answer, then in another month or another year somebody else would have found the answer. Another scientist might have used a different formulation of the problem, or described his or her results with different language, but the answer would have been the same. It seems to me that science is not the best occupation for a person who wants to make a mark as an individual, accomplishing something only that individual can do. In science, it is the final measured number or the final equation that matters most. If Heisenberg and Schrödinger hadn't formulated quantum mechanics, then someone else would have. If Einstein hadn't formulated relativity, then someone else would. If Watson and Crick hadn't discovered the double-helical structure of DNA, then someone else would. Science brims with colorful personalities, but the most important thing about a scientific result is not the scientist who found it but the result itself. Because that result is universal. In a sense, that result already exists. It is found by the scientist. For me, this impersonal, disembodied character of science is both its great strength and its great weakness.

I couldn't help comparing the situation to my other passion, the arts. In the arts, individual expression is everything. You can separate Einstein from the equations of relativity, but you cannot separate Beethoven from the *Moonlight Sonata*. No one will ever write the *The Tempest* except Shakespeare or *The Trial* except Kafka.

I loved the grandeur, the power, the beauty, the logic, and the precision of science, but I also ached to express something of myself, my individuality, the particular way that I saw the world, my unique way of being. On that day in the Cornell library as I feverishly turned the pages of *Astrophysics and Space Science*, I learned something about science, and I also learned something about myself. I would continue following my passion for science, but I could no longer suppress my passion for writing.

Finally, in the early 1980s, I began writing essays. For some years I had been publishing poems in small literary magazines. The essay gave me the greater flexibility I wanted. With an essay, I could be informative, poetic, philosophical, personal. And, at a time when most of my self-identity and confidence were still based on my achievements as a scientist, with the essay I could connect my scientific and artistic interests. I would come home in the evening, elated from a day of research at the Harvard-Smithsonian Center for Astrophysics, and ponder an essay.

One of my first essays concerned Joseph Weber, a distinguished professor of physics at the University of Maryland. Weber had pioneered the first gravitational wave detectors. And he had become somewhat of an outcast in the scientific community because he claimed to see gravitational waves when no one else could.

When you shake an electrical charge, it emits waves of electricity and magnetism that travel through space at the speed of light. Likewise, Einstein's general relativity predicted that when you shake a mass of any kind, whether electrically charged or not, it emits gravitational waves, waves of oscillating gravity that travel through space at the speed of light. Hypothetically, the strongest sources of such waves would be cataclysmic cosmic events, like the collision of black holes in space.

How does one observe a gravitational wave? When a gravitational wave strikes a mass, it causes that mass to expand and contract like a working billows pump. Gravitational waves, however, are fantastically weaker than electromagnetic waves. A typical expansion or contraction expected for a cosmic gravitational wave might be one part in 10^{21} or smaller, corresponding to a thousand-mile-long ruler changing its length by the width of a single atomic nucleus. Consequently, while a high-school student can build a crystal radio set to detect electromagnetic waves, gravitational waves require extraordinarily sensitive equipment to measure them.

In 1960, when no one else was dreaming of detecting gravitational waves, Weber conceived of the idea of a resonant cylinder, a metallic cylinder that would ring like a bell (but an extremely soft bell) when struck by a gravitational wave. One of the problems of building such a resonant cylinder, or any detector, is that it is always expanding and contracting a little bit from tiny random disturbances, such as a truck turning a corner a half a mile away. It is extremely difficult to discriminate such noise from the minuscule motions expected from a gravitational wave. So you build two cylinders, thousands of miles apart, and monitor them closely. If both of them begin softly ringing in precisely the same way at the same time, then perhaps they've just been struck by a gravitational wave.

In the early 1960s, Weber began building such cylinders, the first one located at the University of Maryland near Washington, D.C., the second at Argonne National Laboratory near Chicago. Each cylinder had a length of five feet, a diameter of about two feet, and a weight of about three thousand pounds. In 1968, not long after the completion of his second cylinder, Weber began reporting the observation of simultaneous oscillations of his two cylinders. He claimed to have discovered the first gravitational waves.

In the following decade, other groups of scientists attempted to duplicate Weber's results. They built their own cylinders, hooked them up to their own piezoelectric crystals to measure minute oscillations, compared their own charts of the oscillations in time. No one saw oscillations of the magnitude claimed by Weber, and no one saw simultaneous oscillations of their cylinders except what would be expected by chance. In fact, other detectors were built with a hundred times more sensitivity than Weber's, and they failed to find gravitational waves.

Weber published his results. Other scientists published theirs. Weber dismissed the negative findings of other scientists. Experimental physicists studied Weber's results and said he was making mistakes. Perhaps the tape recorders he used to combine the data from the two cylinders were themselves accidentally injecting simultaneous signals. Or perhaps small magnetic fluctuations in electric power lines or lightning bolts could mimic gravitational waves. Weber held his ground. Theorists got into the act. They calculated the amount of expansion and contraction that would be expected from realistic sources of gravitational waves in space. According to these calculations, Weber's resonant cylinders were not remotely sensitive enough to detect gravitational waves, even if such waves did indeed exist. A few theorists proposed the possibility of exotic mechanisms to generate gravitational waves with enormous power, and these proposals confused the discussion. Weber passionately held his ground. In telephone conversations, in personal visits, at scientific conferences, he got into scathing arguments. He lost friends and colleagues. Yet, in the face of a mountain of contradictory evidence, he continued to maintain that he was measuring gravitational waves. Clearly, Weber was not behaving in the traditions of science. Joseph Weber was allowing his personal investment to interfere with good judgment.

Then I, a greenhorn essayist, leaped into the fray. I wrote an essay about emotional prejudice in scientists for the magazine *Science 83*. The title: "Nothing but the Truth." In this essay, I ridiculed several scientists, including Weber. I cringe when I reread it. With self-righteous flourish, I wrote that "The white-haired Weber has become something of a tragic figure in the scientific community, continuing to declare his rightness in the face of incontrovertible evidence."

A few months after the essay was published, I found myself ten feet from Weber at a scientific conference. Some unsuspecting colleague introduced us. Weber's face immediately turned purple, he snarled something at me, and he stomped away.

Later, I decided that I deserved his contempt, and I hated myself for what I had written. Because Joseph Weber was really a hero. Yes, he was almost certainly sloppy in his experiment. And he should have graciously accepted the opposing results of other scientists. But he had imagined the first gravitational wave detector, he had built the first gravitational wave detector, and his insights about gravitational wave detectors had created the field. Today, the most advanced gravitational wave detector in the world, the Laser Interferometer Gravitational Wave Observatory (LIGO), has just recently begun operations. If LIGO does not detect the first gravitational wave, then its upgraded version probably will. LIGO would not exist without Weber's seminal work.

And it is quite possible that Weber would not have accomplished that work without his emotional prejudice and passion. In the book *Personal Knowledge*, the chemist Michael Polanyi argues that such personal passion is vital to the advance of science. I agree. Without a powerful emotional commitment, scientists could not summon up the enormous energy needed for pursuing an idea for years, working day and night in the lab or at their desks doing calculations, often sacrificing the rest of their lives. It is little wonder that such a personal commitment sometimes causes the scientist to defend his or her beliefs regardless of facts.

Even extraordinary physicists such as Einstein and Planck have defended their prejudices in the face of opposing evidence. Soon after Einstein published his theory of special relativity in 1905, a German experimental physicist named Walter Kaufmann repeated a crucial experiment to measure the mass of electrons moving at high speed. According to Einstein's theory, the mass of a moving particle should increase with speed in a particular way. A competing theory by Max Abraham, a colleague of Kaufmann's at Göttingen University, proposed a different formula for the increase in mass. Kaufmann's experimental results were closer to Abraham's predictions than to Einstein's. Over the next year, the great Max Planck, father of the quantum, carefully studied Kaufmann's experiment but could find no flaw. Nevertheless, Planck threw his support behind Einstein's theory.

Einstein himself, in a review article in 1907, said he could see nothing wrong with Kaufmann's experiments and agreed that they fit Abraham's theory better than his. Yet, he continued, "In my opinion other theories [theories other than his own] have a rather small probability because their fundamental assumptions concerning the mass of the moving electrons are not explainable in terms of theoretical systems which embrace a greater complex of phenomena." Here and elsewhere, Einstein clearly preferred his prejudice for comprehensive theoretical systems over actual experimental data. And data do sometimes change. A few years later, the experiments of Kaufmann were proved to be in error, and Einstein was vindicated. In future years, however, his prejudices sometimes led him astray. For decades, Einstein was personally committed to his nonquantum unified theory that combined gravity and electromagnetism. In a letter to his friend Paul Ehrenfest in 1929, Einstein wrote, "[My] latest results are so beautiful that I have every confidence in having found the natural field equations of such a variety." This time, Einstein turned out to be wrong. But that is not the point. When right and when wrong, Einstein's passion, his aesthetic and philosophical prejudices, and his personal commitment were probably essential to his scientific creativity.

All of which led me to question the meaning of 'the scientific method.' Since high school, I had been taught that scientists must wear sterile gloves at all times and remain detached from their work, that the distinguishing feature of science is the much vaunted scientific method, whereby hypotheses and theories are objectively tested against experiments. If the theory is contradicted by experiments, then it must be revised or discarded. If one experiment is contradicted by many other experiments, then it must be critically examined. Such an objective procedure would seem to leave little room for personal prejudice.

I have since come to understand that the situation is more complex. The scientific method does not derive from the actions and behavior of *individual* scientists. Individual scientists are not emotionally detached from their research. Rather, the scientific method draws its strength from the *community* of scientists, who are always eager to criticize and test each other's work. Every week there are many journal articles, conferences, and informal gatherings at the blackboard in which scientists analyze the latest ideas and results from all over the world. It is through this collective activity that objectivity emerges.

So how could I reconcile the Popperian view of science, with its unbudging demand for objective experimental tests, against the Polanyian view, with its emphasis on the personal commitments and passions of individual scientists? The answer, perhaps obvious but at first shocking to a young scientist, is that one must distinguish between science and the practice of science. Science is an ideal, a conception of logical laws acting in the world and a set of tools for discovering those laws. By contrast, the practice of science is a human affair, complicated by all the bedraggled but marvelous psychology that makes us human.

About the time of my ill-considered essay on Joseph Weber, I had a most beautiful experience with scientific discovery, perhaps the most beautiful of my life. I was studying the effects of particle creation in high-temperature gases. According to Einstein's famous formula, $E = mc^2$, energy can be created from matter and matter can be created from energy. The phenomenon has been observed in the lab. It should also occur in space. Whenever the temperature of a gas is high enough, as should happen in strong gravity, then some of that thermal energy can be transformed into electrons and their antiparticles, the positrons. In turn, the creation of those particles will act back on the properties and emitted radiation of the gas. Thus, a good theoretical understanding of the nature of such a 'relativistic thermal plasma' would be interesting not only in its own right, but also as a diagnostic for interpreting the gamma rays and X-rays observed from high-energy objects in space.

This research problem had been suggested to me by Martin Rees of the Institute of Astronomy in England. I first met Martin during a visit to his institute in the summer of 1974, just after receiving my Ph.D. Martin was only thirty-two at the time. In the world of astrophysics, he was already a natural phenomenon. Among his many accomplishments, he was one of the first to point out that the distribution of quasars in space was inconsistent with the steady-state theory of cosmology, thus lending support to the big bang theory. He has made major contributions to the astrophysics of black holes, the theory of galaxy formation, the origin of the cosmic background radiation, and many other topics. In fact, there has been practically no area of modern astronomy and cosmology that has not benefited from Martin Rees's imagination. Martin is always erupting with new ideas, and he freely shares these without seeking acknowledgment or credit. Many of the nearly illegible letters I received from him during the middle and late 1970s, when we were working on similar problems, would begin, "Thank you Alan for your very interesting preprint on X. I agree almost entirely with you, except for one or two small points." And then he would go on to elaborate on a number of important and often critical effects that I had missed in my investigation.

Many a pleasant summer I spent enjoying the unhurried pace and intimacy of Cambridge, England, walking through the luxurious gardens of the colleges and bicycling up Madingley Road to the Institute of Astronomy. At that time, it was a modest one-story building bordered by a wooden fence and a cow pasture. In the 1970s and 1980s, nearly everyone in the world worth their salt in astrophysics visited that building – to quietly work, to gather for British tea at four in the afternoon, and to catch ideas thrown out by the youthful but silver-haired Martin Rees, Plumian Professor of Astronomy and Experimental Philosophy. (In the 1990s, Martin became Sir Martin and was further elevated to Astronomer Royal of England.)

Sometime around 1980, Martin suggested the importance of understanding the theoretical properties of high-temperature gases. The problem nagged at me for a couple of years before I found a way to approach it. There were two obvious extreme cases. When the temperatures were low, there would be no creation of particles. The properties of such a gas were well understood. In particular, the emitted radiation increased with increasing temperature in a known way. (All gases emit some radiation, except at zero temperature.) Also well understood was the case of extremely high temperatures. Here, there would be such a huge number of electrons and positrons created that the radiation would be trapped, except for a thin layer at the outer edge of the gas. The properties of this gas were also well understood. In such a situation, the emerging radiation would have a well-known form, called black-body radiation, that would increase with temperature in a known way. However, because of the prodigious energy requirements, such extremely high-temperature gases with black-body radiation would not actually exist in space. Most interesting, therefore, was the intermediate case, when the temperature is high enough to create particles but not so high to produce enough particles to trap the radiation and yield black-body radiation.

I was fascinated by the question of how the intermediate case would join to the others. I expected that as energy was put into the gas at a higher and higher rate, the temperature would first start to increase according to the low-temperature case, then increase at some other intermediate rate, then finally begin increasing according to the ultra high-temperature case.

To my astonishment, I discovered something entirely different. With increasing energy input, the temperature at first did indeed rise as expected. But after increasing to a critical value, the temperature began *decreasing* with further increase of the rate of energy input and emitted radiation. Finally, at a very high rate of energy input, the temperature turned around and began increasing again, in the known way for a very high-temperature gas.

At first, this result seemed absolutely counter to my physical intuition. Put more energy into something and you expect its temperature to go up, not down. Then I understood. The temperature of a gas is the average energy of a particle in that gas. Once you begin creating new particles, the additional particles can soak up all the increased energy, so much so that the average energy per particle actually can decrease. By analogy, when you give increasing quantities of food to a nation, the amount of food per person normally increases. But if the people of that nation produce children at a fast enough rate, then the food per person can actually begin decreasing even though there is more and more total food.

The result was not only astonishing. It was delightful, it was beautiful, and it was a little mysterious. Again, I experienced a kaleidoscope of emotions. Initially, I was surprised. Then, I was puzzled. Then, when I understood the result, I was extremely happy. I had found something new – again not terribly important in the grand scheme of science, but something that no one had ever known before me – and I felt elated and powerful with the knowledge. (In fact, a Swedish physicist, Roland Svensson, independently found the same result about the same time, and we published nearly simultaneously.)

Then I felt a sense of mystery. I had shed light on a small corner of nature. Other scientists had illuminated larger regions. But there were almost certainly vast chambers and ballrooms that remained in the dark. So many beautiful and strange things as yet unknown. In an article published in 1931, Einstein wrote, "The most beautiful experience we can have is the mysterious. It is the fundamental emotion which stands at the cradle of true art and true science." What did Einstein mean by "the mysterious?" I don't think he meant that science is full of unpredictable or unknowable or supernatural forces. I believe that he meant a sense of awe, a sense that there are things larger than us, that we do not have all the answers. A sense that we can stand right at the edge between known and unknown and gaze into that cavern and be exhilarated rather than frightened. I have experienced that beautiful mystery both as a physicist and as a novelist. As a physicist, in the infinite mystery of physical nature. As a novelist, in the infinite mystery of human nature and the power of words to portray some of that mystery.

In the decade after my project on high-temperature gases, my science began gently subsiding, like a retreating blue tide. I looked out at the horizon and felt that my best work as a scientist was moving away into my past. At the same time, I gazed into the future and began pushing the boundaries of my essays, which took on more of a fabulist quality, like the writings of Italo Calvino and Primo Levi. I invented. I told stories. I wrote about life and society on a planet made entirely of iron. I wrote about a moody Isaac Newton visiting my office. The science in my essays became only a doorway to what lay beyond. Eventually, when I was about forty years old, I began writing fiction. The time had arrived for my other passion to take over. Around 1990, when I left Harvard for MIT, I had stopped doing scientific research altogether. I miss it terribly, despite the many pleasures and rewards of being a writer.

But I am still a scientist. I am still fascinated by how things work, by the beauty and logic of the natural world. When I see something interesting, like a particular angle made by the wake of a boat, I still take out a pencil and calculate why. When I travel on airplanes, I still amuse myself by rederiving mathematical theorems that I learned years ago. Even when I write a scene for a novel, I sometimes subconsciously begin a paragraph with a topic sentence – a perfect metaphor for science, but nearly fatal for art.

Every writer has a source for his writing, a deep hidden well that he draws from to create. For me that source is science. In ways that I cannot explain, science suffuses all of my novels, characters, scenes, sentences, even individual words. Some people have told me that my novels have an architectural quality, a prominence of design. Perhaps that is a sign of the source.

Over the years, I have learned to recognize the different sensations of science and of art in my body. Some of the sensations, such as the creative moment, are the same. But I know the feeling in my body of deriving an equation. I know the different feeling in my body of listening to one of my characters speak before I have told her what to say. I know the line. I know the swoop of an idea. I know the wavering note. Most of the time, these feelings swirl all together as a rumbling in my stomach, a wondrous and beautiful and finally mysterious cry of the world, logic and illogic, certainty and uncertainty, questions with answers and questions without.

Albert Einstein

Physics & reality

Editor's Note: There is probably no modern scientist as famous as Albert Einstein. Born in Germany in 1879 and educated in physics and mathematics at the Swiss Federal Polytechnic School in Zurich, he was at first unable to find a teaching post, working instead as a technical assistant in the Swiss Patent Office from 1901 until 1908.

Early in 1905, Einstein published "A New Determination of Molecular Dimensions," a paper that earned him a Ph.D. from the University of Zurich. More papers followed, and Einstein returned to teaching, in Zurich, in Prague, and eventually in Berlin, where an appointment in 1914 to the Prussian Academy of Sciences allowed him to concentrate on research.

In November of 1919, the Royal Society of London announced that a scientific expedition had photographed a solar eclipse and completed calculations that verified the predictions that Einstein had made in a paper published three years before on the general theory of relativity. Virtually overnight, Einstein was hailed as the world's greatest genius, instantly recognizable, thanks to "his great mane of crispy, frizzled and very black hair, sprinkled with gray and rising high from a lofty brow" (as Romain Rolland described in his diary).

In the essay excerpted here, and first published in 1936, Einstein demonstrates his substantial interest in philosophy as well as science. He is pragmatic, in insisting that the only test of concepts is their usefulness in describing the physical world, yet also idealistic, in aiming for the minimum number of concepts to achieve that description.

In 1933, Einstein renounced his German citizenship and moved to the United States, where he lived until his death in 1955. A recipient of the Nobel Prize in physics in 1921, he was elected a member of the American Academy of Arts & Sciences in 1924.

General consideration concerning the method of science

It has often been said, and certainly not without justification, that the man of science is a poor philosopher. Why, then, should it not be the right thing for the physicist to let the philosopher do the philosophizing? Such might indeed be the right thing at a time when the physicist believes he has at his disposal a rigid system of fundamental concepts and fundamental laws which are so well established that waves of doubt cannot reach them; but, it cannot be right at a time when the very foundations of physics itself have become problematic as they are now. At a time like the present, when experience forces us to seek a newer and more solid foundation, the physicist cannot simply surrender to the philosopher the critical contemplation of the theoretical foundations; for, he himself knows best, and feels more surely where the shoe pinches. In looking for a new foundation, he must try to make clear in his own mind just how far the concepts which he uses are justified, and are necessities.

The whole of science is nothing more than a refinement of everyday thinking. It is for this reason that the critical thinking of the physicist cannot possibly be restricted to the examination of the concepts of his own specific field. He cannot proceed without considering critically a much more difficult problem, the problem of analyzing the nature of everyday thinking.

Our psychological experience contains, in colorful succession, sense experiences, memory pictures of them, images, and feelings. In contrast to psychology, physics treats directly only of sense experiences and of the "understanding" of their connection; but even the concept of the "real external world" of everyday thinking rests exclusively on sense impressions.

Now we must first remark that the differentiation between sense impressions and images is not possible; or, at least it is not possible with absolute certainty. With the discussion of this problem, which affects also the notion of reality, we will not concern ourselves but we shall take the existence of sense experiences as given, that is to say, as psychic experiences of a special kind.

I believe that the first step in the setting of a "real external world" is the formation of the concept of bodily objects and of bodily objects of various kinds. Out of the multitude of our sense experiences we take, mentally and arbitrarily, certain repeatedly occurring complexes of sense impressions (partly in conjunction with sense impressions which are interpreted as signs for sense experiences of others), and we correlate to them a concept – the concept of the bodily object. Considered logically this concept is not identical with the totality of sense impressions referred to; but it is a free creation of the human (or animal) mind. On the other hand, this concept owes its meaning and its justification exclusively to the totality of the sense impressions which we associate with it.

The second step is to be found in the fact that, in our thinking (which determines our expectation), we attribute to this concept of the bodily object a significance, which is to a high degree independent of the sense impressions which originally give rise to it. This is what we mean when we attribute to the bodily object "a real existence." The justification of such a setting rests exclusively on the fact that, by means of such concepts and mental relations between them, we are able to orient ourselves in the labyrinth of sense impressions. These notions and relations, although free mental creations, appear to us as stronger and more unalterable than the individual sense experience itself, the character of which as anything other than the result of an illusion or hallucination is never completely guaranteed. On the other hand, these concepts and relations, and indeed the postulation of real objects and, generally speaking, of the existence of "the real world," have justification only in so far as they are connected with sense impressions between which they form a mental connection.

The very fact that the totality of our sense experiences is such that by means of thinking (operations with concepts, and the creation and use of definite functional relations between them, and the coordination of sense experiences to these concepts) it can be put in order, this fact is one which leaves us in awe, but which we shall never understand. One may say "the eternal mystery of the world is its comprehensibility." It is one of the great realizations of Immanuel Kant that the postulation of a real external world would be senseless without this comprehensibility.

In speaking here of "comprehensibility," the expression is used in its most modest sense. It implies: the production of some sort of order among sense impressions, this order being produced by the creation of general concepts, relations between these concepts, and by definite relations of some kind between the concepts and sense experience. It is in this sense that the world of our sense experiences is comprehensible. The fact that it is comprehensible is a miracle.

In my opinion, nothing can be said *a priori* concerning the manner in which the concepts are to be formed and connected, and how we are to coordinate them to sense experiences. In guiding us in the creation of such an order of sense experiences, success alone is the determining factor. All that is necessary is to fix a set of rules, since without such rules the acquisition of knowledge in the desired sense would be impossible. One may compare these rules with the rules of a game in which, while the rules themselves are arbitrary, it is their rigidity alone which makes the game possible. However, the fixation will never be final. It will have validity only for a special field of application (i.e., there are no final categories in the sense of Kant).

The connection of the elementary concepts of everyday thinking with complexes of sense experiences can only be comprehended intuitively and it is unadaptable to scientifically logical fixation. The totality of these connections – none of which is expressible in conceptual terms – is the only thing which differentiates the great building which is science from a logical but empty scheme of concepts. By means of these connections, the purely conceptual propositions of science become general statements about complexes of sense experiences.

We shall call "primary concepts" such concepts as are directly and intuitively connected with typical complexes of sense experiences. All other notions are – from the physical point of view – possessed of meaning only in so far as they are connected, by propositions, with the primary notions. These propositions are partially definitions of the concepts (and of the statements derived logically from them) and partially propositions not derivable from the definitions, which express at least indirect relations between the "primary concepts," and in this way between sense experiences. Propositions of the latter kind are "statements about reality" or laws of nature, i.e., propositions which have to show their validity when applied to sense experiences covered by primary concepts. The question as to which of the propositions shall be considered as definitions and which as natural laws will depend largely upon the chosen representation. It really becomes absolutely necessary to make this differentiation only when one examines the degree to which the whole system of concepts considered is not empty from the physical point of view.

Stratification of the scientific system

The aim of science is, on the one hand, a comprehension, as *complete* as possible, of the connection between the sense experiences in their totality, and, on the other hand, the accomplishment of this aim by *the use of a minimum of primary concepts and relations*. (Seeking, as far as possible, logical unity in the world picture, i.e., paucity in logical elements.)

Science uses the totality of the primary concepts, i.e., concepts directly connected with sense experiences, and propositions connecting them. In its first stage of development, science does not contain anything else. Our everyday thinking is satisfied on the whole with this level. Such a state of affairs cannot, however, satisfy a spirit which is really scientifically minded; because the totality of concepts and relations obtained in this manner is utterly lacking in logical unity. In order to supplement this deficiency, one invents a system poorer in concepts and relations, a system retaining the primary concepts and relations of the "first layer" as logically derived concepts and relations. This new "secondary system" pays for its higher logical unity by having elementary concepts (concepts of the second layer), which are no longer directly connected with complexes of sense experiences. Further striving for logical unity brings us to a tertiary system, still poorer in concepts and relations, for the deduction of the concepts and relations of the secondary (and so indirectly of the primary) layer. Thus the story goes on until we have arrived at a system of the greatest conceivable unity, and of the greatest poverty of concepts of the logical foundations, which is still compatible with the observations made by our senses. We do not know whether or not this ambition will ever result in a definitive system. If one is asked for his opinion, he is inclined to answer no. While wrestling with the problems, however, one will never give up hope that this greatest of all aims can really be attained to a very high degree.

An adherent to the theory of abstraction or induction might call our layers "degrees of abstraction"; but I do not consider it justifiable to veil the logical independence of the concept from the sense experiences. The relation is not analogous to that of soup to beef but rather of check number to overcoat.

The layers are furthermore not clearly separated. It is not even absolutely clear which concepts belong to the primary layer. As a matter of fact, we are dealing with freely formed concepts, which, with a certainty sufficient for practical use, are intuitively connected with complexes of sense experiences in such a manner that, in any given case of experience, there is no uncertainty as to the validity of an assertion. The essential thing is the aim to represent the multitude of concepts and propositions, close to experience, as propositions, logically deduced from a basis, as narrow as possible, of fundamental concepts and fundamental relations which themselves can be chosen freely (axioms). The liberty of choice, however, is of a special kind; it is not in any way similar to the liberty of a writer of fiction. Rather, it is similar to that of a man engaged in solving a well-designed word puzzle. He may, it is true, propose any word as the solution; but, there is only *one* word which really solves the puzzle in all its parts. It is a matter of faith that nature – as she is perceptible to our five senses – takes the character of such a well-formulated puzzle. The successes reaped up to now by science do, it is true, give a certain encouragement for this faith.

The multitude of layers discussed above corresponds to the several stages of progress which have resulted from the struggle for unity in the course of development. As regards the final aim, intermediary layers are only of temporary nature. They must eventually disappear as irrelevant. We have to deal, however, with the science of today, in which these strata represent problematic partial successes which support one another but which also threaten one another, because today's system of concepts contains deep-seated incongruities.

Gerald Holton

Einstein's Third Paradise

Historians of modern science have good reason to be grateful to Paul Arthur Schilpp, professor of philosophy and Methodist clergyman but better known as the editor of a series of volumes on "Living Philosophers," which included several volumes on scientist-philosophers. His motto was: "The asking of questions about a philosopher's meaning while he is alive." And to his everlasting credit, he persuaded Albert Einstein to do what he had resisted all his years: to sit down to write, in 1946 at age sixty-seven, an extensive autobiography – forty-five pages long in print.

To be sure, Einstein excluded there most of what he called "the merely personal." But on the very first page he shared a memory that will guide us to the main conclusion of this essay. He wrote that when still very young, he had searched for an escape from the seemingly hopeless and demoralizing chase after one's desires and strivings. That escape offered itself first in religion. Although brought up as the son of "entirely irreligious (Jewish) parents," through the teaching in his Catholic primary school, mixed with his private instruction in elements of the Jewish religion, Einstein found within himself a "deep religiosity" – indeed, "the religious paradise of youth."

The accuracy of this memorable experience is documented in other sources, including the biographical account of Einstein's sister, Maja. There she makes a plausible extrapolation: that Einstein's "religious feeling" found expression in later years in his deep interest and actions to ameliorate the difficulties to which fellow Jews were being subjected, actions ranging from his fights against anti-Semitism to his embrace of Zionism (in the hope, as he put it in one of his

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speeches [April 20, 1935], that it would include a "peaceable and friendly cooperation with the Arab people"). As we shall see, Maja's extrapolation of the reach of her brother's early religious feelings might well have gone much further.

The primacy of young Albert's First Paradise came to an abrupt end. As he put it early in his "Autobiographical Notes," through reading popular science books he came to doubt the stories of the Bible. Thus he passed first through what he colorfully described as a "positively fanatic indulgence in free thinking."[1] But then he found new enchantments. First, at age twelve, he read a little book on Euclidean plane geometry – he called it "holy," a veritable "Wunder." Then, still as a boy, he became entranced by the contemplation of that huge external, extra-personal world of science, which presented itself to him "like a great, eternal riddle." To that study one could devote oneself, finding thereby "inner freedom and security." He believed that choosing the "road to this Paradise," although quite antithetical to the first one and less alluring, did prove itself trustworthy. Indeed, by age sixteen, he had his father declare him to the authorities as "without confession," and for the rest of his life he tried to dissociate himself from organized religious activities and associations, inventing his own form of religiousness, just as he was creating his own physics.

These two realms appeared to him eventually not as separate as numerous biographers would suggest. On the contrary, my task here is to demonstrate that at the heart of Einstein's mature identity there developed a fusion of his First and his Second Paradise – into a Third Paradise, where the meaning of a life of brilliant scientific activity drew on the remnants of his fervent first feelings of youthful religiosity.

For this purpose, we shall have to make what may seem like an excursus, but one that will in the end throw light on his overwhelming passion, throughout his scientific and personal life, to bring about the joining of these and other seemingly incommensurate aspects, whether in nature or society. In 1918 he gave a glimpse of it in a speech ("*Prinzipien der Forschung*") honoring the sixtieth birthday of his friend and colleague Max Planck, to whose rather metaphysical conception about the purpose of science Einstein had drifted while moving away from the quite opposite, positivistic one of an early intellectual mentor, Ernst Mach. As Einstein put it in that speech, the search for one "simplified and lucid image of the world" not only was the supreme task for a scientist, but also corresponded to a psychological need: to flee from personal, everyday life, with all its dreary disappointments, and escape into the world of objective perception and thought. Into the formation of such a world picture the scientist could place the "center of gravity of his emotional life [*Gefühlsleben*]." And in a sentence with special significance, he added that persevering on the most difficult scientific problems requires "a state of feeling [*Gefühlszustand*] similar to that of a religious person or a lover."

Throughout Einstein's writings, one can watch him searching for that world picture, for a comprehensive *Weltanschauung*, one yielding a total conception that, as he put it, would include every empirical fact (*Gesamtheit der Erfahrungstatsachen*) – not only of physical science, but also of life.

1 All translations from the original German are this author's, where necessary.

Einstein was of course not alone in this pursuit. The German literature of the late nineteenth and early twentieth centuries contained a seemingly obsessive flood of books and essays on the oneness of the world picture. They included writings by both Ernst Mach and Max Planck, and, for good measure, a 1912 general manifesto appealing to scholars in all fields of knowledge to combine their efforts in order to "bring forth a comprehensive *Weltanschauung*." The thirty-four signatories included Ernst Mach, Sigmund Freud, Ferdinand Tönnies, David Hilbert, Jacques Loeb – and the then still little-known Albert Einstein.

But while for most others this culturally profound longing for unity – already embedded in the philosophical and literary works they all had studied – was mostly the subject of an occasional opportunity for exhortation (nothing came of the manifesto), for Einstein it was different, a constant preoccupation responding to a persistent, deeply felt intellectual and psychological need.

This fact can be most simply illustrated in Einstein's scientific writings. As a first example, I turn to one of my favorite manuscripts in his archive. It is a lengthy manuscript in his handwriting, of around 1920, titled, in translation, "Fundamental Ideas and Methods of Relativity." It contains the passage in which Einstein revealed what in his words was "the happiest thought of my life [*der gluecklichste Gedanke meines Lebens*]" – a thought experiment that came to him in 1907: nothing less than the definition of the equivalence principle, later developed in his general relativity theory. It occurred to Einstein – thinking first of all in visual terms, as was usual for him – that if a man were falling from the roof of his house and tried to let anything drop, it would only move alongside him, thus indicating the equivalence of acceleration and gravity. In Einstein's words, "the acceleration of free fall with respect to the material is therefore a mighty argument that the postulate of relativity is to be extended to coordinate systems that move non-uniformly relative to one another . . . ."

For the present purpose I want to draw attention to another passage in that manuscript. His essay begins in a largely impersonal, pedagogic tone, similar to that of his first popular book on relativity, published in 1917. But in a surprising way, in the section titled "General Relativity Theory," Einstein suddenly switches to a personal account. He reports that in the construction of the special theory, the "thought concerning the Faraday [experiment] on electromagnetic induction played for me a leading role." He then describes that old experiment, in words similar to the first paragraph of his 1905 relativity paper, concentrating on the well-known fact, discovered by Faraday in 1831, that the induced current is the same whether it is the coil or the magnet that is in motion relative to the other, whereas the "theoretical interpretation of the phenomenon in these two cases is quite different." While other physicists, for many decades, had been quite satisfied with that difference, here Einstein reveals a central preoccupation at the depth of his soul: "The thought that one is dealing here with two fundamentally different cases was for me unbearable [*war mir unertraeglich*]. The difference between these two cases could not be a real difference . . . . The phenomenon of the electromagnetic induction forced me to postulate the (special) relativity principle."

Let us step back for a moment to contemplate that word "unbearable." It is reinforced by a passage in Einstein's

"Autobiographical Notes": "By and by I despaired [*verzweifelte ich*] of discovering the true laws by means of constructive efforts based on known facts. The longer and the more despairingly I tried, the more I came to the conviction that only the discovery of a universal formal principle could lead us to assured results." He might have added that the same postulational method had already been pioneered in their main works by two of his heroes, Euclid and Newton.

Other physicists, for example Bohr and Heisenberg, also reported that at times they were brought to despair in their research. Still other scientists were evidently even brought to suicide by such disappointment. For researchers fiercely engaged at the very frontier, the psychological stakes can be enormous. Einstein was able to resolve his discomfort by turning, as he did in his 1905 relativity paper, to the *postulation* of two formal principles (the principle of relativity throughout physics, and the constancy of the velocity of light in vacuo), and adopting such postulation as one of his tools of thought.

Einstein also had a second method to bridge the unbearable differences in a theory: *generalizing it*, so that the apparently differently grounded phenomena are revealed to be coming from the same base. We know from a letter to Max von Laue of January 17, 1952, found in the archive, that Einstein's early concern with the physics of fluctuation phenomena was the common root of his three great papers of 1905, on such different topics as the quantum property of light, Brownian movement, and relativity. But even earlier, in a letter of April 14, 1901, to his school friend Marcel Grossmann, Einstein had revealed his generalizing approach to physics while working on his very first published paper, on capillarity. There he tried to bring together in one theory the opposing behaviors of bodies: moving upward when a liquid is in a capillary tube, but downward when the liquid is released freely. In that letter, he spelled out his interpenetrating emotional and scientific needs in one sentence: "It is a wonderful feeling [*ein herrliches Gefühl*] to recognize the unity of a complex of appearances which, to direct sense experiences, appear to be quite separate things."

The postulation of universal formal principles, and the discovery among phenomena of a unity, of *Einheitlichkeit*, through the *generalization* of the basic theory – those were two of Einstein's favorite weapons,[2] as his letters and manuscripts show. Writing to Willem de Sitter on November 4, 1916, he confessed: "I am driven by my need to generalize [*mein Verallgemeinerungsbeduerfnis*]." That need, that compulsion, was also deeply entrenched in German culture and resonated with, and supported, Einstein's approach. Let me just note in passing that while still a student at the Polytechnic Institute in Zurich, in order to get his certificate to be a high school science teacher, Einstein took optional courses on Immanuel Kant and Goethe, whose central works he had studied since his teenage years.

That *Verallgemeinerungsbeduerfnis* was clearly a driving force behind Einstein's career trajectory. Thus he generalized from old experimental results, like Faraday's, to arrive at special relativity, in which he unified space and time, electric and magnetic forces, energy and mass, and so resolved the whole long dispute

2 A third was his use of freely adopted (non-Kantian) categories, or thematic presuppositions. The prominent ones include unity or unification; logical parsimony and necessity; symmetry; simplicity; causality; completeness of explanation; continuum; and, of course, constancy and invariance.

among scientists between adherence to a mechanistic versus an electromagnetic world picture. Then he generalized the special theory to produce what he first significantly called, in an article of 1913, not the *general* but the *generalized relativity theory*. Paul Ehrenfest wrote him in puzzlement: "How far will this *Verallgemeinerung* go on?" And, finally, Einstein threw himself into the attempt of a grand unification of quantum physics and of gravity: a unified field theory. It is an example of an intense and perhaps unique, life-long, tenacious dedication, despite Einstein's failure at the very end – which nevertheless, as a program, set the stage for the ambition of some of today's best scientists, who have taken over that search for the Holy Grail of physics – a theory of everything.

So much for trying to get a glimpse of the mind of Einstein as scientist. But at this point, for anyone who has studied this man's work and life in detail, a new thought urges itself forward. As in his science, Einstein also *lived* under the compulsion to unify – in his politics, in his social ideals, even in his everyday behavior. He abhorred all nationalisms, and called himself, even while in Berlin during World War I, a European. Later he supported the One World movement, dreamed of a unified supernational form of government, helped to initiate the international Pugwash movement of scientists during the Cold War, and was as ready to befriend visiting high school students as the Queen of the Belgians. His instinctive penchant for democracy and dislike of hierarchy and class differences must have cost him greatly in the early days, as when he addressed his chief professor at the Swiss Polytechnic Institute, on whose recommendation his entrance to any academic career would depend, not by any title, but simply as "Herr Weber." And at the other end of the spectrum, in his essay on ethics, Einstein cited Moses, Jesus, and Buddha as equally valid prophets.

No boundaries, no barriers; none in life, as there are none in nature. Einstein's life and his work were so mutually resonant that we recognize both to have been carried on together in the service of one grand project – the fusion into one coherency.

There were also no boundaries or barriers between Einstein's scientific and religious feelings. After having passed from the youthful first, religious paradise into his second, immensely productive scientific one, he found in his middle years a fusion of those two motivations – his Third Paradise.

We had a hint of this development in his remark in 1918, where he observed the parallel states of feeling of the scientist and of the "religious person." Other hints come from the countless, well-known quotations in which Einstein referred to God – doing it so often that Niels Bohr had to chide him. Karl Popper remarked that in conversations with Einstein, "I learned nothing . . . . he tended to express things in theological terms, and this was often the only way to argue with him. I found it finally quite uninteresting."

But two other reports may point to the more profound layer of Einstein's deepest convictions. One is his remark to one of his assistants, Ernst Straus: "What really interests me is whether God had any choice in the creation of the world." The second is Einstein's reply to a curious telegram.

In 1929, Boston's Cardinal O'Connell branded Einstein's theory of relativity as "befogged speculation producing universal doubt about God and His Creation," and as implying "the ghastly apparition of atheism." In alarm, New York's Rabbi Herbert S. Goldstein asked Einstein by telegram: "Do you believe in God? Stop. Answer paid 50 words." In his response, for which Einstein needed but twenty-five (German) words, he stated his beliefs succinctly: "I believe in Spinoza's God, Who reveals Himself in the lawful harmony of the world, not in a God Who concerns Himself with the fate and the doings of mankind." The rabbi cited this as evidence that Einstein was not an atheist, and further declared that "Einstein's theory, if carried to its logical conclusion, would bring to mankind a scientific formula for monotheism." Einstein wisely remained silent on that point.

The good rabbi might have had in mind the writings of the Religion of Science movement, which had flourished in Germany under the distinguished auspices of Ernst Haeckel, Wilhelm Ostwald, and their circle (the *Monistenbund*), and also in America, chiefly in Paul Carus's books and journals, such as *The Open Court,* which carried the words "Devoted to the Religion of Science" on its masthead.

If Einstein had read Carus's book, *The Religion of Science* (1893), he may have agreed with one sentence in it: "Scientific truth is not profane, it is sacred." Indeed, the charismatic view of science in the lives of some scientists has been the subject of much scholarly study, for example in Joseph Ben-David's *Scientific Growth* (1991), and earlier in Robert K. Merton's magisterial book of 1938, *Science, Technology and Society in Seventeenth-Century England*. In the section entitled "The Integration of Religion and Science," Merton notes that among the scientists he studied, "the religious ethic, considered as a social force, so consecrated science as to make it a highly respected and laudable focus of attention." The social scientist Bernard H. Gustin elaborated on this perception, writing that science at the highest level is charismatic because scientists devoted to such tasks are "thought to come into contact with what is essential in the universe." I believe this is precisely why so many who knew little about Einstein's scientific writing flocked to catch a glimpse of him and to this day feel somehow uplifted by contemplating his iconic image.

Starting in the late 1920s, Einstein became more and more serious about clarifying the relationship between his transcendental and his scientific impulses. He wrote several essays on religiosity; five of them, composed between 1930 and the early 1950s, are reproduced in his book *Ideas and Opinions.* In those chapters we can watch the result of a struggle that had its origins in his school years, as he developed, or rather invented, a religion that offered a union with science.

In the evolution of religion, he remarked, there were three developmental stages. At the first, "with primitive man it is above all fear that evokes religious notions. This 'religion of fear'... is in an important degree stabilized by the formation of a special priestly caste" that colludes with secular authority to take advantage of it for its own interest. The next step – "admirably illustrated in the Jewish scriptures" – was a moral religion embodying the ethical imperative, "a development [that] continued in the New Testament." Yet it had a fatal flaw: "the anthropomorphic character of the concept of God," easy to grasp by "underdeveloped minds" of the masses while freeing them of responsibility.

This flaw disappears at Einstein's third, mature stage of religion, to which he believed mankind is now reaching and which the great spirits (he names Democritus, St. Francis of Assisi, and Spinoza) had already attained – namely, the "cosmic religious feeling" that sheds all anthropomorphic elements. In describing the driving motivation toward that final, highest stage, Einstein uses the same ideas, even some of the same phrases, with which he had celebrated first his religious and then his scientific paradise: "The individual feels the futility of human desires, and aims at the sublimity and marvelous order which reveal themselves both in nature and in the world of thought." "Individual existence impresses him as a sort of prison, and he wants to experience the universe as a single, significant whole." Of course! Here as always, there has to be the intoxicating experience of unification. And so Einstein goes on, "I maintain that the cosmic religious feeling is the strongest and noblest motive for scientific research . . . . A contemporary has said not unjustly that in this materialistic age of ours the serious scientific workers are the only profoundly religious people."

In another of his essays on religion, Einstein points to a plausible source for his specific formulations: "Those individuals to whom we owe the great creative achievements of science were all of them imbued with a truly religious conviction that this universe of ours is something perfect, and susceptible through the rational striving for knowledge. If this conviction had not been a strongly emotional one, and if those searching for knowledge had not been inspired by Spinoza's *amor dei intellectualis*, they would hardly have been capable of that untiring devotion which alone enables man to attain his greatest achievements."

I believe we can guess at the first time Einstein read Baruch Spinoza's *Ethics* (*Ethica Ordinae Geometrico Demonstrata*), a system constructed on the Euclidean model of deductions from propositions. Soon after getting his first real job at the patent office, Einstein joined with two friends to form a discussion circle, meeting once or twice a week in what they called, with gallows humor, the *Akademie Olympia*. We know the list of books they read and discussed. High among them, reportedly at Einstein's suggestion, was Spinoza's *Ethics,* which he read afterwards several times more. Even when his sister Maja joined him in Princeton in later life and was confined to bed by an illness, he thought that reading a good book to her would help, and chose Spinoza's *Ethics* for that purpose.

By that time Spinoza's work and life had long been important to Einstein. He had written an introduction to a biography of Spinoza (by his son-in-law, Rudolf Kayser, 1946); he had contributed to the *Spinoza Dictionary* (1951); he had referred to Spinoza in many of his letters; and he had even composed a poem in Spinoza's honor. He admired Spinoza for his independence of mind, his deterministic philosophical outlook, his skepticism about organized religion and orthodoxy – which had resulted in his excommunication from his synagogue in 1656 – and even for his ascetic preference, which compelled him to remain in poverty and solitude to live in a sort of spiritual ecstasy, instead of accepting a professorship at the University of Heidelberg. Originally neglected, Spinoza's *Ethics,* published only posthumously, profoundly influenced other thinkers, such as Friedrich Schlegel, Friedrich Schleiermacher, Goethe (who called him "our common saint"), Albert Schweitzer, and Romain Rolland (who, on reading *Ethics,* confessed, "I deciphered not what he said, but what he meant to say").

For Spinoza, God and nature were one (*deus sive natura*). True religion was based not on dogma but on a feeling for the rationality and the unity underlying all finite and temporal things, on a feeling of wonder and awe that *generates* the idea of God, but a God which lacks any anthropomorphic conception. As Spinoza wrote in Proposition 15 in *Ethics,* he opposed assigning to God "body and soul and being subject to passions." Hence, "God is incorporeal" – as had been said by others, from Maimonides on, to whom God was knowable indirectly through His creation, through nature. In other pages of *Ethics,* Einstein could read Spinoza's opposition to the idea of cosmic purpose, and that he favored the primacy of the law of cause and effect – an all-pervasive determinism that governs nature and life – rather than "playing at dice," in Einstein's famous remark. And as if he were merely paraphrasing Spinoza, Einstein wrote in 1929 that the perception in the universe of "profound reason and beauty constitute true religiosity; in this sense, and in this sense alone, I am a deeply religious man."

Much has been written about the response of Einstein's contemporaries to his Spinozistic cosmic religion. For example, the physicist Arnold Sommerfeld recorded in Schilpp's volume that he often felt "that Einstein stands in a particularly intimate relation to the God of Spinoza." But what finally most interests us here is to what degree Einstein, having reached his Third Paradise, in which his yearnings for science and religion are joined, may even have found in his own research in physics fruitful ideas emerging from that union. In fact there are at least some tantalizing parallels between passages in Spinoza's *Ethics* and Einstein's publications in cosmology – parallels that the physicist and philosopher Max Jammer, in his book *Einstein and Religion* (1999), considers as amounting to intimate connections. For example, in Part I of *Ethics* ("Concerning God"), Proposition 29 begins: "In nature there is nothing contingent, but all things are determined from the necessity of the divine nature to exist and act in a certain manner." Here is at least a discernible overlap with Einstein's tenacious devotion to determinism and strict causality at the fundamental level, despite all the proofs from quantum mechanics of the reign of probabilism, at least in the subatomic realm.

There are other such parallels throughout. But what is considered by some as the most telling relationship between Spinoza's Propositions and Einstein's physics comes from passages such as Corollary 2 of Proposition 20: "It follows that God is immutable or, which is the same thing, all His attributes are immutable." In a letter of September 3, 1915, to Else (his cousin and later his wife), Einstein, having read Spinoza's *Ethics* again, wrote, "I think the *Ethics* will have a permanent effect on me."

Two years later, when he expanded his general relativity to include "cosmological considerations," Einstein found to his dismay that his system of equations did "not allow the hypothesis of a spatially closed-ness of the world [*raeumliche Geschlossenheit*]." How did Einstein cure this flaw? By something he had done very rarely: making an ad hoc addition, purely for convenience: "We can add, on the left side of the field equation a – for the time being – unknown universal constant, - λ." In fact, it seems that not much harm is done thereby. It does not change the covariance; it still corresponds with the observation of motions in the solar system ("as long as λ is small"), and so forth. Moreover, the proposed new universal constant λ also determines the average density of the universe with which it can remain in equilibrium, and provides the radius and volume of a presumed spherical universe.

Altogether a beautiful, immutable universe – one an immutable God could be identified with. But in 1922, Alexander Friedmann showed that the equations of general relativity did allow expansion or contraction. And in 1929 Edwin Hubble found by astronomical observations the fact that the universe does expand. Thus Einstein – at least according to the physicist George Gamow – remarked that "inserting λ was the biggest blunder of my life."

Max Jammer and the physicist John Wheeler, both of whom knew Einstein, traced his unusual ad hoc insertion of λ, nailing down that "spatially closed-ness of the world," to a relationship between Einstein's thoughts and Spinoza's Propositions. They also pointed to another possible reason for it: In Spinoza's writings, one finds the concept that God would not have made an empty world. But in an expanding universe, in the infinity of time, the density of matter would be diluted to zero in the limit. Space itself would disappear, since, as Einstein put it in 1952, "On the basis of the general theory of relativity ... space as opposed to 'what fills space' ... had no separate existence."

Even if all of these suggestive indications of an intellectual, emotional, and perhaps even spiritual resonance between Einstein's and Spinoza's writings were left entirely aside, there still remains Einstein's attachment to his "cosmic religion." That was the end point of his own troublesome pilgrimage in religiosity – from his early vision of his First Paradise, through his disillusionments, to his dedication to find fundamental unity within natural science, and at last to his recognition of science as the devotion, in his words, of "a deeply religious unbeliever" – his final embrace of seeming incommensurables in his Third Paradise.

Peter Pesic

The bell & the buzzer: on the meaning of science

To seek the meaning of science is to seek its human significance. At first glance, that seems problematic because modern science characteristically calls into question many of our all-too-human preconceptions in its effort to discover the truth. Still, to those who care for it, science can have a compelling, human quality. It is a quest, and as such has common elements with other heroic journeys.

Jason and the Argonauts knew they were seeking the Golden Fleece. But scientists seek something that is unknown and hidden – the ultimate laws of nature. The elusiveness of this goal conditions the search and the searchers. Even setting aside the complex effects of science on the world, to seek the meaning of science, like the scientific quest itself, is to seek something unknown, to gather seemingly disconnected stories and perspectives fully aware of their discontinuity. As with science itself, our story emerges as much in the gaps as in what we can connect.

Modern science is a newcomer, barely four hundred years old. Though indebted in deep ways to Plato, Aristotle, and Greek natural philosophy, the pioneers of the 'new philosophy' called for a decisive break with ancient authority. In 1536, Pierre de La Ramée defended the provocative thesis that "everything Aristotle said is wrong." Francis Bacon and René Descartes criticized scholarship that remained in thrall to the ancients. This adversarial stance implied a problematic relation to the established order. In spite of Bacon's efforts to persuade his king to support his fledgling scientific research efforts, King James mockingly compared Bacon's words with the peace of God that "passeth all understanding." Though later rulers came to value the powers that science gave them, they recurrently turned against its ever more expensive projects of 'pure' research.

To render the new philosophy more comprehensible to an audience steeped in classical learning, Bacon often resorted to reinterpretations of ancient myths. He compared science to the Sphinx because each, "being the wonder of the ignorant and unskillful, may be not ab-

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surdly called a monster." His irony implies that this superficial view has its own truth, though it also must be considered within a larger, deeper perspective. Here the concept of depth is crucial, for the essential innovation of modern science has been to disclose the secrets and depths of nature. Though this has become a familiar image, it represents a radical departure from Aristotle's view that nature is fundamentally open to human understanding, not hidden. Instead, Bacon turned to alternative insights, to Heraclitus's enigmatic teaching that "nature loves to hide" and to Isaiah's recognition that "thou art a God that hidest thyself."

We have only begun to estimate the effect on human understanding of this quest for the depths. Bacon envisaged that the new philosopher, as a "skillful Servant of Nature," would wrestle with Proteus, "the messenger and interpreter of all antiquity and all secrets," whom he identified as "Matter – the most ancient of things, next to God." Bacon emphasized that this ordeal of experiment was to be heroic testing, not the torture of a slavish and submissive victim. Bacon also anticipated that the evidence that emerged would be enigmatic, even enciphered. He judged that "the universe to the eye of the human understanding is framed like a labyrinth," requiring a new kind of interpretation akin to the then emergent art of codebreaking. Bacon did not anticipate the form this decipherment would take – symbolic mathematics – though he mused on the unexplored possibilities that lay beyond the mathematics he knew, convinced that the future would far outstrip any anticipation. He guessed that this extraordinary quest would have deep effects on the seekers, penetrating the nature and wellsprings of their passions as they scourged and tested their own intensely felt theories, no less than they vexed nature with experiments.[1]

Bacon anticipated that the votaries of his 'new philosophy' would prick their desire to know with the spur of self-questioning. Fired with visionary excitement, they should nevertheless try to undermine their own dearest theories, lest they fall victim to self-delusion. He compared this dilemma to struggling with the Sphinx's menacing claws: "distraction and laceration of mind, if you fail to solve them; if you succeed, a kingdom." If they solve her riddle, the seekers will discover the secret sources of power over the political and natural worlds, thereby facing the deepest possibilities of corruption. In such works as his unfinished *New Atlantis*, Bacon framed the hope that these "sons of science" (as he called them) would emerge triumphant from this ordeal whose tragic possibilities he also sensed.

Four centuries later, we continue to wonder at this unfolding drama, trying to gauge whether Bacon's hopes were vain or whether they might yet be sustained. Kepler, Newton, Darwin, and Einstein bore out many of Bacon's anticipations, both in the heroic tenor of what they attempted and achieved but also in the peculiar difficulties their quests raised for their desires. Einstein speaks for all of them: "I want to know God's thoughts. The rest is trash." Those who seek such knowledge must wrestle with something beyond the human.

Consider the paradoxical demands that Bacon anticipated. On one hand,

1 My book *Labyrinth* (Cambridge, Mass.: MIT Press, 2000), drawing on the important work of John C. Briggs, *Francis Bacon and the Rhetoric of Nature* (Cambridge, Mass.: Harvard University Press, 1989), treats these Baconian themes and their relation to the work of Kepler, Newton, and Einstein.

the seekers must be cold, impersonal, testing each theory mercilessly. On the other, they must be filled with ardor, on fire to imagine radically new insights into the depths. Their imaginations must be feverish enough to conjure up ever more daring flights of fancy, but then cold enough to try to annihilate their own creations. This paradox threatens to unravel the seekers' selves and to paralyze their desires. As a result, their humanity may be hostage to their integrity as 'scientists' or 'physicists.'

These names, only coined in the 1830s, replaced the older term 'natural philosopher,' which Isaac Newton and Michael Faraday had applied to themselves. Our literary representations of this new breed are similarly recent. Consider the 'mad' scientists inspired by Mary Shelley's *Frankenstein: or, The Modern Prometheus* (1818). The original Victor Frankenstein is sensitive and intelligent, deeply affected by the early death of his mother. "The world was to me a secret I desired to divine," he recalls. "Curiosity, earnest research to learn the hidden laws of nature, gladness akin to rapture" are his earliest recollections, blending intellectual with passionate response. After a youthful infatuation with alchemy and magic, he encounters the wonders of modern chemistry and is seized by the desire to "explore unknown powers, and unfold to the world the deepest mysteries of creation." His obsessive quest eclipses ordinary human love and even makes him forget his own family. His only offspring is his creature, a monstrous man-child who disappears into inhuman isolation and whose delicate sensibility turns to cruelty as his sufferings transpose Rousseau's noble savage into a dark key.

The mad scientist is also akin to Goethe's Faust (Part I, 1808), who wants to know the inmost secrets of the world but sickens from the emotional aridity of his erudition and develops an inordinate desire to control the world as a surrogate or perhaps cure. Goethe's Mephistopheles, a hedonistic *grand seigneur*, deplores the conflicted desires of his protégé: "You can't get the Doctor out of your system [*Dir steckt der Doktor noch im Leib*]." The mad scientist cuts a tragicomic figure because of his obsessions and his dislocation from the ordinary human world. Hair disheveled, erotically unfulfilled, he sells his soul for delusive dreams of power.

Thus far, the mad scientist is a kind of parody of Bacon's forebodings. Nevertheless, the parodic exaggerations point back to the emotional dilemma that Bacon more subtly discerned when he pointed to wounded seekers such as Oedipus as archetypes of the new philosophers. In Bacon's account, Oedipus solves the Sphinx's riddle not despite but because of his wounded, limping feet. And Bacon did not allude to the tragic sequel – incest and parricide – as if *his* Oedipus has emerged triumphant, blessed by his wound and thereby bestowing blessings. Perhaps Bacon imagined a more positive and heroic version of the ancient story, whose foreboding power he must have known. He went on to depict benign scientist-priests as the hidden rulers of his scientific utopia, the *New Atlantis*, who conceal even from their wise king scientific discoveries they deem too dangerous.

Here again popular imagination follows with its own version of the scientist as magus. Einstein's wild hair is not the mad scientist's coiffure but a secular aureole, bespeaking his superhuman intelligence and wisdom. A Jew fleeing race hatred, he defies its threats. He is even (if wrongly) credited with the atomic bomb, but he is saddened and wounded by the use of that bomb. He is an advocate of peace, a rebel against the establishment that reveres him, offering a new vision of human potentiality. His casual dress and dislike of wearing socks reflects his liberation from convention, an anti-style adopted by students since the 1960s. Like all true myths, the scientist-magus lives on, as does the wounded hero: Stephen Hawking's popular appeal reflects the fascination with a powerful intellect struggling to overcome a crippling physical disability.

Besides these exceptional stories, studies show that scientists suffer from illness and disability during childhood far in excess of the general population.[2] Scientists bear the mark of their struggle, but they also may attain compensatory powers. Between the extremes of magus and mad scientist, consider the *nerd*. About 1957, MIT undergraduates began referring to 'gnurds,' studious grinds, especially in science and engineering. The nerd is emotionally immature, socially isolated, unfashionably dressed, and erotically unattractive. He is the scientist as *Unmensch* and scapegoat, the locus of feelings of confusion, inadequacy, and mistrust that modern science can excite. Though he tends to be the butt of comedy, there is a certain pathos about his human incapacity.

The nerd is a figure in contemporary mythology, but he is not without antecedents. What is known of Descartes's persona fits the category. His mother died when he was very young; he was a sickly child, emotionally remote from his father. At age eight he became a boarding student at a Jesuit *collège*, where he excelled. Such institutions fostered a new kind of self-discipline that bred overzealous students who read by moonlight, spent all their money on books, and neglected their health – proto-nerds, if you will.[3] Descartes added the crucial element by turning this intensified and interiorized studiousness not toward humane letters and classical scholarship but toward a new mathematics and natural science, and he did so in phases of his life in which he notably shut himself off from other people for long periods of time. His intense aloneness deeply marks important passages in his philosophical works. He shut himself up in a stove-heated room to make his fateful experiment on himself, to get rid of all his opinions "all in one go, in order to replace them afterwards with better ones, or with the same ones once I had squared them with the standards of reason."

Of course, calling Descartes the first nerd grossly ignores his personal refinement, elegant prose style, sly wit, even his surprising career as a soldier of fortune. I only want to point to a certain constellation of qualities that link him with continuing elements in the modern mythology of science. Consider, for instance, the 1701 frontispiece to Descartes's posthumous works, depicting him as Faust, seated in his study, surrounded by mathematical instruments, illuminated by the ostentatious rays of the light of nature shining into his chamber. Though Descartes was melancholic, the figure in the frontispiece has a debonair smile of self-satisfaction. This Faust is not tormented or agonizingly conflicted, but quietly triumphant even in his isolation. Descartes chose as his motto *bene vixit bene qui latuit* – "he lived well who hid well" – and gazed at the world through the mask of a scholar

2 See Anne Roe, *The Making of a Scientist* (New York: Dodd, Mead, 1953), and Gerald Holton, *The Scientific Imagination: Case Studies* (New York: Cambridge University Press, 1978), 229 – 252.

3 See Stephen Gaukroger, *Descartes: An Intellectual Biography* (Oxford: Clarendon Press, 1995), 15 – 37.

who outwits the world in the hidden fortress of his mind. On the other hand, he hid in a kind of inner exile from the outer world, and placed just this separation between mind and body.

The nerd, the magus, and the mad scientist are modern mythic figures, somewhat disheveled descendants of Bacon's attempts to reenvision ancient myth. In different ways, they live out the implications of the project to find out what is hidden behind nature. Yet this presumes a basic split between manifest and underlying realities, which Bacon had already discerned but whose full dimensions only emerged much later. Nature is more protean than Bacon dreamed: Proteus merely assumes different shapes; nature shifts between whole realities.

Indeed, no one could have anticipated the way quantum mechanics transformed our sense of reality. Consider a particle observed at point A and time t_A, then at point B and time t_B. The laws of quantum mechanics assign to each possible path connecting A and B an 'amplitude,' a complex number that depends on the 'action,' the difference between kinetic and potential energy summed along that path. Where Newtonian mechanics had allowed only one possible path (that of least action), quantum mechanics allows all possible paths, each weighted by its action. The net amplitude is the sum of the separate amplitudes for all the paths. But this is a complex number, not directly observable. If you take the absolute square of the net amplitude, the result is a positive real number that tells the total probability of that particle appearing at point A and time t_A, then at point B and time t_B.[4]

Einstein satirized quantum theory's reliance on probability in his aphorism "God does not play dice." He insisted on the necessity of distinguishing the constituents of the world and following their individual careers. But ironically Einstein was a great practitioner of the statistical method, a pioneer in applying statistical concepts to fundamental physics, as when he used the observed jittering of microscopic particles (Brownian motion) to deduce the size of the atom. Einstein also pioneered the new statistics of quanta in advance of the full flowering of quantum theory in 1926. But in these cases, he always sought a nonstatistical underlying theory.

The essentially probabilistic character of quantum theory emerges as we compel subatomic matter to respond to experiments built to human size. In so doing, we exert an unavoidable and uncontrollable (though limited) influence on what we observe, an influence that always bears the mark of our observation. As Werner Heisenberg put it, "the object of research is no longer nature in itself but rather nature exposed to man's questioning, and to this extent man here also meets himself." We are no longer grappling only with the protean forms of matter in the labyrinth. Commenting on Heisenberg's insight, Gerald Holton evoked the possibility that we traverse "the labyrinth with the empty center, where the investigator meets only his own shadow and his blackboard with his own chalk marks on it, his own solutions to his own puzzles."[5] Here even the dice-playing God has disappeared, or never

4 Any complex number z can be written as $z = a + bi$, where a and b are real numbers and i is $\sqrt{-1}$. Then the absolute square of z is defined to be $|z|^2 = (a + bi)(a - bi) = a^2 + b^2$, a positive real number.

5 See Gerald Holton, *Thematic Origins of Scientific Thought*, 1st ed. (Cambridge, Mass.: Harvard University Press, 1973), 34–36.

come, leaving only a mocking echo to taunt us.

Well before these issues emerged in physics, Darwin's account of natural selection pointed to the randomness at the heart of biology. Under the urbane, cheerful civility of *The Origin of Species* lies an abyss. Contrary to common opinion, identifying us as ambitious apes was not Darwin's greatest scandal; after all, the doctrine of original sin also undermines human pretension, holding that nature fell with our fall. No, our relation to the primates merely reveals us to be *nouveaux riches* trying to live down our humble origins. Far more disturbing is Darwin's veiled but unmistakable disproof of divine providence, though he himself remained faithful to the older tradition of natural theology and did not draw this more radical conclusion.[6] Nevertheless, in flat contradiction of any "special providence in the fall of a sparrow," Darwin's nature is utterly heedless. No purpose or direction guides natural selection; there is only the battle to survive and (far more important) to prevail in reproduction.

As a result, the process of the origination of species constantly hides and even annihilates those origins, not purposively but through random carnage and mere oblivion. If so, what is hidden about that process is not some divine secret or intelligible law, but a blind, implacable play of random variations in mindless competition. Indeed, in Darwin's account, mind itself emerges randomly in the course of that struggle.

Darwin did not merely present an alternative account to Genesis; he undermined any account not based on chance. In so doing, he tacitly questioned the presumption that physical science excludes randomness and natural selection. To be sure, he himself raised no such question, but gradually physicists raised it themselves.

James Clerk Maxwell, a religious man, would not allow Darwin's theories to be discussed in his presence. In 1872, Maxwell took pains to deny that atoms evolved, since they show no evidence of variation or selection, no "missing links" or signs of evolution or change, "as though they had all been cast in the same mould, like bullets, not merely selected and grouped according to their size, like small shot." Likewise, Maxwell noted the perfect likeness of atomic spectra on Earth and distant stars, "like tuning-forks all tuned to concert pitch," all cut to a universal measure, "the double royal cubit of the Temple of Karnak." For him, this was powerful testimony to the perfect workmanship of the divine Manufacturer. Implicitly, Maxwell wished to exorcise the ghastly specter of Darwinian randomness from any intercourse with the universality of physical law. Yet his reaction indicated that the Darwinian possibility was present in his mind. Maxwell took the observed equality of atomic properties and spectra as positive evidence for the unity of the universe and the sameness of its constituents. So far, no evidence has emerged to contradict either of those propositions.

But now consider Andrei Linde's suggestion that, rather than there being only one universally valid set of physical laws, there are many different universes, each with its own laws of nature, each randomly different from the other. Linde's "chaotic inflationary universe" calls into question the presumption that there is a unique set of God's thoughts, the physical laws of a unique universe.

6 See John F. Cornell, "God's Magnificent Law: The Bad Influence of Theistic Metaphysics on Darwin's Estimation of Natural Selection," *Journal of the History of Biology* 20 (1987): 381 – 412.

His proposal that multiple universes have randomly different physical laws still lacks any observation that might confirm or deny it. Yet his hypothesis is not merely a perverse possibility but follows the probabilistic direction of quantum mechanics. Uncomfortably, we remember that once we presumed the Earth was unique, central. Is the assumption that there is *any* unique universal physical law another childish dream from which we must awaken?

Here the crux may be the randomness of the physical laws differentiating these universes. Such 'laws' appear ungrounded on any principle or necessity. If random, they cannot be God's thoughts, because they are not the product of *any* thought, much less that of God. In the 'many worlds' interpretation of quantum theory put forward by Hugh Everitt in 1957, each possible path is a world unto itself. At every instant, an infinite array of branching paths leads into the future, though at any time we only experience *one* of these possibilities, the fork we happen to have taken. Linde's suggestion takes this idea a step further: alternative universes may not be absolutely separated (as in the many worlds view), but extremely distant. To be sure, Everitt's many worlds may be simply alternative versions of the same universe, while Linde's universes may have no relation to each other, since their physical laws are fundamentally (if randomly) different.

The bizarre quality of these suggestions shows why Einstein would have wanted to exclude them from God's thoughts. (In contrast, Niels Bohr thought we have no right to tell God what to do; surely the Old One may gamble without our consent.) Yet I think that this problem has a deeper resolution stemming from the interpretation of amplitudes and probabilities first articulated by Max Born in 1926. So far, we have treated 'reality' as a single level, whether encompassing one universe or many. But quantum mechanics operates on *two* levels, even in the simplest examples. First is the inner level of the amplitudes. Since these are complex numbers, they are not observable. Nevertheless, they follow strictly deterministic mathematical equations (like those of Erwin Schrödinger or Paul Dirac) as they unfold in time. Second is the outer level of probabilities. These are positive real numbers predicting the results of actual observation and experiment. However, these probabilities do not, like their constituent amplitudes, follow deterministic mathematical equations; this is the very meaning of probability as opposed to certainty. Despite randomness on the level of observation, the inner level of quantum mechanics is deterministic, not random.

This may give the key to our problem: wherever there is randomness, consider another level of reality that weights the manifold of possibilities. In the case of Linde's universes, let each universe and its space-time be represented by a single point in a superspace and by a corresponding amplitude for its formation. Seek then the equation (now in superspace, not ordinary space) that describes the evolution of each sort of universe. God only appears to be gambling if we look only at one level of reality. To make sense of this, we must give up a simple, unequivocal sense of 'reality.'

Einstein was not willing to pay this price; he thought that physics should deal with observation and be determined unequivocally on that level. He hoped by some artifice of fields and geometry to account for quantum phenomena. His efforts met with no success, and quantum theory remains uncontradicted by any experiment so far.

This is a warrant to embrace the multiplicity of realities – not to resist them.

The idea of such multiple realities is not new. Mathematics has considered alternatives to Euclidean space since the early nineteenth century. In the early twentieth century, John von Neumann showed that quantum theory is most naturally formulated in Hilbert space, an infinite-dimensional manifold of 'state vectors.' Economic models routinely rely on 'spaces' of high dimensionality, each dimension a different economic index. Yet we speak of the Dow Jones Index going 'up,' as if it were an object in ordinary space.

But these are only *representations*, whose relation to reality was Immanuel Kant's deep concern. His *Critique of Pure Reason* (1781) separated *phenomena* (the world as it appears to us) from *noumena* (the ultimate nature of things in themselves). By dividing reality in this way, Kant sought to protect Newtonian physics from David Hume's skeptical question: What guarantees that physical law and causality are valid, beyond our expectations based on past experience? To this, Kant conceded that we cannot know by pure reason *anything* about things in themselves. Physical law applies to phenomena alone. In his vivid image, we live on an isolated island (the phenomena) surrounded by vast, unfathomable depths (the noumena). The coherence of our science depends on the built-in categories of the human mind, rather than the unknowable depths of nature.

Kant's two levels of reality are comparable to those of quantum theory. Observable appearances are like probabilities; noumena are like amplitudes. However, Kant denies that pure reason can acquire any knowledge of noumena, but the inner, unobservable quantum amplitudes are perfectly intelligible, totally determined by fundamental equations. Ironically, it is the outer level of observation that is probabilistic, not completely knowable. In this way, quantum theory shares Kant's divided view of reality but takes it in a very different direction. This dialogue between physics and philosophy has only just begun.

Every reality has its price and its value, which we need to gauge. The possibility of illusion is ever-present, for the multiplication of 'realities' lends each one of them a certain quality of unreality, of deceptiveness through being an alternative or a part, not a whole. The difference between levels of reality cannot be dismissed; probabilities are not the same as amplitudes, though we must pay heed to both. Here, Bacon reminds us that we must not merely gaze aimlessly at the varying shapes of Proteus.

First and foremost, we have to wrestle with the premise that reality could be multiple. Is not the concept of 'reality' singular, unique by its very definition? Out of several 'realities,' must not one of them be the most fundamental, the real reality? So at least Einstein seemed to assume. Yet the two levels of quantum theory both seem necessary because neither can be reduced to the other. If we consider amplitudes more fundamental, we dismiss the observable world and its inescapable probabilities. Since each of us is composed of roughly a hundred trillion trillion (10^{26}) atoms, we take for granted prejudices based on our sheer size. Because of this, we tend to identify 'reality' with the familiar world of distinguishable, macroscopic individuals. But on the atomic scale, there are no such individuals.[7] This subverts our 'common-sense' assumptions about

7 I have discussed this at length in *Seeing Double* (Cambridge, Mass.: MIT Press, 2002).

reality and is at the heart of quantum theory.

However, our argument does show the problem of insisting on wholly incoherent, separate 'realities,' for probabilities and amplitudes are deeply connected because the one is the absolute square of the other. Perhaps then the better term for them is 'levels of reality.' Bacon held that the "hidden God" of scripture delights in our search into his divine abyss. Perhaps it may be naive or outmoded to speak thus about the hidden levels of reality. Yet what more secret mark could sign a book of secrets?

What unites these divergent realities may be nothing other than the human mind itself. The effort to connect the disparate, to mediate between our inner and outer worlds, is precisely the struggle of consciousness. Here, it is crucial that there is no formula that connects them, that our experience is irreducibly multiform. In the face of this, our efforts of thought aim to bridge these gaps and grasp a seamless whole. Certainly it is the ambition of most philosophical systems to resolve the blooming confusion of the world into consonance.

In contrast, Plato reminds us that the basic notion of 'system' misses the essential character of our experience, which is closer to dialogue than monologue. Science works by drastically oversimplifying the world, cutting out everything that cannot be mathematized. Our quest for meaning must bracket this unsparing simplification within a broader perspective that struggles to grasp some larger wholeness, if only by trying, and failing, to connect the disparate pieces. In the moment of failure, we feel most clearly the leap between levels. That surprising, sinking, excited feeling may be the essence of thought as felt experience, rather than as bare abstraction.

The felt character of this divided world, which is the inner dilemma of the scientist, reaches out to touch all who partake in the insights of science. Unlike the common stereotype of cold abstraction, the real problem is that the process of scientific thought is so hot to grasp something radically new, yet deliberately chilled to temper and chasten merely wishful thinking. The simultaneous feeling of opposites, of hot and cold together, results in a kind of shiver, exactly the feeling Einstein remembered in old age about his earliest memory – looking at the compass in his father's hand and realizing that "something deeply hidden had to be behind things." Such a *frisson* goes beyond pain and pleasure to indicate the powerful experience of new insight, and signal a drastic departure from common humanity. It is, I suggest, a deep element of the inner perils and exaltations of the scientific experience.

There is a curious parallel in behavioral psychology. Consider Ivan Pavlov's famous experiments conditioning dogs to expect food after a bell is rung or an electric shock after a buzzer sounds. When both the bell and buzzer sound simultaneously, most dogs exhibit strong signs of anxiety, unsure whether they are to be fed or shocked. However, at that juncture a very few dogs suddenly cease to be conditioned to *either* stimulus. Under the paradoxical stress, it is as if the scales fall from the dogs' eyes to reveal bell and buzzer as meaningless constructs. Through their peculiar experience of cognitive dissonance, those few dogs have entered a new relation to 'reality,' precisely because they fully experienced its doubleness, if not duplicity. Perhaps they enter into complete canine cynicism and disillusionment about their trainers' deceitfulness. At least, they are intractable to further conditioning.

Like Pavlov's dogs confronted with the simultaneous sounding of bell and buzzer, scientists subjected to contrary yet superimposed levels of reality may suddenly cease to regard any single level in the way they had been conditioned. They may feel:

> like some watcher of the skies
> When a new planet swims into his ken;
> Or like stout Cortez when with eagle eyes
> He stared at the Pacific – and all his men
> Look'd at each other with a wild surmise –
> Silent, upon a peak in Darien.[8]

The crisis comes not from one level but from the deeply felt dissonance between many. If they can withstand the resultant emotional stress, they may experience a sudden realization. What then? Perhaps they will recognize the one, true level of reality, of which all other levels are merely distorted reflections. Perhaps they will turn away in disillusionment, as if such discord mocks all meaning. Or perhaps in the very multiplicity they will recognize a new, dissonant polyphony.

Einstein once remarked that "the real nature of things, that we shall never know, never." Max Planck also believed that "science cannot solve the ultimate mystery of nature. And that is because, in the last analysis, we ourselves are part of nature and therefore part of the mystery that we are trying to solve." Even so, Planck considered that the chief attraction of science is "the pursuit of the unknowable." In the struggle to know what may be unknowable, our mind and nature wrestle on all levels. The bell and buzzer are sounding ever louder. To what will we awaken?

8 John Keats, "On First Looking into Chapman's Homer" (1817).

David Pingree

The logic of non-Western science: mathematical discoveries in medieval India

One of the most significant things one learns from the study of the exact sciences as practiced in a number of ancient and medieval societies is that, while science has always traveled from one culture to another, each culture before the modern period approached the sciences it received in its own unique way and transformed them into forms compatible with its own modes of thought. Science is a product of culture; it is not a single, unified entity. Therefore, a historian of premodern scientific texts – whether they be written in Akkadian, Arabic, Chinese, Egyptian, Greek, Hebrew, Latin, Persian, Sanskrit, or any other linguistic bearer of a distinct culture – must avoid the temptation to conceive of these sciences as more or less clumsy attempts to express modern scientific ideas. They must be understood and appreciated as what their practitioners believed them to be. The historian is interested in the truthfulness of his own understanding of the various sciences, not in the truth or falsehood of the science itself.

In order to illustrate the individuality of the sciences as practiced in the older non-Western societies, and their differences from early modern Western science (for contemporary science is, in general, interested in explaining quite different phenomena than those that attracted the attention of earlier scientists), I propose to describe briefly some of the characteristics of the medieval Indian *śāstra* of *jyotiṣa*. This discipline concerned matters included in such Western areas of inquiry as astronomy, mathematics, divination, and astrology. In fact, the *jyotiṣīs*, the Indian experts in *jyotiṣa*, produced more literature in these areas – and made more mathematical discoveries – than scholars in any other culture prior to the advent of printing. In order to explain how they managed to make such discoveries – and why their discoveries remain largely unknown – I will also need to describe briefly the general social and economic position of the *jyotiṣīs*.

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'*Śāstra*' ('teaching') is the word in Sanskrit closest in meaning to the Greek 'ἐπιστήμη' and the Latin 'scientia.' The teachings are often attributed to gods or considered to have been composed by divine *ṛṣis*; but since there were many of both kinds of superhuman beings, there were many competing varieties of each *śāstra*. Sometimes, however, a school within a *śāstra* was founded by a human; scientists were free to modify their *śāstras* as they saw fit. No one was constrained to follow a system taught by a god.

Jyotiḥ is a Sanskrit word meaning 'light,' and then 'star'; so that *jyotiḥśāstra* means 'teaching about the stars.' This *śāstra* was conventionally divided into three subteachings: *gaṇita* (mathematical astronomy and mathematics itself), *saṃhitā* (divination, including by means of celestial omens), and *horā* (astrology). A number of *jyotiṣīs* (students of the stars) followed all three branches, a larger number just two (usually *saṃhitā* and *horā*), and the largest number just one (*horā*).

The principal writings in *jyotiḥśāstra*, as in all Indian *śāstras*, were normally in verse, though the numerous commentaries on them were almost always in prose. The verse form with its metrical demands, while it aided memorization, led to greater obscurity of expression than prose composition would have entailed. The demands of the poetic meter meant that there could be no stable technical vocabulary; many words with different metrical patterns had to be devised to express the same mathematical procedure or geometrical concept, and mathematical formulae had frequently to be left partially incomplete. Moreover, numbers had to be expressible in metrical forms (the two major systems used for numbers, the *bhūtasaṅkhyā* and the *kaṭapayādi*, will be explained and exemplified below), and the consequent ambiguity of these expressions encouraged the natural inclination of Sanskrit *paṇḍits* to test playfully their readers' acumen. It takes some practice to achieve sureness in discerning the technical meanings of such texts.

But in this opaque style the *jyotiṣīs* produced an abundant literature. It is estimated that about three million manuscripts on these subjects in Sanskrit and in other Indian languages still exist. Regrettably, only a relatively small number of these has been subjected to modern analysis, and virtually the whole ensemble is rapidly decaying. And because there is only a small number of scholars trained to read and understand these texts, most of them will have disappeared before anyone will be able to describe correctly their contents.

In order to make my argument clearer, I will restrict my remarks to the first branch of *jyotiḥśāstra* – *gaṇita*. Geometry, and its branch trigonometry, was the mathematics Indian astronomers used most frequently. In fact, the Indian astronomers in the third or fourth century, using a pre-Ptolemaic Greek table of chords,[1] produced tables of sines and versines, from which it was trivial to derive cosines. This new system of trigonometry, produced in India, was transmitted to the Arabs in the late eighth century and by them, in an expanded form, to the Latin West and the Byzantine East in the twelfth century. But, despite this sort of practical innovation, the Indians practiced geometry without the type of proofs taught by Euclid, in

1 For a description of the table of chords, cyclic quadrilaterals, two-point iteration, fixed-point iteration, and several other mathematical terms mentioned in this essay, please see Victor J. Katz, *A History of Mathematics: An Introduction* (New York: HarperCollins, 1993).

which all solutions to geometrical problems are derived from a small body of arbitrary axioms. The Indians provided demonstrations that showed that their solutions were consistent with certain assumptions (such as the equivalence of the angles in a pair of similar triangles or the Pythagorean theorem) and whose validity they based on the measurement of several examples. In their less rigorous approach they were quite willing to be satisfied with approximations, such as the substitution of a sine wave for almost any curve connecting two points. Some of their approximations, like those devised by Āryabhaṭa in about 500 for the volumes of a sphere and a pyramid, were simply wrong. But many were surprisingly useful.

Not having a set of axioms from which to derive abstract geometrical relationships, the Indians in general restricted their geometry to the solution of practical problems. However, Brahmagupta in 628 presented formulae for solving a dozen problems involving cyclic quadrilaterals that were not solved in the West before the Renaissance. He provides no rationales and does not even bother to inform his readers that these solutions only work if the quadrilaterals are circumscribed by a circle (his commentator, Pṛthūdakasvāmin, writing in about 864, follows him on both counts). In this case, and clearly in many others, there was no written or oral tradition that preserved the author's reasoning for later generations of students. Such disdain for revealing the methodology by which mathematics could advance made it difficult for all but the most talented students to create new mathematics. It is amazing to see, given this situation, how many Indian mathematicians did advance their field.

I will at this point mention as examples only the solution of indeterminate equations of the first degree, described already by Āryabhaṭa; the partial solution of indeterminate equations of the second degree, due to Brahmagupta; and the cyclic solution of the latter type of indeterminate equations, achieved by Jayadeva and described by Udayadivākara in 1073 (the cyclic solution was rediscovered in the West by Bell and Fermat in the seventeenth century). Interpolation into tables using second-order differences was introduced by Brahmagupta in his *Khaṇḍakhādyaka* of 665. The use of two-point iteration occurs first in the *Pañcasiddhāntikā* composed by Varāhamihira in the middle of the sixth century, and fixed-point iteration in the commentary on the *Mahābhāskarīya* written by Govindasvāmin in the middle of the ninth century. The study of combinatorics, including the so-called Pascal's triangle, began in India near the beginning of the current era in the *Chandaḥsūtras*, a work on prosody composed by Piṅgala, and culminated in chapter 13 of the *Gaṇitakaumudī* completed by Nārāyaṇa Paṇḍita in 1350. The fourteenth and final chapter of Nārāyaṇa's work is an exhaustive mathematical treatment of magic squares, whose study in India can be traced back to the *Bṛhatsaṃhitā* of Varāhamihira.

In short, it is clear that Indian mathematicians were not at all hindered in solving significant problems of many sorts by what might appear to a non-Indian to be formidable obstacles in the conception and expression of mathematical ideas.

Nor were they hindered by the restrictions of 'caste,' by the lack of societal support, or by the general absence of monetary rewards. It is true that the overwhelming majority of the Indian mathematicians whose works we know were Brāhmaṇas, but there are exceptions (e.g., among Jainas, non-Brahmānical scribes, and craftsmen). Indian society was far from open, but it was not absolutely rigid; and talented mathematicians, whatever their origins, were not ignored by their colleagues. However, astrologers (who frequently were not Brāhmaṇas) and the makers of calendars were the only *jyotiṣīs* normally valued by the societies in which they lived. The attraction of the former group is easily understood, and their enormous popularity continues today. The calendar-makers were important because their job was to indicate the times at which rituals could or must be performed. The Indian calendar is itself intricate; for instance, the day begins at local sunrise and is numbered after the tithi that is then current, with the tithis being bounded by the moments, beginning from the last previous true conjunction of the Sun and the Moon, at which the elongation between the two luminaries had increased by twelve degrees. Essentially, each village needed its own calendar to determine the times for performing public and private religious rites of all kinds in its locality.

By contrast, those who worked in the various forms of *gaṇita* usually enjoyed no public patronage – even though they provided the mathematics used by architects, musicians, poets, surveyors, and merchants, as well as the astronomical theories and tables employed by astrologers and calendar-makers. Sometimes a lucky mathematical astronomer was supported by a Mahārāja whom he served as a royal astrologer and in whose name his work would have been published. For example, the popular *Rājamṛgāṅka* is attributed, along with dozens of other works in many *śāstras*, to Bhojadeva, the Mahārāja of Dhārā in the first half of the eleventh century. Other *jyotiṣīs* substituted the names of divinities or ancient holy men for their own as authors of their treatises. Authorship often brought no rewards; one's ideas were often more widely accepted if they were presented as those of a divine being, a category that in many men's minds included kings.

One way in which a *jyotiṣī* could make a living was by teaching mathematics, astronomy, or astrology to others. Most frequently this instruction took place in the family home, and, because of the caste system, the male members of a *jyotiṣī*'s family were all expected to follow the same profession. A senior *jyotiṣī*, therefore, would train his sons and often his nephews in their ancestral craft. For this the family maintained a library of appropriate texts that included the compositions of family members, which were copied as desired by the younger members. In this way a text might be preserved within a family over many generations without ever being seen by persons outside the family. In some cases, however, an expert became well enough known that aspirants came from far and wide to his house to study. In such cases these students would carry off copies of the manuscripts in the teacher's collection to other family libraries in other locales.

The teaching of *jyotiḥśāstra* also occurred in some Hindu, Jaina, and Buddhist monasteries, as well as in local schools. In these situations certain standard texts were normally taught, and the status of these texts can be established by the number of copies that still exist, by their geographical distribution, and by the number of commentaries that were written on them.

Thus, in *gaṇita* the principal texts used in teaching mathematics in schools were clearly the *Līlavatī* on arithmetic and the *Bījagaṇita* on algebra, both written by Bhāskara in around 1150, and, among Jainas, the *Gaṇitasārasaṅgraha* composed in about 850 by their coreligionist, Mahāvīra. In astronomy there came to be five *pakṣas* (schools): the *Brāhmapakṣa*, whose principal text was the *Siddhānta-*

śiromaṇi of the Bhāskara mentioned above; the *Āryapakṣa*, based on the *Āryabhaṭīya* written by Āryabhaṭa in about 500; the *Ārdharātrikapakṣa*, whose principal text was the *Khaṇḍakhādyaka* completed by Brahmagupta in 665; the *Saurapakṣa*, based on the *Sūryasiddhānta* composed by an unknown author in about 800; and the *Gaṇeśapakṣa*, whose principal text was the *Grahalāghava* authored by Gaṇeśa in 1520. Each region of India favored one of these *pakṣas*, though the principal texts of all of them enjoyed national circulation. The commentaries on these often contain the most innovative advances in mathematics and mathematical astronomy found in Sanskrit literature. By far the most popular authority, however, was Bhāskara; a special college for the study of his numerous works was established in 1222 by the grandson of his younger brother. No other Indian *jyotiṣī* was ever so honored.

Occasionally, indeed, an informal school inspired by one man's work would spring up. The most noteworthy, composed of followers of Mādhava of Saṅgamagrāma in Kerala in the extreme south of India, lasted for over four hundred years without any formal structure – simply a long succession of enthusiasts who enjoyed and sometimes expanded on the marvelous discoveries of Mādhava.

Mādhava (c. 1360 – 1420), an Emprāntiri Brāhmaṇa, apparently lived all his life on his family's estate, Ilaññipaḷḷi, in Saṅgamagrāma (Irinjālakhuḍa) near Cochin. His most momentous achievement was the creation of methods to compute accurate values for trigonometric functions by generating infinite series. In order to demonstrate the character of his solutions and expressions of them, I will translate a few of his verses and quote some Sanskrit.

He began by considering an octant of a circle inscribed in a square, and, after some calculation, gave the rule (I translate quite literally two verses):

> Multiply the diameter (of the circle) by 4 and divide by 1. Then apply to this separately with negative and positive signs alternately the product of the diameter and 4 divided by the odd numbers 3, 5, and so on.... The result is the accurate circumference; it is extremely accurate if the division is carried out many times.

This describes the infinite series:

$$C = \frac{4D}{1} - \frac{4D}{3} + \frac{4D}{5} - \frac{4D}{7} + \frac{4D}{9} \dots.$$

That in turn is equivalent to the infinite series for π that we attribute to Leibniz:

$$\frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \frac{1}{9} \dots.$$

Mādhava expressed the results of this formula in a verse employing the *bhūtasaṅkhyā* system, in which numbers are represented by words denoting objects that conventionally occur in the world in fixed quantities:

> vibudhanetragajāhihutāśanatriguṇaved-
> abhavāraṇabāhavaḥ ǀ
> navanikharvamite vṛtivistare
> paridhimānam idaṃ jagadur budhāḥ ǁ

A literal translation is:

> Gods [33], eyes [2], elephants [8], snakes [8], fires [3], three [3], qualities [3], Vedas [4], nakṣatras [27], elephants [8], and arms [2] – the wise say that this is the measure of the circumference when the diameter of a circle is nine hundred billion.

The *bhūtasaṅkhyā* numbers are taken in reverse order, so that the formula is:

$$\pi = \frac{2827433388233}{900000000000}$$

(= 3.14159265359, which is correct to the eleventh decimal place).

Another extraordinary verse written by Mādhava employs the *kaṭapayādi* system in which the numbers 1, 2, 3, 4, 5, 6, 7, 8, 9, and 0 are represented by the consonants that are immediately followed by a vowel; this allows the mathematician to create a verse with both a transparent meaning due to the words and an unrelated numerical meaning due to the consonants in those words. Mādhava's verse is:

> vidvāṃs tunnabalaḥ kavīśanicayaḥ sarvārthaśīlasthiro
> nirviddhāṅganarendraruṅ

The verbal meaning is: "The ruler whose army has been struck down gathers together the best of advisors and remains firm in his conduct in all matters; then he shatters the (rival) king whose army has not been destroyed."

The numerical meaning is five sexagesimal numbers:

0;0,44
0;33,6
16;5,41
273;57,47
2220;39,40.

These five numbers equal, with R = 3437;44,48 (where R is the radius) :

$$\frac{5400^{11}}{R^{10}11!}$$

$$\frac{5400^{9}}{R^{8}9!}$$

$$\frac{5400^{7}}{R^{6}7!}$$

$$\frac{5400^{5}}{R^{4}5!}$$

$$\frac{5400^{3}}{R^{2}3!}$$

These numbers are to be employed in the formula:

$$sin\theta = \theta - \left(\frac{\theta}{5400}\right)^3\left[\frac{5400^3}{R^2 3!} - \left(\frac{\theta}{5400}\right)^2\left[\frac{5400^5}{R^4 5!} - \left(\frac{\theta}{5400}\right)^2\left[\frac{5400^7}{R^6 7!} - \left(\frac{\theta}{5400}\right)^2\left[\frac{5400^9}{R^8 9!} - \left(\frac{\theta}{5400}\right)^2\left[\frac{5400^{11}}{R^{10}11!}\right]\right]\right]\right]\right]$$

and this formula is a simple transformation of the first six terms in the infinite power series for $sin\theta$ found independently by Newton in 1660:

$$sin\theta = \theta - \frac{\theta^3}{R^2 3!} + \frac{\theta^5}{R^4 5!} - \frac{\theta^7}{R^6 7!} + \frac{\theta^9}{R^8 9!} - \frac{\theta^{11}}{R^{10}11!}$$

Not surprisingly, Mādhava also discovered the infinite power series for the cosine and the tangent that we usually attribute to Gregory.

The European mathematicians of the seventeenth century derived their trigonometrical series from the application of the calculus; Mādhava in about 1400 relied on a clever combination of geometry, algebra, and a feeling for mathematical possibilities. I cannot here go through his whole argument, which has fortunately been preserved by several of his successors; but I should mention some of his techniques.

He invented an algebraic expansion formula that keeps pushing an unknown quantity to successive terms that are alternately positive and negative; the series must be expanded to infinity to get rid of this unknown quantity. Also, because of the multiplications, as the terms increase, the powers of the individual factors also increase. One of these factors in the octant is one of a series of integers beginning with 1 and ending with 3438 – the number of parts in the radius of the circle that is also the tangent of 45°, the angle of the octant; this means that there are 3438 infinite series that must be summed to yield the final infinite series of the trigonometrical function.

Mathematical discoveries in medieval India

It had long been known in India that the sum of a series of integers beginning with 1 and ending with n is: $n\left(\frac{(n-1)}{2}+1\right)$, that is, $\frac{n^2}{2}-\frac{n}{2}+n$. Since n here equals 3438, Mādhava decided that $n-\frac{n}{2}$, which equals $\frac{3438}{2}$, is negligible with respect to $\frac{3438^2}{2}$. Therefore, an approximation to the sum of the series of n integers is $\frac{n^2}{2}$. Similarly, the sums of the squares of a series of n integers beginning with 1 was known to be $\frac{\frac{n}{2}[2(n+1)^2-(n+1)]}{3}$. If n is large, this is approximately equal to $\frac{n(n+1)^2}{3}$ since $\frac{-(n+1)}{6}$ is negligible. But, with $n = 3438$, $\frac{3438 \times 3439^2}{3}$ is little different from $\frac{3438^3}{3}$. Therefore, as an approximation, the sum of the series of the squares of 3438 integers beginning with 1 is $\frac{n^3}{3}$. Finally, it was known that the sum of the cubes of a series of n numbers beginning with 1 is: $\left(\frac{n}{2}\right)^2(n+1)^2$ or $\frac{n^2(n+1)^2}{4}$. If n is 3438, there is little difference between $\frac{3438^2 \times 3439^2}{4}$ and $\frac{3438^4}{4}$. Therefore, the expression $\frac{n^4}{4}$ is a close approximation to the sum of the cubes of a series of n numbers beginning with 1. From these three examples Mādhava guessed at the general rule that the sum of n numbers in an arithmetical series beginning with 1 all raised to the same power, p, is approximately equal to $\frac{n^{p+1}}{p+1}$.

It had also been realized in India since the fifth century – from examining the sine table in which the radius of the circle, R, is $\frac{21{,}600}{2\pi}$ (which was approximated by 3438) and in which there are 24 sines in a quadrant of 90°, so that the length of each arc whose sine is tabulated is 225′ – that the sine of any tabulated angle θ is equal to θ minus the sum of the sums of the second differences of the sines of the preceding tabulated angles. Mādhava discovered, by some very clever geometry, that the sum of the sums of the second differences approximately equals $\frac{\theta^3}{R^2 3!}$ and that the versine of θ is approximately equal to $\frac{\theta^2}{2R}$. Since $sin^2\theta = R^2 - cos^2\theta$ and $vers\theta = R - cos\theta$, Mādhava could correct the approximation to the versine by the approximation to the sum of the sums of the second differences of tabulated sines; then he could correct the approximation to the sum of the sums of the second differences by the corrected approximation to the versine; and he could continue building up the two parallel series by applying alternating corrections to them. He finally arrives at two infinite power series, equivalent, if $R = 1$, to:

$$sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \frac{\theta^9}{9!} \ldots,$$

and

$$cos\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \frac{\theta^6}{6!} + \frac{\theta^8}{8!} \ldots.$$

Subsequent members of the 'school' of Mādhava did remarkable work as well, in both geometry (including trigonometry) and astronomy. This is not the occasion to recite their accomplishments, but I should remark here that, among these members, Indian astronomers attempted especially to use observations to correct astronomical models and their parameters.

This began with Mādhava's principal pupil, a Nampūtiri Brāhmaṇa named Parameśvara, whose family's illam was Vaṭaśreṇi in Aśvatthagrāma, a village about thirty-five miles northeast of Saṅgamagrāma. He observed eighteen lunar and solar eclipses between 1393 and 1432 in an attempt to correct traditional Indian eclipse theory. One pupil of Parameśvara's son, Dāmodara, was

Nīlakaṇṭha – another Nampūtiri Brāhmaṇa who was born in 1444 in the Kelallūr illam located at Kuṇḍapura, which is about fifty miles northwest of Aśvatthagrāma.

Nīlakaṇṭha made a number of observations of planetary and lunar positions and of eclipses between 1467 and 1517. Nīlakaṇṭha presented several different sets of planetary parameters and significantly different planetary models, which, however, remained geocentric. He never indicates how he arrived at these new parameters and models, but he appears to have based them at least in large part on his own observations. For he proclaims in his *Jyotirmīmāṃsā* – contrary to the frequent assertion made by Indian astronomers that the fundamental *siddhāntas* expressing the eternal rules of *jyotiḥśāstra* are those alleged to have been composed by deities such as Sūrya – that astronomers must continually make observations so that the computed phenomena may agree as closely as possible with contemporary observations. Nīlakaṇṭha says that this may be a continuous necessity because models and parameters are not fixed, because longer periods of observation lead to more accurate models and parameters, and because improved techniques of observing and interpreting results may lead to superior solutions. This affirmation is almost unique in the history of Indian *jyotiṣa*; *jyotiṣīs* generally seem to have merely corrected the parameters of one *pakṣa* to make them closely corresponded to those of another.

The discoveries of the successive generations of Mādhava's 'school' continued to be studied in Kerala within a small geographical area centered on Saṅgamagrāma. The manuscripts of the school's Sanskrit and Malayālam treatises, all copied in the Malayālam script, never traveled to another region of India; the furthest they got was Kaṭattanāt in northern Kerala, about one hundred miles north of Saṅgamagrāma, where the Rājakumāra Śaṅkara Varman repeated Mādhava's trigonometrical series in a work entitled *Sadratnamālā* in 1823. This was soon picked up by a British civil servant, Charles M. Whish, who published an article entitled "On the Hindú Quadrature of the Circle and the Infinite Series of the Proportion of the Circumference to the Diameter in the Four Sástras, the Tantra Sangraham, Yocti Bháshá, Carana Paddhati and Sadratnamála" in *Transactions of the Royal Asiatic Society* in 1830.[2] While Whish was convinced that the Indians (he did not know of Mādhava) had discovered calculus – a conclusion that is not true even though they successfully found the infinite series for trigonometrical functions whose derivation was closely linked with the discovery of calculus in Europe in the seventeenth century – other Europeans scoffed at the notion that the Indians could have achieved such a startling success. The proper assessment of Mādhava's work began only with K. Mukunda Marar and C. T. Rajagopal's "On the Hindu Quadrature of the Circle," published in the *Journal of the Bombay Branch of the Royal Asiatic Society* in 1944.

So while the discoveries of Newton, Leibniz, and Gregory revolutionized European mathematics immediately upon their publication, those of Mādhava, Parameśvara, and Nīlakaṇṭha, made between the late fourteenth and early sixteenth centuries, became known to a handful of scholars outside of Kerala in

2 Note that the *Tantrasaṅgraha* was written by the Nīlakaṇṭha whom we have already mentioned, the *Yuktibhāṣa* by his colleague and fellow pupil of Dāmodara, Jyeṣṭhadeva, and the *Karaṇapaddhati* by a resident of the Putumana illam in Śivapura in 1723.

India, Europe, America, and Japan only in the latter half of the twentieth century. This was not due to the inability of Indian *jyotiṣīs* to understand the mathematics, but to the social, economic, and intellectual milieux in which they worked. The isolation of brilliant minds was not uncommon in premodern India. The exploration of the millions of surviving Sanskrit and vernacular manuscripts copied in a dozen different scripts would probably reveal a number of other Mādhavas whose work deserves the attention of historians and philosophers of science. Unfortunately, few scholars have been trained to undertake the task, and the majority of the manuscripts will have crumbled in just another century or two, before those few can rescue them from oblivion.

Susan Haack

Trials & tribulations: science in the courts

> "I should like to know" [asked Mr. Chichely] "how a coroner is to judge of evidence if he has not had a legal training?"
>
> "In my opinion," said Lydgate, "legal training only makes a man more incompetent in questions that require knowledge of another kind. People talk about evidence as if it could really be weighed in scales by a blind Justice. No man can judge what is good evidence on any particular subject unless he knows that subject well. A lawyer is no better than an old woman at a post-mortem examination. How is he to know the action of a poison? You might as well say that scanning verse will teach you to scan the potato crops."
>
> – George Eliot, *Middlemarch* (1872)

Justice requires just laws, of course, and just administration of those laws; but it also requires factual truth. And in determining factual truth, in both criminal and civil cases, courts very often need to call on scientists: on toxicologists and tool-mark examiners, epidemiologists and engineers, serologists and psychiatrists, experts on PCBs and experts on paternity, experts on rape trauma syndrome and experts on respiratory disorders, experts on blood, on bugs, on bullets, on battered women, etc. For, as science has grown, so too has the legal system's dependence on scientific evidence; it has been estimated that by 1990 around 70 percent of cases in the United States involved expert testimony, most of it scientific. Such testimony can be a powerful tool for justice; but it can also be a powerful source of confusion – not to mention opportunities for opportunism.

Who could have imagined, when DNA was first identified as the genetic material half a century ago, that DNA analysis would by now have come to play so large a role in the criminal justice system, and in the public perception of the law? Even twenty years ago, forensic scientists could tell only whether a blood sample was animal or human, male or female, and, if human, of what type (the least common blood type being found in 3 percent, and the commonest in 43 percent, of the U.S. population). Then, in the mid-1980s, DNA 'fingerprinting' made vastly more accurate identification

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possible, to probabilities of the order of a billion to one; and by now new techniques have made it possible to amplify and test the tiniest samples.

At first, such evidence was strenuously contested in court; but as its solidity, and its power to enable justice, became unmistakable, the 'DNA wars' gradually died down. By the spring of 2002, DNA testing had exonerated more than a hundred prisoners, including a significant number on death row, and helped convict numerous rapists and murderers. In at least one instance, it both exonerated and convicted the same person: after serving nearly eleven years of a twenty-five-to-fifty-year sentence for rape, Kerry Kotler was released in 1992 when newly conducted DNA tests established his innocence; less than three years after his release, he was charged with another rape, and this time convicted on the basis of DNA analysis identifying him as the perpetrator.

Even so, DNA evidence can present problems of its own: police officers and forensic technicians make mistakes – and have been known deliberately to falsify or misrepresent evidence; juries may misconstrue the significance of expert testimony about the probability of a random match with the defendant, or of information about the likelihood that a sample was mishandled – and attorneys have been known to contribute to such misunderstandings; criminals devise devious ways to circumvent DNA identification – and at least one prisoner, apparently hoping to exploit the potential for confusion, has petitioned for a DNA test that, as he must have anticipated, confirmed his guilt.

And who could have imagined, when Hugo Münsterberg urged in his *On the Witness Stand: Essays on Psychology and Crime* (1908) that the law avail itself of the work of experimental psychologists on the reliability of memory, perception, and eyewitness testimony, that less than half a century later psychological evidence would play a significant role in such landmark constitutional cases as *Brown v. Board of Education* (1954), or that by now it would have come to play so large a role in the criminal justice system – or that it would be the focus of seemingly endless controversy? For while the work of experimental psychologists on eyewitnesses, memory, etc., has indeed proved useful, clinical psychologists' and psychiatrists' diagnoses of this syndrome and that, and especially their theories about the repression and recovery of traumatic memories, have been the subject of heated battles in the courtroom, in the press, and in the academy.

In the mid-1980s, testimony of allegedly repressed and recovered memories came to public attention in the McMartin Preschool case – the longest U.S. criminal trial ever (six years), and one of the most expensive (around $15 million). But in 1990 the seven defendants were acquitted of the ritual sexual abuse that, under the influence of therapists, numerous children at the school had claimed to remember. George Franklin spent nearly seven years in prison for the murder of nine-year-old Susan Nason, convicted on his daughter's supposed memory of the event, recovered under hypnosis twenty years afterward; he was released in 1996, after his daughter also 'remembered' his committing two other murders, with respect to one of which he could be unambiguously ruled out. (Franklin later sued prosecutors and the experts who testified against him for wrongful prosecution and violation of his civil rights.) By the late 1990s, it began to seem that critics such as experimental psychologist Elizabeth Loftus, who had maintained all along that supposedly repressed and recovered 'memories' could be the result of therapists' suggestive questioning, were vindicated. But recently the 'memory wars' have flared up all over again, this time in legal claims filed against Catholic priests accused of sexual abuse of children and young people.

Why has the legal system found scientific testimony hard to handle? Ever since there have been scientific witnesses, lawyers and legal scholars – like Eliot's Mr. Chichely – have had their doubts about them. The commonest complaint has been that venal scientists brought in by unscrupulous attorneys will testify to just about anything a case demands. In 1858, the Supreme Court observed that "experience has shown that the opposite opinions of persons professing to be experts may be obtained in any amount"; in 1874, John Ordronaux wrote in the *American Journal of Insanity* that "If Science, for a consideration, can be induced to prove anything which a litigant needs in order to sustain his side of an issue, then Science is fairly open to the charge of venality and perjury, rendered the more base by the disguise of natural truth in which she robes herself." More than a century later, in *Galileo's Revenge* (1991), Peter Huber was sounding a similar theme: junk science – "data dredging, wishful thinking, truculent dogmatism, and, now and again, outright fraud" – was flooding the courts. Some scientists concur. In her study of the silicone breast implant fiasco, *Science on Trial* (1996), Marcia Angell complains that "[e]xpert witnesses may wear white coats, be called 'doctor,' purport to do research, and talk scientific jargon. But too often they are merely adding a veneer to a foregone, self-interested conclusion"; in *Whores of the Court* (1997), an exposé of flimsy psychiatric and clinical testimony, experimental psychologist Margaret Hagen writes of "charlatans and greedy frauds."

But other scientists – like Eliot's Dr. Lydgate – think the real problem is, rather, that jurors, attorneys, and judges are too illiterate scientifically to discriminate sound science from charlatanism. Norman Levitt, for example, commenting in *Prometheus Bedeviled* (1999) on the "noisome travesty" of the O. J. Simpson trial, complains that "the basic principles of statistical inference were opaque to all concerned except the witnesses themselves. The lawyers . . . , the judge, the dozens of commentators . . . , and certainly the woozy public – all seemed utterly ignorant as to what . . . statistical independence might mean . . . . All the other scientific issues encountered the same combination of neglect and evasion."

There surely are venal and incompetent scientific witnesses, and there surely are scientifically ignorant and credulous jurors, attorneys, and judges; but the familiar complaints gloss over many complexities. Scientific testimony may be flawed by outright fraud, or, more often, by the overemphatic presentation of scanty or weak evidence; it may be solid science misapplied by a poorly run laboratory, or serious but highly speculative and controversial science, or sloppily conducted scientific work, or pseudoscientific mumbo jumbo. The motive may be an expert's greed, or his desire to feel important, or his anxiety to help the police or a sympathetic plaintiff; or it may be a scientist's conservatism about new and radical-sounding ideas; or a plaintiff's attorney's interest in keeping disputes long settled in science legally alive. Failures of understanding may be due to jurors' or judges' or attorneys' inability to follow complex statistical reasoning, or to their ignorance of the kind of controls needed in this or that type of experiment or study, or to their excessive deference to science, or their resentment of its perceived elitism. Or the problem may simply be jurors' sense that *someone* should compensate the victim of an awful disease or injury, or that *someone* should be punished for a horrible crime.

And the familiar complaints also gloss over the deep tensions between science and the law that are at the root of these problems. The culture of the law is adversarial, and its goal is case-specific, final answers. The culture of the sciences, by contrast, is investigative, speculative, generalizing, and thoroughly fallibilist: most scientific conjectures are sooner or later discarded, even the best-warranted claims are subject to revision if new evidence demands it, and progress is ragged and uneven. Science doesn't always have the final answers the law wants, or not when it wants them; and even when science has the answers, the adversarial process can seriously impede or distort communication. It's no wonder that the legal system often asks more of science than science can give, and often gets less from science than science could give; nor that strong scientific evidence sometimes falls on deaf legal ears, while flimsy scientific ideas sometimes become legally entrenched.

One response to the difficulties has been to try to tame scientific testimony by devising legal rules of admissibility to ensure that judges don't allow flimsy stuff to be presented to juries. But, as the tortuous history of efforts to frame such formal rules suggests, no legal form of words could guarantee that only good-enough scientific testimony is admitted. Another response has been, instead, to adapt the culture of the law, bringing it more into line with science by compromising adversarialism or the concern for finality. But these pragmatic and piecemeal strategies, though in some ways more promising, raise hard questions about why we value trial by jury, why we want finality, and whether the adversarial process is really an optimal way of ensuring – in the words of the preamble to the Federal Rules of Evidence – "that the truth be ascertained."

The present practice of relying on experts proffered by the parties not to report on what they saw but rather to give their informed opinion, evolved only gradually, along with the growth of the adversary system, cross-examination, and formal rules governing the admissibility of evidence. For a long time it was required only that a scientific witness, like any other expert witness, establish his qualifications as an expert – until 1923, when the *Frye*[1] ruling imposed new restrictions on the proffered testimony itself.

In *Frye*, excluding testimony of a then new blood-pressure deception test, the D.C. court ruled that novel scientific evidence was admissible only if it had gained "general acceptance in the field to which it belongs." At first cited only quite rarely, and almost always with regard to lie-detector evidence, the *Frye* rule gradually came to be widely followed in criminal trials, and by 1979 had been adopted in a majority of states. (It remains officially the law today in a number of states, Florida included.) Of course, general acceptance is a better proxy for scientific robustness when the field in question is a mature, established scientific specialty than when it is a highly speculative area of research – or, worse, the professional turf of a trade union of mutually supportive charlatans. Moreover, the rule is highly manipula-

1 *Frye v. United States*, 54 App. D.C. 46, 293 F. 1013 (1923).

ble, depending, among other things, on how broadly or narrowly a court construes the field in question. Nevertheless, a main focus of criticism was that the *Frye* test was too restrictive.

The Federal Rules of Evidence (1975) seemed to set a less restrictive standard: the testimony of a qualified expert is admissible provided only that it is relevant, and not legally excluded on grounds of unfair prejudice, waste of time, or potential to confuse or mislead the jury. In line with the Federal Rules' apparently liberal approach, in *Barefoot*,[2] a 1983 constitutional case, the Supreme Court affirmed that the rights of a Texas defendant were not violated by the jury's being allowed, in the sentencing phase, to hear psychiatric testimony predicting his future dangerousness – even though an amicus brief filed by the American Psychiatric Association reported that two out of three psychiatric predictions of future dangerousness are mistaken. Justice White, writing for the majority, observed that the Federal Rules anticipate that courts will admit relevant evidence and leave it to juries, with the help of cross-examination and presentation of contrary witnesses, to determine its weight. In dissent, however, noting that a scientific witness has a special aura of credibility, Justice Blackmun averred that "[i]t is extremely unlikely that the adversary process will cut through the facade of superior knowledge."

By the late 1980s, as legal scholars debated whether the Federal Rules had or hadn't superseded *Frye*, and whether a more or a less restrictive approach to scientific testimony was preferable, there was rising public and political concern that the tort system was getting out of hand; a crisis due in large measure, Huber argued in his influential book, to scandalously weak scientific testimony that would have been excluded under *Frye* but was being admitted under the Federal Rules. Then in 1993, with proposals before Congress to tighten up the Federal Rules, the Supreme Court issued its ruling in the landmark *Daubert* case[3] – the first case in the Court's 204-year history where the central issue was the standard of admissibility of scientific testimony.

Daubert was a tort action against Merrell Dow Pharmaceuticals brought by parents who claimed that their children's severe birth defects had been caused by their mothers' taking the company's morning sickness drug, Bendectin, during pregnancy. In excluding the plaintiffs' expert testimony, the lower court had cited *Frye* (which up till then, contrary to Huber's diagnosis, had almost always been cited in criminal, not civil, cases). Remanding the case, the Supreme Court held that the Federal Rules had superseded *Frye*, but added that the Rules themselves required judges to screen proffered expert testimony not only for relevance, but also for reliability.

Justice Blackmun wrote for the majority that courts must look not to an expert's conclusions, but to his methodology, to determine whether proffered testimony is really "scientific . . . knowledge," and hence reliable. Citing law professor Michael Green citing philosopher of science Karl Popper, and adding a quotation from Carl Hempel for good measure, the ruling suggested four factors for courts to consider: falsifiability, i.e., whether the proffered evidence can be, and has been, tested; the known or potential error rate; peer review and publication; and (in a nod to *Frye*) acceptance in the relevant scientific com-

2 *Barefoot v. Estelle*, 463 U.S. 880, 103 S.Ct. 3383 (1983).

3 *Daubert v. Merrell Dow Pharm. Inc.*, 509 U.S. 579, 113 S.Ct. 2786 (1993).

munity. Dissenting in part, however, Justice Rehnquist pointed out that the word 'reliable' nowhere occurs in the text of Rule 702; anticipated that there would be difficulties over whether and how *Daubert* should be applied to nonscientific expert testimony; worried aloud that federal judges were being asked to be amateur scientists; and questioned the wisdom of his colleagues' foray into the philosophy of science.

That foray was indeed (if you'll pardon the expression) ill judged. As Justice Blackmun's ellipses acknowledge, Rule 702 doesn't speak of "scientific knowledge," but of "scientific or other technical knowledge." However, doubtless influenced by the honorific use of "science" and "scientific" as all-purpose terms of epistemic praise, the majority apparently took for granted that there is some mode of inference or procedure of inquiry, some methodology, that is distinctive of genuinely scientific, and hence reliable, investigation. And so they reached for Popper's criterion of demarcation, according to which the hallmark of genuine science is that it is falsifiable, i.e., could be shown to be false if it is false; and for his account of the scientific method as conjecture and refutation, i.e., as making bold hypotheses, testing them as severely as possible, and, if they are falsified, giving them up and starting again rather than protecting them by ad hoc maneuvers. Unfortunately, however, Popper's philosophy of science is singularly ill suited as a guide to reliability; for, if he were right, scientific theories could never be shown to be true or even probable, but at best "corroborated," by which Popper means only "tested but not yet falsified." And so the Court ran Popper together with Hempel, whose logic of confirmation does allow that scientific claims can be confirmed as well as disconfirmed.

But Popper's and Hempel's philosophies of science are not compatible. Worse, neither can supply the hoped-for crisp criterion to discriminate the scientific, and hence reliable, from the unscientific, and hence unreliable. No philosophy of science could do this; no such criterion is possible, for not all scientists, and not only scientists, are good, reliable inquirers. Nor is there a uniquely rational mode of inference or procedure of inquiry used by all scientists and only by scientists – no 'scientific method' in the sense the Court assumed. Rather, as Einstein once put it, scientific inquiry is "a refinement of our everyday thinking," superimposing on the inferences, desiderata, and constraints common to all serious empirical inquiry a vast variety of amplifications and refinements of human cognitive powers: instruments of observation, models and metaphors, mathematical and statistical techniques, experimental controls, etc., devised by generation upon generation of scientists, constantly evolving, and often local to this or that area of science.

So perhaps it is no wonder that in the two subsequent decisions in which it has spoken on the admissibility of expert testimony, the Supreme Court quietly backed away from the confused philosophy of science built into *Daubert*. In the Court's ruling in *Joiner*[4] (a toxic tort case involving PCB exposure), references to Hopper, Pempel, falsifiability, scientific method, etc., are conspicuous by their absence; and the distinction between methodology and conclusions, crucial to *Daubert*, is repudiated as not really viable after all. And in response to inconsistent rulings across the circuits over the applicability of *Daubert* to nonscientific experts, in *Kumho*[5] (a product liability case

4 *General Electric Co. v. Joiner*, 522 U.S. 136, 118 S.Ct. 512 (1997).

5 *Kumho Tire Co. v. Carmichael*, 526 U.S. 137, 119 S.Ct. 1167 (1999).

involving a tire blowout) the Court ruled that *Daubert* applies to all expert testimony, not only the scientific. According to the *Kumho* Court, the key word in Rule 702 is "knowledge," not "scientific"; what matters is whether proffered testimony is reliable, *not* whether it is science.

However, the Supreme Court certainly didn't back away from its commitment to federal judges' gatekeeping responsibilities. Far from it. In *Joiner*, the Court affirmed that a judge's decision to allow or exclude scientific testimony, even though it may determine the outcome of a case, is subject only to review for abuse of discretion, not to any more stringent standard. And in *Kumho*, stressing that the factors listed in *Daubert* are "flexible," the Court ruled that a judge may use any, all, or none of them. So, abandoning the false hope of finding a form of words to discriminate "reliable, scientific" testimony from the rest, the *Kumho* Court left federal judges with wide-ranging responsibility and considerable discretion in determining whether expert testimony is reliable enough for juries to hear, but with little guidance about how to do this.

Though the *Daubert* ruling spoke of the Federal Rules' "preference for admissibility," it imposed significantly more stringent requirements than Justice White had envisaged in *Barefoot*; arguably, indeed, more stringent requirements than *Frye*. (In 2000, revised Federal Rules made explicit what, according to *Daubert*, had been implicit in Rule 702 all along: admissible expert testimony must be based on "sufficient" facts or data and be the product of "reliable" principles or methods, which the witness has "reliably" applied to the facts of the case.) And, despite the usual rhetoric about the Court's confidence in the adversarial system and in jurors' ability to sift strong scientific testimony from weak, the *Daubert* ruling involved a significant shift of responsibility from juries to judges, a shift Justice White had resisted. As Judge Alex Kozinski, to whom *Daubert* was remanded,[6] caustically observed, he and his colleagues "face a far more complex and daunting task in a post-*Daubert* world .... [T]hough we are largely untrained in science and certainly no match for any of the witnesses whose testimony we are reviewing, it is our responsibility to determine whether the experts' proposed testimony amounts to 'scientific knowledge,' constitutes 'good science,' and was derived by the 'scientific method.'" In a post-*Kumho* world, the task is even more daunting.

In the wry words of Federal Judge Avern Cohn: "You do the best you can." A sensible layperson might suspect that an expert witness is confused, self-deceived, or dishonest, or that he has failed to take account of readily available relevant information; and should be capable of grasping the importance of double-blinding, independence of variables, etc. But the fact is that serious appraisal of the worth of complex scientific evidence (as Dr. Lydgate pointed out long ago) almost always requires much more than an intelligent layperson's understanding of science: the specialized knowledge needed to realize that an experimenter failed to control for this subtle potentially interfering factor; that these statistical inferences failed to take account of that subtle dependence of variables; that new work has cast doubt on this widely accepted theory; that this journal is credible, that journal notorious for such-and-such editorial bias.

Since *Daubert* there have been various efforts to educate judges in science – such as the two-day seminar on DNA for

6 *Daubert v. Merrell Dow Pharm. Inc.*, 43 F.3d 1311 (1995).

Massachusetts Superior Court judges at the Whitehead Institute for Biomedical Research, after which, the director of the institute told *The New York Times*, they would "understand what is black and white . . . what to allow in the courtroom." But while a bit of scientific education for judges is certainly all to the good, a few hours in a science seminar will no more turn judges into scientists competent to make subtle and sophisticated scientific judgments than a few hours in a legal seminar would transform scientists into judges competent to make subtle and sophisticated legal judgments; and may risk giving judges the false impression that they are qualified to appraise specialized and complex scientific evidence.

As judges' gatekeeping responsibilities have grown, so too has their willingness to call directly on the scientific community for help. Since 1975, under FRE 706, a court has had the power to "appoint witnesses of its own selection." Used in a number of asbestos cases between 1987 and 1990, the practice came to public attention in the late 1990s, when Judge Sam Pointer, to whom several thousand federal silicone breast implant cases had been consolidated, appointed a National Science Panel to report on whether these implants were implicated in the systemic connective-tissue diseases attributed to them. In 1998, the four-member panel reported that the evidence did not warrant claims that the implants caused these diseases. (Six months later, a thirteen-member committee of the Institute of Medicine reached the same conclusion.) The plan had been for the videotaped testimony of panel members to be presented at trial; after the contents of the report became known, however, and before the testimony had been transcribed, most of the cases were settled.

When the report was made public, a headline in *The Washington Post* hailed it as a "Benchmark Victory for Sound Science," and an editorial in *The Wall Street Journal* announced that "reason and evidence have finally won out." And it is not only those whose sympathies lie with defendant companies in danger of being bankrupted by baseless tort claims who welcome the idea; so do the many scientists impatient with what they see as lawyers' pointless wrangling over well-known scientific facts. Indeed, where mass torts involve vast numbers of litigants on the same issue, where the science concerned is especially complex, and where hired scientific guns are entrenched on both sides, court-appointed experts may well be the best way to reach the right upshot (and more uniform results than the kind of legal lottery in which some plaintiffs win huge awards and others nothing) – especially if judges learn from Judge Pointer's experience about the pitfalls of choosing scientists to advise them, and about instructing those scientists on record-keeping, conflict of interest, etc.

Still, though the conclusion the Pointer panel reached was almost certainly correct, it is troubling to think that just four scientists – all of whom combined this work with their regular jobs, and one of whom revealed poor judgment, to say the least, in signing a letter, while serving on the panel, to ask for financial support for another project from one of the defendant companies – were in effect responsible for the disposition of thousands of cases. More radically than *Frye*'s oblique deference to the relevant scientific community – more radically even than *Daubert*'s (and *Joiner*'s and *Kumho*'s) extension of judges' gatekeeping powers – reliance on court-appointed scientists departs from the adversarial culture of the common-law approach. Proponents have recognized this from the beginning: "[t]he expert should be regarded as an *amicus curiae*" (John Ordronaux); a court should have the power to appoint "a board of experts or a single expert, not called by either side" (Judge Learned Hand, 1901). So have contemporary critics of the practice, such as Sheila Jasanoff, who complain that it is elitist, undemocratic, a move in the direction of an inquisitorial system.

Then there are the ripple effects of those disturbing DNA exonerations, which have prompted not only renewed scrutiny of forensic laboratories, renewed concern about how lineups are conducted and photographs presented to eyewitnesses, moves to videotape interrogations, and so on – all, surely, welcome developments – but also legislation to overcome obstacles to admitting 'new' evidence, i.e., the results of new DNA tests on old material. Notwithstanding the law's traditional emphasis on (in Justice Blackmun's words) "quick, final, and binding" solutions, some states have mandated post-conviction DNA testing, and others have extended or eliminated the statute of limitations where DNA evidence may be available.

"The basic purpose of a trial is the determination of truth," the Supreme Court averred in a 1966 ruling. "Our system of criminal justice is best described as a search for the truth," Attorney General Janet Reno affirmed in her introduction to the 1996 National Institute of Justice report on DNA evidence, *Convicted by Juries, Exonerated by Science*. So we like to think; but it would be more accurate to say that the law seeks resolutions that correspond as closely as possible to the ideal of convicting X if and only if X did it, or obliging Y to compensate Z if and only if Y caused harm to Z, given other desiderata of principle or policy: that it is worse to convict the innocent than to free the guilty; that constitutional rights must be observed; that legal resolutions should be prompt and final; that people should not be discouraged from making repairs that, if made earlier, might have prevented the events for which they are being sued; etc. We also like to think that our adversarial system (under which a jury is asked to decide, on the basis of evidence presented by competing advocates, held to legally proper conduct by a judge, whether guilt or liability has been established to the required degree of proof) is as good a way as we can find to reach the desired balance. But problems with scientific testimony oblige us to think harder both about exactly what balance is most desirable and about the best means to achieve it.

There is no question about the desirability of prompt and final legal decisions; think of totalitarian regimes where people routinely languish in jail without trial, or of Dickens's *Jarndyce v. Jarndyce*. Nevertheless, if new scientific work makes it possible to establish that an innocent person has been convicted, it seems obtuse to refuse to compromise finality in the service of truth. And, while it is salutary to remember that the brouhaha over recovered memories also prompted some modifications of statutes of limitations, with DNA analysis there really are the strongest grounds for such an adaptation of the culture of the law.

There is no question, either, that trial by jury is a vastly superior way of getting at the truth than the trials by oath, ordeal, or combat that gradually came to an end after 1215, when the Fourth Lateran Council prohibited priests from participating in such theologically grounded tests. Our adversarial system is a distant and highly evolved descendant of the first English jury trials; but it is not perfectly adapted for an environment in which key factual questions can be answered only with the help of scientific work beyond the comprehension of anyone not trained in the relevant discipline. We value trial by jury in part because we think it desirable that citizens participate in public life not only by voting, but also by jury service; still, though such participation is a desirable expression of the democratic ethos, civics education for jurors hardly seems adequate justification for tolerating avoidable, consequential factual errors.

But we also value trial by jury for a more fundamental reason: the protection it affords citizens against partial or irrational determinations of fact. Court-appointed experts are no panacea, and there are both legal and practical problems to be worked out; but if, where complex scientific evidence is concerned, we can sometimes do a significantly better job of determining the truth with their help, adapting the culture of the law in this way might afford better protection, and thus better serve the fundamental goal.

Andrew Jewett

Science & the promise of democracy in America

The intellectual skirmishes known as the science wars have centered on whether scientific facts and theories are socially constructed. This is, of course, a substantive argument over meaningful issues: the nature of truth, the possibility of objective knowledge, and the proper methodology for scholarly inquiry.

But why in the past decade has debate over this particular set of abstract questions become so acrimonious, so deeply politicized? And why has the debate erupted most stridently in the United States?

Commentators sometimes claim that sociological factors explain the intensity of the conflict, and that this philosophical quarrel gains its emotional tenor from an underlying struggle over academic turf. Thomas F. Gieryn argues, for example, that sociologists and literary theorists are trying to portray their own disciplines as the only sources of authoritative judgment – an assertion that physicists, chemists, and biologists naturally dispute. The science wars, he writes, are a series of "credibility contests in which rival parties manipulate the boundaries of science in order to legitimate their beliefs about reality and secure for their knowledge-making a provisional epistemic authority that carries with it influence, prestige, and material resources."[1]

For Gieryn what is really at stake is social status. But I am not convinced. I believe that the science wars express something more than a substantive debate over epistemological issues, and something deeper than a dispute over academic status. What we are witnessing is a new chapter in an ongoing struggle over the meaning of modern science for American democracy.

This is a struggle that took shape in the first half of the twentieth century, especially during the 1920s and 1930s. The vigorous debates of that period about the political meaning of science inform today's political, institutional, and cultural climate, and by reconsidering them we may discover the deep roots and true stakes of the science wars today.

In the late nineteenth century, a few Americans began to argue that the nation could best guarantee its political

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1 Thomas F. Gieryn, *Cultural Boundaries of Science: Credibility on the Line* (Chicago, Ill.: University of Chicago Press, 1999), 337.

health by expanding its scientific institutions. After the turn of the century, an increasingly broad group of academics – some based in the natural sciences but most in the social sciences, philosophy, history, and educational theory – were joined in this endeavor by journalists and educators outside the academy who agreed that science held great social promise.

This group of 'scientific democrats' included (to name only a few of the most famous) the philosopher John Dewey, President Herbert Hoover, the physicist Robert A. Millikan, the anthropologist Franz Boas – and Vannevar Bush, the electrical engineer who directed the wartime effort to build the first atomic bomb.[2] They constituted a large proportion, perhaps even an outright majority, of those Americans engaged in research, study, and writing during the first half of the twentieth century. And, although their views were far from uniform, they shared enough ideas that we can consider them a social movement.

For the scientific democrats the most salient fact of American life during the Gilded Age was the spread of egoistic and self-seeking behavior. As the frontier closed and the economy industrialized, the nation seemed increasingly in danger of developing some of the most feared solvents of a republican society: a permanent class of dependent wage-earners and an economically parasitic elite.

One response was the Social Gospel movement in American Protestantism. Theologians of this bent emphasized that the path to individual salvation ran through social salvation, and they advocated for, among other moralities, the worker's right to a living wage and safe working conditions. Other responses included socialism and trade unionism.

But the scientific democrats felt that none of these programs could adequately address the political challenges of an industrial society. Since most of these democrats had been raised in evangelical Protestant environments, they still believed that personal benevolence was central to solving the nation's industrial woes. They therefore rejected what they saw as the narrowly material goals of the socialists and the trade unionists.

Yet they also moved away from institutional Protestantism, believing that it was still tainted by a stringent Calvinist emphasis on self-denial and failed to explain how benevolence, by itself, could transform a complex industrial society. The "major problem of life," as Ralph Barton Perry put it, was to foster simultaneously "sentiments" and "modes of organization" by which "human suffering may be mitigated, and by which every unnecessary thwarting of human desire may be eliminated."[3]

To solve this problem, the scientific democrats proposed a return to the scientific method, as they understood it. (By the standards of contemporary physics or biology, what they meant by 'science' was quite broad – it implied a general commitment to the experimental investigation and theoretical explanation of a variety of phenomena, both natural and social.) In their optimistic view, modern science had proved its power in practice, by harnessing natural resources and creating new inventions such as the steam engine and the rail-

2 I use the term 'democrat' in a relatively loose sense to refer to those who rejected authoritarian solutions to the nation's problems and who retained a place for universal suffrage and the consent of the governed. We have, of course, come to see many of their proposals as something less than democratic in the wake of the New Left's renewed emphasis on the value of political participation.

3 Ralph Barton Perry, "Realism in Retrospect," in *Contemporary American Philosophy*, ed. George P. Adams and William P. Montague (New York: Macmillan, 1930), 187 – 209, 206.

road, creating an industrial society with the potential to overcome scarcity. The task now was to apply the methods of modern science to the improvement of social organization itself. The application of such methods might allow the nation to close the gap between its professed ideals and the realities of industrial social life, by organizing a new kind of political community that was capable of enlightened self-rule.

By taking as givens both political democracy and an industrial system based on extensive personal interdependence, the scientific democrats were forced to reject the nineteenth-century equation of civic virtue with economic independence. In effect, the scientific democrats neatly severed the two halves of what Sacvan Bercovitch describes as the nineteenth-century American model of "representative selfhood": "independence of mind" and "independence of means."[4] What virtue, they asked, was economic independence supposed to have protected in the first place?

Their answer was *intellectual freedom*, a social-psychological state that allowed the individual to participate constructively in collective action and decision-making. The problem, as they saw it, was to restore the intellectual freedom that had been lost during the rise of the industrial economy. According to Lyman Bryson, "scientific or objective thinking" was the source of "the only kind of freedom that is worth having, the freedom to use the mind in all its untrammeled strength and to abide by clearly seen conclusions." And in order to keep the people from "suffering at the hands of those who have knowledge and would use it against them," Bryson continued, society had to provide for "common ownership" of such "effective thought." Science would protect the public against not only errors in judgment, but also "enslavement" by the more knowledgeable.[5] Universal access to science would liberate the public from its mental bondage.

To modern ears, the scientific democrats' program may sound as deeply authoritarian as the intellectual tyranny they feared. But the now common charge that these figures imposed a concrete ethical system under the cover of absolute neutrality misses the point, for the scientific democrats defined intellectual freedom in far different terms than we do. Scholars have long noted that Progressive Era reformers developed a positive notion of political freedom, in which removing obstacles to action was only the first step toward making freely chosen action possible. The scientific democrats understood intellectual freedom in equally positive terms, conceiving it as the possession of sufficient resources to think effectively in a social setting, rather than as merely the absence of coercion. "No man and no mind," Dewey wrote in 1927, "was ever emancipated by being left alone."[6] Freedom was a product of social relations, not of the escape from them. Meanwhile, science seemingly reinforced the point that an attitude of pure neutrality or pure self-seeking was counterproductive; what characterized science as a cultural practice was the participants' emotional commitment to the pursuit of collective truths.

4 Sacvan Bercovitch, "The Rites of Assent: Rhetoric, Ritual, and the Ideology of American Consensus," in *The American Self: Myth, Ideology, and Popular Culture*, ed. Sam B. Girgus (Albuquerque, N.Mex.: University of New Mexico Press, 1981), 5 – 42, 13.

5 Lyman Bryson, *The New Prometheus* (New York: Macmillan, 1941), 74, 82, 99, 107.

6 John Dewey, "The Public and Its Problems," in *John Dewey: The Later Works, 1925 – 1953*, vol. 2, ed. Jo Ann Boydston (Carbondale, Ill.: Southern Illinois University Press, 1988), 340.

During its first phase, in the years before World War I, the movement for scientific democracy centered on two goals. The first was increasing the cognitive and social authority of science. This meant familiarizing the public with the inevitability of industrialization, as well as expanding the predictive power of the physical and social sciences, establishing these disciplines on a firmer professional basis, and strengthening the universities with which these disciplines were increasingly associated. Despite internal divisions, the nascent movement united during these early years behind a general program of persuading Americans that a commitment to 'science' – however vaguely defined – promoted social integration and the only kind of democracy compatible with an industrial society.

The second shared goal prior to World War I was more subtle, though equally consequential: redefining how scientific inquiry itself was understood. Nineteenth-century American interpreters of science offered a narrowly empirical reading based on the work of Francis Bacon, as filtered through the writings of the Scottish common-sense realists. They held that all individuals possessed a truth-finding faculty that could perceive the orderly, lawful structures of the universe, just as the eye perceived light and shape. Scientific facts were like objects to be collected or discovered, available to all and requiring little analysis beyond systematic classification. The scientist was like a pioneer on the prairie, struggling to organize the elements of an inhuman but morally responsive nature.[7]

But to the scientific democrats it was abundantly clear that morally normative facts were not simply strewn about the landscape to be collected and assembled by any frontiersman. The general public consistently got the facts wrong, and, more importantly, consistently read the social implications of even the most well-established facts – in particular, the irreversible rise of the industrial economy – incorrectly. Abandoning common-sense realism, then, the scientific democrats developed a range of new theories based on the work of European thinkers such as John Stuart Mill, Karl Pearson, and Ernst Mach. These theories, typically designated either positivism or pragmatism, held that the production of scientific knowledge required coordinated effort by specially trained individuals.

When these scientific democrats invoked objectivity as a characteristic of scientific knowledge, they meant neither that the knowledge was absolutely certain nor that the generalizations would necessarily hold permanently true. As one researcher summarized recently, "All the great scientists of the last hundred years (and some much earlier ones) have in one place or another clearly stated that their purpose was to create plausible theoretical models for the organisation of experience and that these models must not be considered representations of absolute reality."[8] Objectivity, for these theorists, meant that scientific

7 Historians have demonstrated that science flourished in the nineteenth-century state only where it was linked firmly to the colonization of the continent. The government scientist was, in many cases, a pioneer in actual as well as metaphorical terms, accompanying various expeditions to work in relatively unpopulated areas on the frontier. See Philip J. Pauly, *Biologists and the Promise of American Life: From Meriwether Lewis to Alfred Kinsey* (Princeton, N.J.: Princeton University Press, 2000), esp. 44–70.

8 Ernst von Glasersfeld, "Comment on Neil Ryder's 'Science and Rhetoric,'" *Pantaneto Forum* 10 (April 2003), <http://www.pantaneto.co.uk/issue10/glasersfeld.htm>.

knowledge was as immune as possible to the influence of the observer's own desires. Science was, in the new theories, most fundamentally a means of error correction, producing not perfect truths but simply the best available truths.

In the wake of World War I, a new variant of scientific democracy appeared, endorsed by such figures as Dewey, Perry, Bryson, and Eduard C. Lindeman. Rather than leave the organization of society to the political-economic conclusions of a small group of scientific experts, this group of 'deliberative democrats' wanted to engage the public in the intellectual freedom represented by science. If science was the preeminent form of free communication, then it was also the preeminent means by which the social organism could alter itself democratically. By Dewey's account, "Society not only continues to exist *by* transmission, *by* communication, but it may fairly be said to exist *in* transmission, *in* communication."[9] Even if substantial socialization of property was the wave of the future, the process would attain political legitimacy only through the public's active intellectual participation.

The deliberativists agreed with their predecessors that the scientific method as such was value neutral, in that it neither forced any particular values nor produced facts that were inherently normative. Yet they suspected that the scientific methodologies inherited from their European predecessors were themselves part of the social problem; science would have to be purified or Americanized so that it could perform its appointed task of buttressing democratization. So the deliberativists set out to create not merely a new science but what they often called 'a science of science' – a methodologically self-conscious form of inquiry that, by going beyond both realism and positivism, would automatically generate democratic knowledge. The most influential formulation of this idea was Dewey's instrumentalism. This philosophy held that all intellectual constructs and even the scientific method itself were merely tools for the achievement of human values, available for use by any and all actors in the pursuit of any and all conceivable ends.

A purely methodological conception of science had positive consequences for the organization of intellectual life. It allowed the specialized disciplines to claim scientific authority without stepping on each other's toes. In lieu of transcendent or universal principles, standards of explanation could be determined locally, according to the specific characteristics of the phenomena under investigation. It also provided a quasi-political role for a new group of scientific democrats: first- and second-generation immigrants, almost all of them Jews. These figures were deeply committed to the tenets of democracy, but found the United States far less egalitarian and open than it proclaimed itself to be. Suspicious of crass business values, and harboring idealized images of the highly integrated Old World communities they or their parents had left behind, they faced what one historian has called a standing ideological challenge "to relate the myth of America to the context and conditions of modern America."[10] Tools of inquiry that retained their validity no matter who cre-

9 John Dewey, "Democracy and Education: An Introduction to the Philosophy of Education," in *John Dewey: The Middle Works, 1899–1924*, vol. 9, ed. Jo Ann Boydston (Carbondale, Ill.: Southern Illinois University Press, 1976), 7.

10 Sam B. Girgus, "The New Covenant: The Jews and the Myth of America," in *The American Self: Myth, Ideology, and Popular Culture*, ed. Girgus, 105–123, 111.

ated or used them offered an important means by which they could help close the cultural gap.

On the other hand, installing this methodological definition of science at the heart of American democratic theory forced a split between institutionally committed religious thinkers – no matter how supportive they were of modern science's findings – and scientific democrats. A strict insistence on scientific methods ruled out reference to biblical authority or mystical visions as guides to political action. The program of the deliberative democrats was, in this regard, radically secular. And because it denigrated in principle the beliefs and religious convictions held by many ordinary Americans, the movement was never able to win the democratic support its own vision demanded.

The ascendancy of the movement to create a scientific democracy did not in any case last long. The Great Depression, the rise of fascism and Nazism, and America's entry into World War II and subsequent emergence as a global power with a large standing army presented formidable new challenges to the ideal of a deliberative democracy. By the 1950s, with new support in all quarters for research and a seemingly endless Cold War underway, the language of scientific democracy had lost much of its critical edge.

The rhetorical identification of science with democracy remained a staple of Cold War rhetoric, but in the publicly visible invocations of this equation, both science and democracy were defined in strictly material fashion and shorn of the deliberative idealism championed by Dewey.[11] Defenders of science had jettisoned Dewey's emphasis on science as a tool for the pursuit of human values in favor of rigorous new theories of objectivity that gained their support from the work of the logical empiricists in the new field of philosophy of science. The new, postwar emphasis was summarized by Harvard economics professor John D. Black, writing that the growth of science secured a new Bill of Rights for Americans:

> *To every man shall be given a job suited to his abilities, or a shop of his own in which to turn out products or services needed by his fellow men, or a piece of land upon which to make a living for his family. To every woman shall be given a home or these same opportunities. To every father and mother shall be given the same opportunities for their children to be well-fed and educated and successful as are given to any other children. No man or woman is entitled to any share of the world's goods larger than he produces; but he shall be given an opportunity to produce according to his abilities and his ambition and a necessary minimum of food, clothing, and shelter, regardless of his means; and the child shall not be denied an equal opportunity merely because of the poverty of the parent.*[12]

11 As Rebecca Lowen shows in her study of Stanford University, *Creating the Cold War University: The Transformation of Stanford* (Berkeley: University of California Press, 1997), even during the depths of the Cold War there were scientists who fought against a militaristic reading of their enterprise. The socio-political meaning of science has always been contested, both inside and outside the scientific disciplines. David Hollinger discusses scientific intellectuals' participation in the cultural battles of the midcentury in "Science as a Weapon in Kulturkämpfe in the United States during and after World War II," in *Science, Jews, and Secular Culture: Studies in Mid-Twentieth-Century Intellectual History* (Princeton, N.J.: Princeton University Press, 1996), 155 – 174.

12 John D. Black, *Design for Defense: A Symposium of the Graduate School*, U.S. Department of Agriculture (Washington, D.C.: American Council on Public Affairs, 1941), 40.

Such a deeply chastened consensus set the stage for an inevitable reaction.

When the ideological pressures of the Cold War eased in the early 1960s, a new generation began to wonder why consumption and military spending were politically untouchable. The situation was galling, in part, precisely because educated middle-class Americans – and the generation of the 1960s was no exception – had entertained such lofty political hopes for science and the universities. Faced with the argument that not even those scientists funded by the Department of Defense bore responsibility for the use of their discoveries, many social critics turned against the language of scientific objectivity itself. Believing that they were forced to choose between democratic values and the benefits of science, many Americans were prepared to reject the dream of the scientific democrats and their Enlightenment-inspired vision of a society modeled on the intellectual freedom of scientists.

As they entered academia, these critics retained their focus on science as the ideological core of the American social and political system. Assuming, as had the scientific democrats, that intellectual and institutional change were causally linked, they insisted that the critique of objectivity offered a theoretical lever for moving society toward social justice. In fact, historian Edward A. Purcell, Jr., writes, the "most characteristic and significant intellectual endeavor of the Sixties" was the "attempt to reevaluate the nature of science: to analyze its sociological bases, to illuminate its political functions, and, above all, to deny its pretensions to exclusive and total access to truth." The goal was to "dethrone objectivist science as the supreme intellectual authority."[13]

And as the conservative ascendancy of the 1970s and 1980s swept away hopes of social reconstruction, the critics redoubled their efforts to unmask the pretensions of science to enlighten and liberate. Meanwhile, defensively minded scientists dug in their feet and took a stand for the possibility of objectivity, even if they personally sought different political goals than those articulated by Black. The outspoken entomologist Edward O. Wilson wrote in a characteristic recent passage that "The propositions of the original Enlightenment are increasingly favored by objective evidence, especially from the natural sciences."[14] The stage was set for the science wars.

Still, the original vision of scientific democracy has yet to disappear fully from the American scene. Despite the sound and fury of contemporary arguments in the academy, the prospect that science can have cultural as well as material benefits for ordinary Americans has not entirely lost its hold on the national imagination. And while it seems unlikely that any group of academics will ever voluntarily surrender its hard-won claims to institutional authority, the time may come again when America's natural and social scientists, leaving behind the disputes of the 1990s, undertake a new joint effort to redeem the promise of American democracy under the banner of intellectual freedom.

13 Edward A. Purcell, Jr., "Social Thought," *American Quarterly* 35 (Spring/Summer 1983): 80 – 100, 84.

14 Edward O. Wilson, *Consilience: The Unity of Knowledge* (New York: Alfred A. Knopf, 1998), 8.

Poems by Les Murray

The Tune on Your Mind

Asperges me hyssopo
the snatch of plainsong went,
Thou sprinklest me with hyssop
was the clerical intent,
not *Asparagus with hiccups*
and never *autistic savant*.

Asperger, mais. Asperg is me.
The coin took years to drop:

Lectures instead of chat. The want
of people skills. The need for Rules.
Never towing a line from the Ship of Fools.
The avoided eyes. Great memory.
Horror not seeming to perturb –
Hyssop can be a bitter herb.

Photographing Aspiration

Fume-glossed, unhearably shrill,
this car is dilated with a glaze
that will vanish before standstill –

and here's the youth swimming in space
above his whiplash motorcycle:
quadriplegia shows him its propped face –

after, he begged video scenes
not display his soaking jeans,
urine that leathers would have hidden
and the drag cars have engines on their engines.

Les Murray is Australia's leading poet. His most recent collections are "Poems the Size of Photographs" (2002) and "Collected Poems 1961 – 2002" (2002). He has published some thirty books, including the verse novel "Fredy Neptune" (1999).

Fiction by Joanna Scott

That place

At first the doctor assured Nora that her mother's complaints – nausea, mouth ulcers, headaches, dizziness – were the inevitable response to the regimen of chemo. But then Bev developed a low-grade fever, indicating the presence of an infection and earning the patient a prescription for erythromycin. Twelve hours later the fever had climbed to 101. By the next day her lips had swelled and turned the pale, pinkish hue of the underside of her tongue. The doctor changed the antibiotic and prescribed a course of antihistamines to relieve the symptoms of the allergic reaction as well as reduce the stiffness in her neck. The next morning, she sat propped up in bed, a coffee mug tucked in the crumpled sheet between her thighs. She felt improved enough to request a breakfast of scrambled eggs.

Returning to Bev's bedside with the plate of eggs in hand, Nora thought that her mother's surgical incision across her lower abdomen had begun to bleed. The stain on the sheet, though, didn't have the tint of fresh blood. The stain, Nora realized after a moment, was coffee, which led her to the temporary conclusion that her mother had fallen asleep and the mug had overturned. But the way her mother's head, tilted back against the pillow, moved in a rhythmic twitch indicated either that her sleep was troubled or she was having difficulty breathing. Nora tried nudging her awake. Bev kept twitching. The cracks between her eyelids showed only white.

The seizure lasted less than five minutes, but by then the ambulance was already en route, and Nora agreed to let the medics transport her groggy mother to the hospital. After a wait that extended into the early afternoon, the emergency department physician diagnosed a brain abscess. An anticonvulsant was given to prevent repeated seizures – this, a nurse explained, would act as a sedative, so Nora shouldn't be surprised if her mother remained difficult to rouse for another day or two. By 10 P.M., Bev was resting comfortably, and Nora's husband, Adam, who had driven up to Massachusetts from Philadelphia, took Nora back to her mother's house.

A call from the neurologist early the next morning brought Nora and Adam

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back to the hospital. A corticosteroid, administered intravenously to control the swelling in the brain, failed to have the desired effect. The neurologist needed consent to drain the pus, which involved drilling a small hole through Bev's skull. This, or Nora's mother could suffer permanent brain damage.

The procedure took less than half an hour, though Nora imagined that she would have to wait for time to move in reverse before she saw her mother again. While she sat with Adam in the lobby outside of surgery she heard a buzzing sound – the sound, she was convinced, of a hand-held drill grinding through bone. She touched her husband's arm to draw his eyes away from the soccer game on television and told him she was going to be sick. He grabbed a plastic wastebasket and held it in front of her. It was empty, except for a piece of white gum stuck to the black disc at the bottom.

Nothing more than old peppermint gum. Shimmer of a fluorescent light overhead. Colors flickering on the TV. On again, off again. Who's winning? Everything conspiring to remind her of the contest between life and death.

"Do you still feel sick?"

"I'm fine. Thanks."

She leaned back into the curve of his arm and took in the action on the screen, the players' leaping jubilation, a World Cup game, U.S. leading Spain 1 – 0. And then the long exhalation in the aftermath. Bev Knox, formerly Bev Owen, born Beverly Diamond, topped with a turbaned bandage, scrubbed and ruddy and looking younger than she had in years, was wheeled into a private room in the critical care unit.

"Bev? Bev, it's me, Nora." The stupid human need to be oneself. And even stupider – "How are you doing?" As if she expected her mother to lift up on her elbows and say through the airway, I'm fine, dear. And you?

"She looks good, doesn't she?"

"She looks peaceful."

"She looks like photographs of herself when she was in her thirties. Bev? I wonder if she can hear us. Bev? Can you wiggle your finger for me? This finger here, on your right hand. This one. Can you lift it?"

Between the shush-shushing of the ventilator, the heartbeat graph on the monitor, and the flat gray sky outside the window, the room had a contagious serenity. Adam and Nora stayed with Bev through much of the afternoon, passing sections of the newspaper between them. They spoke in whispers. Adam stared out the window for a long while. When he turned back he seemed to be trying to hide his confusion, as though he didn't want to admit that he didn't understand how he'd come to be here.

"We're not doing much good," he finally said, stretching out his arms. "Why don't we go back to the house?"

"You go on. I'll stick around for a while."

But she needed to eat, Adam pointed out. She said she wasn't hungry. She needed rest, he insisted. She said she'd stretch out on the cushioned alcove bench. She'd stay as long as hospital rules allowed, and then she'd take a taxi and join Adam at Bev's.

"Look," she murmured with her eyes closed. "I'm already asleep." He kissed her on the forehead beneath the peppered arc of her bangs.

She must have some idea that she's not lying in her own bed in her own home. Not working in her garden. Not dancing with Gus. Bev can't have forgotten that Gus is dead. His final whisper of a groan. Who could forget? The man whom others described to her as a shrink with a passion for tofu. His shroud of gray curls. Straw sandals. Remember the evening of his first visit to the Ridgefield house, Gus chasing a bat around the kitchen with a broom? He finally managed to trap it beneath an overturned pot, and they all relaxed with tall glasses of lemonade and then watched in amazement as the bat flattened itself into a puddle and seeped from under the rim of the pot, unfolded its wings, and flew across the room and out the open door.

Or the time she was pregnant with Nora, and she and Lou stayed in a cheap motel in the Berkshires. Animals crackling through the dry groundcover outside their open window all night. And then when Lou was getting dressed the next morning he discovered a chipmunk asleep inside his boot. Bev, come see!

Lou's ambition to follow the example of the Raytheon executive who at the age of fifty quit his job and took his family to live among the Bushmen in the Kalahari. Bev, out of necessity, adept at pretending that anything is possible.

Making puppets out of rosehips. Making whistles out of acorn shells.

Benny Goodman's thin lips and rimless glasses. Goodnight, my love.

Listening to a bird in the garden while she waited for Nora to bring her breakfast. Chickadee-dee-dee-dee-dee.

It felt good to give into fatigue. But when Nora found herself awake later in the evening, she wasn't certain she'd actually been asleep. How much time had passed since Adam had left the hospital? Since her mother had gone into surgery? Since her mother had been diagnosed with ovarian cancer? Since Nora's birth?

The strange fact of passing time. Acceptance had felt like defeat when she was a young girl and her mother finally convinced her that the Earth was turning beneath her feet. Even now, what she knew to be the truth seemed the opposite of such dependable impressions as these: the day's filmy residue on her teeth, the steady breathing of the ventilator, the bulge of her mother's eyeballs under the thin skin of her lids, the figure of a man in the doorway, backlit by the recessed ceiling lights.

"Nora, honey . . ."

It was her father's voice, all right, and her father's bald, freckled head and full beard. Nora half-rose, then settled back onto the bench.

"Lou! You startled me."

"Didn't Adam tell you I was coming?"

"What are you doing here?"

"I'm here to see your mother."

Why? she wanted to ask – a purely spiteful question that would have put him on the defensive. Instead, she remained silent while he stepped into the room. He stepped forward again with a jerk, as though pushing through an invisible barrier, and stood beside Bev's bed.

Watching him graze his ex-wife's hand with his forefinger and then lift it, tubes and all, to his lips, Nora didn't know whether to feel embarrassed, offended, or impressed. She couldn't muster pity; she couldn't tell whether the gesture was purely for show – an old gentleman's debonair display of affection. A display for whose benefit? Nora suspected that Lou would have done the same whether or not he'd had his daughter for an audience. He even seemed mildly taken aback either by his own impulsive action or by the taste of Bev's skin. Beverly Knox, formerly Owen. This wife Lou had left thirty years ago for another woman and who wouldn't take him back when he came begging.

Lou gently lay Bev's hand back on the mattress and bowed his head with a solemnity that Nora thought both tender and portentous.

"Were you planning to stay with us at Bev's house?" she asked.

"Is that all right?"

"I guess so."

"I appreciate it."

Fiction by Joanna Scott

Nora was used to Lou's habit of visiting without invitation. He moved around so frequently he used a PO box for his home address. But she was surprised by how old he looked. She'd seen him last... when? Summer a year ago, and he'd been fit enough to dive naked from the dock of the lake house. Shedding his jeans right there in front of his daughter and son-in-law, he'd squeezed together those skinny buttocks of his, pushed off his toes, and with a yelp dove into the water that by then, mid-August, was topped with a thick scum of algae. Right through the green bloom went Lou, and he didn't surface again for so long that Nora had risen to her feet in panic and was about to dive in after him when he finally did bob up ten yards away, on the other side of the dock.

Rising again from the murky depths in Bev's hospital room after an absence of eleven months.

"How is Brunswick?" she asked him.

"I moved down to Harpswell for the summer. How is your mother?"

"For a woman with a hole in her head, she's managing."

"What in heaven's name have you let them do to her?"

His expression of indignation was typical. He had a deft way of implying that Nora only ever made the wrong decision. She'd gone to the wrong college, shacked up with the wrong man, and had denied herself the pleasure of having a child of her own. She'd never be more than what she was: an assistant superintendent in a pint-sized suburban school district. She'd never know better than to give consent to a surgeon who wanted to drill a hole through her mother's skull. She was her father's daughter, condemned to repeat his mistakes in judgment, and like Lou, she'd have to wait until old age to recognize that she'd caused more trouble than she was worth.

Nora explained to her father the reasons for the surgery. Lou wanted to know if she'd gotten a second opinion. Yes, she lied. She'd gotten a second and a third opinion, and all the doctors had said the same: surgery or brain damage. Which would you choose, Lou?

Surgery or brain damage? "What about surgery *and* brain damage? What's the point of that?"

As predictable as Lou was in his disapproval, Nora couldn't be sure how best to respond. It always took some time to size him up after a long absence. *Youthful* was the word others used to describe him even into his seventies. The better word, Nora thought, was *incomplete*. Whoever her father had been the last time she'd seen him, he'd be more stubborn, more resigned in his misgivings about his past actions, and more blatantly contradictory when she saw him again.

More Lou than Lou. A man who couldn't see the point of putting a hole in an old woman's head.

Nora might have folded her arms and scowled. Or she might have given Lou a detailed description of traumatized brain tissue. Instead, she decided to challenge him: "What's the point of life?" she asked with a twitch of a grin.

The point of life? he echoed, unexpectedly deflated. Life as he lived it before his split with Bev or after? How about both? Nora had heard him talk on many occasions about his regret. She knew what he would say – how he'd never gotten over Bev and had spent the last three decades longing for reconciliation. What unnerved Nora now was that he was saying it in Bev's presence.

Louis Owen was an old man, and he had come to make a full disclosure. Time was running out. Nora already knew what had happened to her father after Bev refused to take him back. He'd told her the story plenty of times. And now he wanted to tell the same story over again, for Bev's sake.

He sat on the lower corner of Bev's bed near where the catheter emerged from under the sheet, and he lifted a cigarette out of the pack in his shirt pocket. Nora reminded him that smoking was prohibited in the hospital. He left the cigarette dangling unlit from the corner of his mouth and looked at his daughter with a raised-brow expression clearly intended to challenge her to pay careful attention.

Or the time Bev called Nora into the kitchen to examine a germinating bean. Forget the television show, for god's sake, and come see this. The seed coat disintegrating. The withered cotyledon. Trying to explain the paradox of loss and gain, all that we have to give up in order to move forward, arriving in this place. What place? And who asked Lou to come along?

Deep in thought, running her fingers over the velvety purple sepal of a larkspur. Doesn't that feel nice? Clouds gathering for a late afternoon thunderstorm. Her garden. Her house. 7 Fairport Lane. Built in 1890, the floorboards warped, the chimney crumbling where the vines have grown into the mortar. The place Gus and Bev went to live out their last years together. Sweet Gus. Plucking dead blossoms off a rhododendron. The perfume of lily of the valley hanging in the humid air. The wind picking up. Silver shine of the poplar leaves.

On that terrible night ending with Bev's assurance that she would never again speak his name aloud, Louis Owen drove north. It was summer, between semesters, and he would miss nothing more than a couple of conferences with inconsequential panels about theoretical rubrics and anthropology's hidden bias. Talk, talk, talk. Lou had always been too eccentric, as he liked to think of himself, or too lazy, as others thought, to have anything productive to say about theory, and he'd lost interest in the social element of the conferences. He'd met the woman for whom he'd left his wife at one of those conferences; he wasn't in the mood to meet another woman right then.

He'd intended to keep driving up through Canada into the wilderness of the Northwest Territories, but his car broke down in Niagara just before he'd cleared the border. So he booked himself the cheapest room he could find in a motel across from a Nabisco factory. How many times had he told Nora about this motel? Seventy dollars a week, morning coffee included, the smell of burnt sugar clinging to the sheets and towels.

Finishing this first part of the account, he paused and through his unlit cigarette drew in a long breath that was synchronized with Bev's respirator.

"So you hung out in Niagara Falls for a while."

"Feeling sorry for myself, I admit. Having lost the love of a good woman, I'd lost my future."

You and your sentimental clichés, she wanted to say. Instead – "What's that supposed to mean?"

"You know how many people throw themselves over the Falls each year? You don't want to know. Every morning I'd walk from my motel room to the park and spend the day there. What a wreck I was, destined for the junkyard. And yet somehow I found ways to make myself useful – snapping photographs for tourists, pointing them in the right direction. I got friendly with the grounds staff and when one of the guys quit I was offered his job. Did you know that your dad had a job picking up trash?"

"You've always kept yourself busy."

Fiction by Joanna Scott

"Collecting soda cans and hot dog wraps, newspaper, old socks, and lost hats. I wish you could have seen me."

"I can imagine."

"I was missing you like crazy, Nora. Believe me, I never wanted to stop being your father. You know, I wrote to you. More than once." *How come you never answered me?* he would say next. "How come you never – forget it." He gave a dull shrug. "Your mother forwarded the bills. Of course she did. I'm not complaining. And wouldn't you know, she sent along the certificate confirming our plots at White Oak Cemetery."

"Where?"

"Crazy business, eh? We bought our little patch of land on sale. And she'd sent a copy of the certificate to remind me of our commitment."

"Where did you say?"

At first he'd thought it was a nasty joke designed to remind him that his life would add up to no more than dates carved in stone. But the more he'd thought about it, the more he'd studied the paper and traced his fingers across the numbers, the more he'd been comforted by the idea. He and Bev would be together in the end.

Where?

She'd heard correctly. *Cemetery*, he'd said. And *White Oak*. It had to be White Oak. He'd never mentioned this before, and neither had Bev. They had purchased plots there. That place. The same place. Crazy business.

"A pact made long ago," he said, his irony tinged with pride, though he admitted it must be disturbing for Nora to imagine her parents together in the end, given their years of estrangement, planted side by side.

Or the time Nora stepped on the spiny husk of a chestnut, and to stop her from crying Bev split open the nut and showed her the shadow of the seed leaf inside. Then they went inside and Nora dressed up in Bev's old belted blue dress with padded shoulders. Bev painted Nora's eyelashes blue and dusted her cheeks with cyclamen rouge, and Nora went clacking around the house in her mother's high heels. Hey gorgeous!

Or the time, the last time, Lou came to dinner. Asking for Bev's forgiveness. Begging for Bev's forgiveness. Demanding Bev's forgiveness. Don't you dare threaten me, Lou! Get out! No. Yes. And snap, she's an old woman pulling out a maple sapling by its roots and trying to recall a song she once knew about mandrakes. Her back aching, her head throbbing, only wisps of hair left after the chemo, her ears ringing, and Nora's at the kitchen door calling –

Bev! Bev! Telephone.

Did someone say something? Voices swishing, or is that the dry leaves moving in the breeze? Sky darkening. All the work she wants to finish before the rain.

It didn't have to be that way, he reminded Nora. She thought he meant it didn't have to be White Oak Cemetery – he and Bev could have chosen a different place. But he meant that Bev didn't have to refuse him. She could have forgiven him and taken him back. That they were never a family again was her decision.

He spent that whole summer hanging out in Niagara Falls, having decided that he could never love anyone else but the woman he'd betrayed. What a mess he'd made of his life. Had he ever told Nora about the bar in Niagara? That dingy saloon, where he could drink away his sorrows. A white man adrift. The linoleum floor was sticky with beer. Cigarette smoke hung so thickly he could hold it in fistfuls. Two men were singing with the jukebox. A drunk old woman laughed in delight, her wrinkles like a fine net pressed against her face. Her joy was infectious.

"Did I ever tell you about that woman in the bar?"

"No," Nora said, though she was thinking *yes*.

Or this same dream that returns to her when she's ill: she is in a waiting room. There are strangers sitting in seats against the opposite wall. They are reading books they had the foresight to bring with them. Bev brought nothing with her, so she sits there bored with her thoughts. Idly, she scratches her shoulder and feels an odd patch like hardened syrup stuck to her skin. She finds another patch on her elbow. She is spotted with this hard, transparent substance – tiny crystals on her arms, her legs, and at the base of her throat.

Beverly Diamond Owen Knox is becoming the woman she'd been named to be. At first she's not sure whether to resist or give in. There are patches on the back of her hands. Brilliant crystals picking up the buttery tint from the surface of her skin. The ache in her joints is worse than arthritis. The discomforting bristle of crystals between her toes and behind her ears. The sensation of being buried alive inside precious stone. Help me, Nora. I'm not ready yet. Her lips tearing at the corners. Help me. The taste of blood. Help me.

"Bev!"

"She said something. What did she say?"

"Bev, it's me, Nora. Lou's here as well. Can you open your eyes? Do you think she can hear us? Bev? Maybe we should call the nurse. Bev, are you OK?"

The nurse, summoned by Lou, listened with a stethoscope to Bev's chest and checked fluid levels in the IV bag. Any sounds she made, the nurse explained, were the body's normal effort to clear the lungs of mucus. Bev wasn't in any pain, and she wouldn't wake up from sedation anytime soon. But it would be best not to disturb her.

After the nurse left the room, Lou needed to be reminded: "Where were we?"

He'd finished one bourbon. Two. Three. And then, oh shit, he'd realized he didn't have enough money to pay for his drinks. A new crisis to follow the last. What could he do? Stiff the bartender? Admit that he had only spare change in his pocket? Then his eyes settled on the drunk old lady with the fishnet face. She represented life and hope, and she would surely have compassion on a man who had no family anymore.

"What did I know? I was an idiot."

There was so much he didn't know. For instance, Nora considered telling him right then and there about what happened in White Oak Cemetery when she was a girl. But now the thought of all the necessary explanation she'd have to offer Lou exhausted her, like the work that would go into renovating an old house that had been shut up for years. It would be better to build a new house on the property.

Lou was talking about the old lady in the bar in Niagara Falls: her head tipped back in laughter, skin a toffee brown, darker in the creases, with lips painted a fiery red, and dark, leathery pouches beneath the rims of her eyeglasses. She wore a red saucer hat to match her red shoes, and her summery dress was a loose black-and-white polka-dot wrap. She looked like a charitable person who would lend a few dollars to a man in need.

"I called to her – Ma'am! – but she couldn't hear me above the music. I called louder. Excuse me, Ma'am, pardon – but she still didn't hear me. So I went ahead and tapped her on the shoulder. She tipped her head to look at me over the top of her spectacles. She switched off her smile. And at the same time the music stopped. I don't know whether someone pulled the jukebox plug or, by coincidence, the song had ended."

This was the scene in the story that Lou liked to label *a situation*. An old woman who happened to be the mother of one of the singing men. And it sure looked like the bartender was her grandson, while Louis Owen was a white nobody who stupidly decided to call attention to himself.

He spoke in the direction of the window facing the hospital parking lot, as though his intended audience were the ghost of his reflection. He didn't seem to care anymore whether Nora was paying attention. And he might as well have forgotten about Bev. He was talking to himself, refining the patterns of experience that had made him who he was. His tendency, as he would say, to put his foot in it.

"Next thing I knew, one man was holding me by the collar, and another had a knife at my throat."

Nearly had his throat sliced because he'd been bold enough to tap an old woman on the shoulder. And yet he was alive because of that same old woman's dispensation. All she had to do was give a slight, severe nod in the direction of the door, and the two men threw Lou out on the sidewalk.

That was Nora's father: savvy only in the aftermath.

His conclusion, always the same, invited dramatic comment. Nora imagined Bev sitting up and uttering a good, verifying insult. She thought of the fight they'd had in the kitchen when she was thirteen years old, the night Lou returned to apologize. She remembered lying in her bed pretending to sleep and listening for the shrill explosions in Lou's voice when his pleading turned into threats. She thought about how wrong it was that Bev and Lou should be buried side by side in White Oak Cemetery, though she didn't say this. The truth was, though she sometimes needled him with her rebuttals, she never meant to say anything that would cause her father pain.

"Sometimes," she said to Lou, who sat waiting for her response, "it's better just to keep your mouth shut."

Or just the other day, wasn't it, when a storm blew in. The smell of fresh-cut grass. Screeching of red-wing blackbirds in the marsh. The first drops of rain. Growl of thunder. Flicker of lightning. On again, off again. Crash, bang, run for cover in the shed!

Dripping beneath the cloth hat she uses to hide her thinning hair. The chill of damp clothes. It's not the same kind of chill as the chill in her bones. This despite the doctor's optimism. But she can still notice things. There in the corner, for instance, a nest made of dry grass and shredded paper from a fertilizer bag, crowded with four baby mice. And there's the mama retreating with the fifth baby in her mouth to the safe shelter behind an old wheelbarrow that had been overturned and left to rust by the previous owner. Back again, to fetch the rest of her offspring, carrying them one by one while Bev watches.

Nora, come see!

Bev, you're soaked.

Watch now. The mother carrying them to safety one right after the other, failing none of them.

Or the time Gus and Bev threw a party for themselves one year after they'd gone off to City Hall to get married. The two of them dancing to "This Year's Kisses" in the center of the crowd of guests while Nora watched from the ballroom's balcony.

Or the day after Lou left for good and Bev hired a locksmith to change the locks. She sipped her coffee and chatted with the man while he worked on the kitchen door. Nora came into the kitchen to pour herself some milk and overfilled the glass.

Nora!

Or watching Nora watching *Jeopardy*, her one leg thrown over the back of the couch. Bev gave her big toe a tug.

You OK?

Yeah.

Want to talk?

Nope.

The one thing they needed to talk about kept Nora from wanting to talk at all. She couldn't be budged. Bev had better luck guessing the answers to the questions on *Jeopardy*: Dale Carnegie's number one best-seller. What is *How To Win Friends & Influence People*?

X-shaped stigma, reflexed yellow sepals. What is an evening primrose? What are ragged robins and corn cockles? Did you know that a fly must beat its wings two hundred times a second to stay airborne? Look: you can tell from the white dots and the red-barred forewings that it's a red admiral butterfly. Nora, take out the garbage please! Nora, did you hear me?

"Thrown out on my ass," Lou was saying. "First by your mother. And then by two toughs in a bar." His tone was wryer than earlier, his eyes narrowed in a slightly mischievous squint.

"It's true I learned from you," Nora said, "how to get into trouble. But also how to get out of it."

"And remember that there's rest at the end." He leaned forward and patted Bev's hand, the same hand he'd kissed. "The peace of our eternal sleep together on some shady slope in White Oak."

"You did say White Oak."

Their own private property. Two names, two stones. They didn't even have to let on that they'd once been married. Just as long as they were together in the end.

"Lou – "

"The only home I'll never lose to foreclosure."

"Lou – "

"Thirty years I've been waiting to hold her in my arms again."

"Lou!"

"What? You think I'm not sincere?"

"If you'd be quiet and listen, for once."

"You have something you want to tell me?"

He looked at her with a smile she interpreted as smug, as if he were satisfied that the setup had worked and he'd trapped her, making it impossible for her not to match his disclosures with some of her own – and yet because of this expression of expectation he made it necessary for her to resist. This was an unfamiliar predicament. Usually she was adept at closing the conversation with a decisive comment. But she thought she'd had something else she'd wanted to say. What? She wasn't sure.

That place

There was no way she'd tell Lou about what happened thirty years ago in White Oak Cemetery. That place she and her girlfriends used to go to smoke in secret. The same place where a troubled teenager named Jonathan Baggley strangled little Larry Groton and left the body lying on a bed of pine needles for Nora to find as she was walking home alone. Climbing the hill, seeing first his sneaker turned at an odd angle, then the mud-caked fingers of his left hand resting on his knee.

Fiction by Joanna Scott

The coincidence of White Oak Cemetery. Lou had been living in Thailand at the time, and as far as Nora knew, Bev never told him what had happened. It was important to Nora not to tell him. She hadn't wanted to tell anyone, except her mother – she'd told her mother right away, as soon as she'd raced home from the cemetery. When Bev called the police, Nora couldn't help but feel betrayed. She felt tainted and newly vulnerable in a way her mother didn't understand. She had cooperated with the police and led them up the cemetery hill, but only out of necessity. And afterward, she'd shut up. Even when her friends gathered around her and demanded to know what she'd seen, she'd kept her mouth closed.

But thirty years had passed, and she was ready to talk to Bev about it now. She needed to know why Bev hadn't found somewhere else to spend eternity. Why White Oak, the place where children died horrible deaths and were left to rot? Why did Bev want to be buried there – and next to Lou, no less? Why hadn't she ever mentioned this to Nora?

They'd talk as soon as Bev's condition improved. They'd begin with the story of finding Larry Groton, and from there, wherever. The past or the present. It would depend upon Bev. Nora could only guess what her mother would tell her. But she didn't want to guess. She wanted to know what Bev would say, if she could say anything. That and more. Her mother being far less predictable than her father, complete, though partially hidden from view. Lou, much as he liked to talk, would never adequately answer the one question Nora wanted to ask:

"Why White Oak, of all places?"

"What?"

"Why did you choose White Oak Cemetery?"

"Why?"

"Yes."

"Don't you remember? We lived down the street. We used to take you sledding there, and walk the dog."

"And you really thought you'd stay in that town forever? You, who couldn't settle down?"

"I don't know..."

"Why White Oak?"

"What's the big deal? Why White Oak, why that place, why any place? We just wanted to be together, if you can believe it. Doesn't seem possible, does it? Hey, Bev? Can you hear me, Bev? I wonder if she's been listening? Why there? Why us? Why did we spend thirty years apart if we planned to be together in the end? Why did we do anything?"

Both Lou and Nora watched Bev for some indication that she had an opinion she wanted to share. She just lay there, unblinking, unsmiling, her chest swelling and flattening with the action of the respirator, but Lou and Nora would have gone on watching her forever if the nurse hadn't come in to tell them that visiting hours were over, which seemed strange to Nora, whose fatigue had led her to believe that it was the middle of the night. She'd call a taxi, she said. Lou reminded her that he had his car. They could stop at a diner for a bite to eat, she suggested, and they could talk some more. They'd have a good night's rest and come back to visit Bev the next morning. She would probably be awake by then. Lou said he'd bet she had heard everything and would give them an earful!

The voice of her own father. The red circles on his cheeks. He was telling her about Joe Louis KO'ing Natie Brown in the 4th round. One cigar after another.

Bev, phone's for you!

What?

The whir of a fan. The roll of a carousel horse. The swoop of a swallow.

Or the time she found her husband's lover's name and number written on a slip of paper in his wallet. See how it is, Nora, when we have to make do with suspicion? Sometimes it's best to tell.

Two cups of flour. Cream the butter with the sugar. Crack of an egg against the rim of a bowl. The satisfaction of catching the yolk whole.

The time Gus came out to the garden, where Bev was trying to screw the nozzle of the hose on a spigot, and she could see from the look on his face that something terrible had happened. More precisely, somehow she knew that his son was gone. She didn't yet know the details – that he'd been killed in a bus accident while traveling in Mexico. But in that flash of a glance, she felt as though she knew everything.

Or the days following the day Nora ran home to tell her mother she'd found something in the cemetery. Nora wore her softball cap around the house to hide her eyes in shadow.

Or the time Bev was about to remind her again how much she loved Adam and was grateful for Nora's happiness, and the next thing she knew.

What?

She's not sure she weeded the garden before she left. Those stubborn little maple saplings, as tough as mandrakes. The songs she used to sing. Gus, according to his wishes, reduced to ashes and scattered over the North Atlantic. Lou, come closer so I can look at your face. The wiry white curls of your beard. The wide pores of your tanned skin. And you, Nora. Sitting in the garden cradling cups of coffee. We must do something about the potato vine tangled in the pachysandra. Is that what she wanted to say? Also, the thicket of loosestrife at the top of the front walk.

Elizabeth F. Loftus

on science under legal assault

For more than three decades, I have conducted research on memory. My research shows that memory is malleable – and that it is a flimsy curtain indeed that separates memory from imagination.

I've seen how false memories can destroy lives, especially when such mistakes in recollection work their way into the legal system. As a result of eyewitness accounts of imagined events, I've seen more than a few innocent people sent to prison.

Doing research that has practical implications, and being willing to speak out about those implications, can be risky. Giving expert testimony in the adversarial setting of a court case – as I have done – is not simply moving from the laboratory into the field. It's moving into a battlefield.

As a result of publishing findings that have cast doubt on cases of supposed repressed memory, I have become accustomed to receiving harsh criticism, and even personal threats. But nothing had quite prepared me for the Orwellian nightmare I currently confront.

This nightmare began with my reading of a paper coauthored by a psychiatrist named David Corwin. In an article published in 1997 in the journal *Child Maltreatment,* Corwin purported to offer new proof that repressed memory was a genuine phenomenon, by recounting the story of "Jane Doe." Corwin had videotaped Jane on several occasions. The first was in 1984, as part of a custody dispute between her divorcing parents; in this video, the six-year-old Jane described how her mother had sexually abused her. On the basis of Jane's testimony, the mother lost custody of her daughter, and also lost the right to visit her.

Eleven years later, at Jane's request, Corwin videotaped another interview. Now seventeen, Jane was bothered that she could not now recall being sexually abused by her mother. But under further questioning by Corwin, Jane suddenly *did* recall, recounting an instance when her mother had sexually abused her in the bathtub – thus, to Corwin's satisfaction, confirming the phenomenon of traumatic amnesia.

After publishing his paper about Jane Doe in *Child Maltreatment,* Corwin traveled around the country giving lectures and showing videotapes of Jane. Therapists began to use the case as proof of repressed memory. Psychologists began

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to teach the case in their classes. Lawyers began to cite the case in court during the prosecution of other individuals charged with sexually abusing their children.

Despite its currency in courts and classrooms, the story of Jane Doe sounded fishy to me. I became interested in learning more. But studies like this are shrouded in secrecy.

Still, using public records and newspaper clips, I eventually tracked down Jane Doe's mother. I teamed up with Mel Guyer, a psychologist and lawyer from the University of Michigan, and we poured over every page of the divorce file. We immersed ourselves in the public evidence, and we gathered new evidence from new witnesses around the country. We even tracked down Jane's stepmother, who was working in a grocery store. She recounted the battle to wrest custody of Jane from her biological mother. Referring to Jane's alleged memories of sexual abuse, she boasted, "That's how we finally got her – the sexual angle."

To our bewilderment, though, before we had even published a word on the case, Jane Doe complained that her privacy was being violated.

Responding to her complaint, officials from the University of Washington, where I then taught, called to say that they were seizing my files. Within fifteen minutes, my files had been impounded – and an inquiry launched to investigate potential scientific misconduct.

In spite of the university's own statute of limitations – one hundred twenty days – its investigation lasted more than twenty-one months. As long as the investigation was ongoing, I could not publicly discuss the case of Jane Doe, or publish anything about what Guyer and I had discovered.

In June of 2001, while still under investigation, I received the William James Award at the annual convention of the American Psychological Society. Most of my colleagues at the convention had no idea what was going on. Those who had heard about the case history were free to discuss it. But I could not discuss either the case history or the subsequent inquiry.

Instead, in my speech accepting the William James Award, I raised some questions: "Who benefits from my silence? . . . Who benefits from keeping such investigations in the dark? . . . Those of us who value the First Amendment and open scientific inquiry must bring these efforts to suppress freedom of speech into the light."

Shortly afterward, I was exonerated by the university's investigation. Finally, Guyer and I were able to publish our exposé of the case study. And I could take some satisfaction out of thinking that we had disproved Corwin's claims.

But the cost was tremendous. The university's actions left me feeling betrayed. Instead of offering a real apology, university officials would say only that they were sorry that the investigation had taken so long.

And so a year later I left my friends, my lovely old house, and the place where I had worked for twenty-nine years, in order to move to the University of California, Irvine.

And that was the end of the matter, it seemed – until early this year when Jane Doe filed a lawsuit.

She sued Guyer, me, and our colleague Carol Tavris for defamation and invasion of privacy, even though we had never revealed her name. (It was Jane Doe herself who revealed her name – in her lawsuit.)

The three of us have thus become part of a new and disturbing trend: throughout America, scientists are being sued simply for exercising their constitutional right to speak out on matters of grave public concern.

This is not simply a problem for psychologists. In 1997, in an article published in *The New England Journal of Medicine*, R. A. Deyo, B. M. Psaty, G. Simon, E. H. Wagner, and G. S. Omenn recounted a number of instances in which efforts had been made to intimidate medical researchers. An expert on spinal-fusion surgery who raised doubts about its benefits was faced with efforts to block publication of his work, and forced to spend endless hours responding to subpoenas from companies with a vested interest in the procedure. Another scholar who had raised doubts, in this case about the value of certain tests used to support disability claims for chemical sensitivity, had to fend off charges of scientific misconduct and fight to keep his medical license. The conclusion of Deyo et al: "investigators should be aware that applied research is not for the naive or faint of heart."

The possibility of being sued into silence delivers an ominous message for all scientists. Baseless litigation not only affects the defendants – it also discourages scientists from speaking out on controversial topics, for fear that they will be next.

We need better ways to investigate allegations of scientific misconduct. We need stronger judicial sanctions, such as awarding attorneys fees and court costs, to deter people from filing baseless lawsuits. And as my own case demonstrates, we need our universities to offer stronger support to researchers who come under attack. The members of the American Academy of Arts and Sciences have a special role to play in these circumstances. This organization was founded in order "to cultivate every art and science which may tend to advance the interest, honour, dignity, and happiness of a free, independent, and virtuous people." Now, more than ever, that goal is at risk, unless we step up our efforts to defend the right of scientists in a free society to speak out – even when their findings are controversial.

Perez Zagorin

on humanism past & present

Is there, or can there be, any place for humanism in the world of the twenty-first century? After the appalling events of the past century, is there any ground left to believe that mankind may yet come to regard the life and happiness of human beings as a supreme value to be cherished and promoted in every possible way?

These are some of the questions comprised in the broad general question of whether humanism both as a concept and a substantive ideal may still possess the power to help shape the course of human affairs.

In the West, humanism first came to birth in Greece during the fourth and fifth centuries B.C.E., in the age of Plato and Aristotle. It was the Sophists who, as teachers in the fifth century, originated humanism as a cultural-educational program or *paideia* aimed at the many-sided development of man's faculties and the creation of the highest excellence of which he was capable. "The unexamined life," Plato's *Apology* recorded Socrates as saying, "is not worth living." Indeed, although the Greek language had no word for humanism, a concern with man and his dignity became the focus of Greek thought at this period in drama, philosophy, and history. And so Sophocles wrote, "Wonders are many, and none is more wonderful than man."

Greek humanism persisted among the successors of Plato and Aristotle, but, although it included lasting values, it was not an offering to all mankind. It was a cultural program designed predominantly for an elite of free men of aristocratic background and independent means who had the leisure for the pursuit of excellence. It was predicated on the idea of an inherent superiority of the Greek over the barbarian. It arose and developed in an era of internecine war between the Greek cities, and extended down to the time of the conquests of Alexander the Great. It took for granted the existence of war and the institution of human slavery as permanent features of human society.

The humanism that developed in republican Rome rested on similar values. The Romans of the republic were one of the most predatory peoples in world history, as well as among the greatest military leaders, statesmen, empire builders, rulers, legislators, and administrators. In the first century B.C.E., during the final years of the republic, before Julius Caesar's heir Augustus acquired sole power, Cicero, a Roman consul and member of the republican ruling class, defined humanism in a manner that was to remain influential for centuries. For him, humanism was an educational and cultural program and an ideal expressed in the concept of *humanitas*.

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Note by Perez Zagorin

This Latin term designated a number of studies – philosophy, history, literature, rhetoric, and training in oratory – that were considered to be the ingredients of a liberal education, and it also referred to the moral attributes of humaneness, philanthropy or benevolence, gentleness, and kindness. Something of the essence of Ciceronian humanism might be summed up in the words with which the seventeenth-century English poet John Milton, who was a Christian humanist, defined the nature of education. In 1644, Milton wrote that "a complete and generous education" – by which he meant the education of a gentleman – was one that "fits a man to perform justly, skillfully, and magnanimously all the offices, both private and public, of peace and war."

There was also a medieval humanism, whose character has most recently been traced out in the last works of the great English medievalist R. W. Southern. This humanism appeared as part of the renewal of civilization that followed the end of the Roman empire and pagan culture in the West and the gradual emergence of a new Christian and feudalized society in the earlier Middle Ages. The cathedral schools and the new universities of Paris and some of the Italian cities then became the centers for the three disciplines that constituted the bases of order and civilization in medieval Europe: liberal arts, Roman and canon law, and theology. Along with these disciplines, the medieval study of the works of Aristotle in Latin translations was perhaps the single most important intellectual foundation of scholastic humanism. Another foundation was the belief in the dignity of human nature, which scholastic thinkers equated with the power of the human mind to perceive the grandeur of the universe, the principles of nature, and the divine purpose of the creation. But Scholastic humanism was not a general social program based on an ideal of human excellence; it was a select type of higher education designed for the minority of clergy who went to university in order to be trained as theologians and teachers or to take their place as officials in papal and ecclesiastical government or in the expert service of secular rulers.

Of all the major versions of humanism, the Renaissance humanism that developed in Italy during the fourteenth and fifteenth centuries has been the most influential. The humanism of the Renaissance was neither anti-Christian nor irreligious, but it centered increasingly upon human interests and moral concerns rather than religion. Human dignity, the value of the active life in the world, and man's possession of free will to do good or evil were among the essential premises of this humanism. And yet, like the humanisms that preceded it, it exemplified an elitist ideal; its highest aim was the formation of Christian gentlemen – classically educated, morally sound, accomplished in the arts of speaking and writing, competent to advise and serve in the governments of kings, princes, and cities, and possessed of the manners to make a creditable appearance at royal and princely courts.

The conception of culture and education that humanism propounded in the fifteenth and sixteenth centuries established the languages, literature, and thought of classical antiquity as the basis of a proper education in the Western world. Compulsory Greek and Latin in the schools was only one of its consequences. As time passed, and with the advent of the European Enlightenment in the late seventeenth and eighteenth centuries, humanism became ever more independent of religion and sometimes affiliated with deism, religious indifference, and unbelief. The principle of the dignity of man remained, but it was often absorbed into philosophies that were opposed to religion, that exalted human reason and science as the solvent of all otherworldly beliefs and superstitions, and that enthroned humanity and its progress as the supreme meaning of history.

During the nineteenth century, humanist values had to confront the growing importance of the physical and biological sciences, the emergence of social sciences such as political economy and sociology, and the rivalry of new and modern subjects that sought to gain entry into the educational curriculum. So by the end of the century, humanistic disciplines were only one strand in the complex fabric of a liberal education. This collapse of humanism was foreshadowed in the philosophy of Nietzsche, with its invocation of the will to power and challenge to the belief in truth, and in the theories of Sigmund Freud, which stressed the irrational forces and sexual drives of the unconscious in explaining human personality.

During the twentieth century the concept of man ceased to be dominated by humanistic assumptions, so man now not only stood apart from God, but also, with the ascendancy of the naturalistic perspective, ceased to be seen as a special being. The eclipse of humanism was largely completed by the enormous and pointless slaughter of World War I and the disillusionment that followed. Thereafter, the Western faith in progress was largely discarded, and with it the humanistic belief in the dignity and nobility of man, which no longer seemed tenable to most intellectuals.

I have thought it necessary to present a brief sketch of the history of humanism in order to convey an idea of the imposing place humanism once occupied in Western culture, and of its withering away during the past century.

The most important philosophical discussion of humanism since the end of World War II makes clear that a philosophy of antihumanism has become a predominant trend in Western thought. This discussion has taken place largely among French thinkers, although it has also had a wide impact outside France in the form of postmodernism. It began with the proclamation of humanism in the existentialist philosophy of Jean-Paul Sartre and continued with Martin Heidegger's critical response to Sartre's proclamation and its subsequent influence.

In 1946, in reply to objections from communist and Christian critics that his philosophy pictured human life as ugly and meaningless, Sartre defended his views in a lecture affirming that existentialism was a type of humanism. The fundamental premises of his argument were that there is no God to tell us what we ought to do, that there is no human essence to define our ends, and that man, thrown randomly into existence, is compelled to make his own life by his personal choices and actions.

Sartre's humanism, it seems to me, is in general a very debilitated kind of humanism based on a number of nonsequiturs. Among other failings, it is a humanism totally without content, since it offers no objective reasons or principles for our decision to act in one way rather than another. It calls upon us for a commitment, but not to anything in particular, and without any principles of justification. And when it does finally propose such principles, as for example that it is wrong to treat people with cruelty, it only imports them from traditional ethics.

The year after Sartre's lecture, Heidegger wrote his *Letter on Humanism* at the request of Jean Beaufret, a French disciple who regarded him as the greatest living philosopher. The main question Beaufret put to Heidegger was: "How can we restore meaning to the word 'humanism'?" Beaufret's aim in soliciting Heidegger's views was partly to challenge Sartre's current ascendancy over existentialism. But he also hoped that bringing the German philosopher into the French discussion would help rehabilitate Heidegger's reputation, which had been deeply compromised by his previous endorsement of Hitler and Nazism as the salvation of Germany and the West.

Heidegger's well-known attitudes – his hatred of modernity, his certainty of the decline of Western thought and culture, his assumption that he is the one philosopher who preeminently understands what philosophic thinking is, and his contempt for democracy, etc. – pervade his *Letter on Humanism*. The *Letter* also rests on a primordial concept of Being, the conviction of the abandonment of Being in Western philosophy, and the necessity of overcoming metaphysics.

According to Heidegger, every type of humanism, whether Hellenic, Roman, Christian, or Marxist, places man at the center and claims to determine man's essence. Yet each type, he claims, fails to ask about the truth of Being, and each furthers man's destructive aim of imposing his mastery upon the world and nature, the planetary domination of technology, and what Heidegger laments as man's homelessness in the world. So in response to Beaufret's question about how to restore meaning to the word 'humanism,' he suggests that it would be better to abandon the word altogether, because of the damage it has done in turning philosophy away from Being.

After the appearance in France of Heidegger's *Letter*, it is no wonder that the idea of humanism fell into discredit. From the 1950s and 1960s on, the most prominent French thinkers shared a common antihumanism, and, as the French philosopher Vincent Descombes has observed, "humanism became a term of ridicule . . . to be entered among the collection of discarded 'isms.'" Among recent French thinkers, it is Michel Foucault who is perhaps the best-known representative of antihumanism. It was Foucault, writing in *The Order of Things,* who declared the "death of man" – and so became an international celebrity. The excessively abstract and overblown style of Foucault's arguments, the vacuity of many of his generalizations, and his many substantial factual errors that numerous scholars have pointed out, show that he is far from being an accurate or trustworthy historian. Hence, when he erroneously declares in *The Order of Things* that the conception of man is an invention of recent date, no earlier than the end of the eighteenth century, and goes on to voice the hope that man is nearing his end in philosophy and the human sciences, it can only be a cause for surprise that his theories have exerted such an influence upon literary and cultural studies, history, and sociology in the past three decades.

Part of the explanation, of course, is the chastening effect of recent history. After the Holocaust and the more recent atrocities in Cambodia, Bosnia, and Rwanda, many among us find it intolerable to hear mention of the dignity or nobility of man. Yet the principle of the dignity of man remains an essential concept in any viable philosophy of humanism for our time.

This principle does not, of course, deny man's animal traits, his kinship with other living creatures, nor the fact that he is part of nature and came into existence as a result of the creative process of evolution that gave rise in time to life in all its vast and awesome variety. The affirmation of the dignity and special position of man is based on reasons that seem to me unquestionable. These are that humans are by a long way the most intelligent creatures who inhabit the Earth and possibly also, so far as we know at present in our search for extraterrestrial life, the most intelligent beings who exist in the universe. They are also the only one of nature's creations on Earth who have fashioned progressive moral codes ordaining love, care, compassion, and concern for their fellow creatures and other living things, and who by the exercise of their intelligence and through their exclusive and inestimable prerogative of language have achieved a great, ever-growing knowledge of the physical, social, and cultural worlds and of their own historical past.

If a renewed humanism is to be possible, we cannot doubt that it has to be genuinely universal – something past Western humanism never was. But to accomplish this universality, a new humanism must achieve a modus vivendi with religion, of which, since the Enlightenment, Western humanism has increasingly been an adversary. I think, nevertheless, that an accord between humanism and religion may be possible in any society where, as in the contemporary Western world, the state and organized religion fully accept the principles and practice of religious, political, and intellectual tolerance, freedom, and pluralism.

In taking this view, I find support in the American philosopher John Rawls's conception of an "overlapping consensus." In a liberal society, as he points out, people may reasonably disagree in some of their basic beliefs and their conceptions of the good. But those who disagree can nonetheless live peaceably together in their differences as part of an overlapping consensus because they share fundamental reasonable values of pluralism and mutual tolerance. Provided, therefore, that institutional religion renounces the support of the state and recognizes freedom of conscience for everyone, humanism can not only coexist on amicable terms with religion, but should also find it possible to enter into dialogue with it on the basis of common values that both of them affirm.

I believe that the conception of human rights is the best foundation for a new humanism. In 1948, the United Nations General Assembly unanimously adopted the *Universal Declaration of Human Rights*, which asserts equal political, social, and economic rights for all human beings regardless of race, color, religion, and ethnic membership. In relation to a renewed humanism, the rights that people may justifiably claim beyond those that are already assured to them in contemporary democratic societies, and how far the principle of human rights can be expanded without losing itself in utopianism or coming into conflict with the value of political freedom itself are both questions to be decided by philosophical and political debate. Such a humanism can be predicated only on democracy, because this is the sole system of government that recognizes the freedom and rights of the individual and that provides for equal citizenship and peaceful change. Such a humanism would likewise uphold the principle of complete freedom of religion, condemn all religious violence and hatred, and work toward tolerance and understanding between different religious communities.

Humanism also needs to be able to take part in the discussion in contemporary society that weighs the deep and troubling problems resulting from scientific and technological advance against the hopeful prospects of human betterment that science and technology create. It seems obvious to me that humanism must lay aside once and for all the hostility and indifference that its representatives in the past have often shown toward science, in order to establish common ground with science as one of the greatest intellectual achievements of mankind. As part of such an ideal, humanism would most certainly have to include an environmental ethic as an essential component of contemporary human values.

Reflecting on the great history of humanism and its belief in human dignity, I cannot think that humanism has become an outdated philosophy. On the contrary, it seems to me that a renewed humanism, of which the principle of human rights is the germ, would incorporate many of the aspirations of the world's people in this era of global interaction and communication. With the French poet Francis Ponge, I am convinced that "l'homme est l'avenir de l'homme" – man is the future of man. I also agree with the eminent French historian Fernand Braudel, who, in an essay some years ago on the history of civilization, noted the unity and diversity of the world and voiced the need for "a modern Humanism":

> a way of hoping or wishing men to be brothers with one another, of wishing that civilizations, each on its own account and all together, should save themselves and save us. It means accepting and hoping that the doors of the future should be wide open to the present beyond all the failures, declines, and catastrophes predicted by strange prophets. The present cannot be the boundary which all centuries, heavy with eternal tragedy, see before them as an obstacle, but which the hope of man, ever since man has been, has succeeded in overcoming.

Inside back cover: DNA testing for a murder investigation, 1987. "Science doesn't always have the final answers the law wants, or not when it wants them; and even when science has the answers, the adversarial process can seriously impede or distort communication." See Susan Haack on *Trials & tribulations: science in the courts,* pages 54–63. Photograph


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