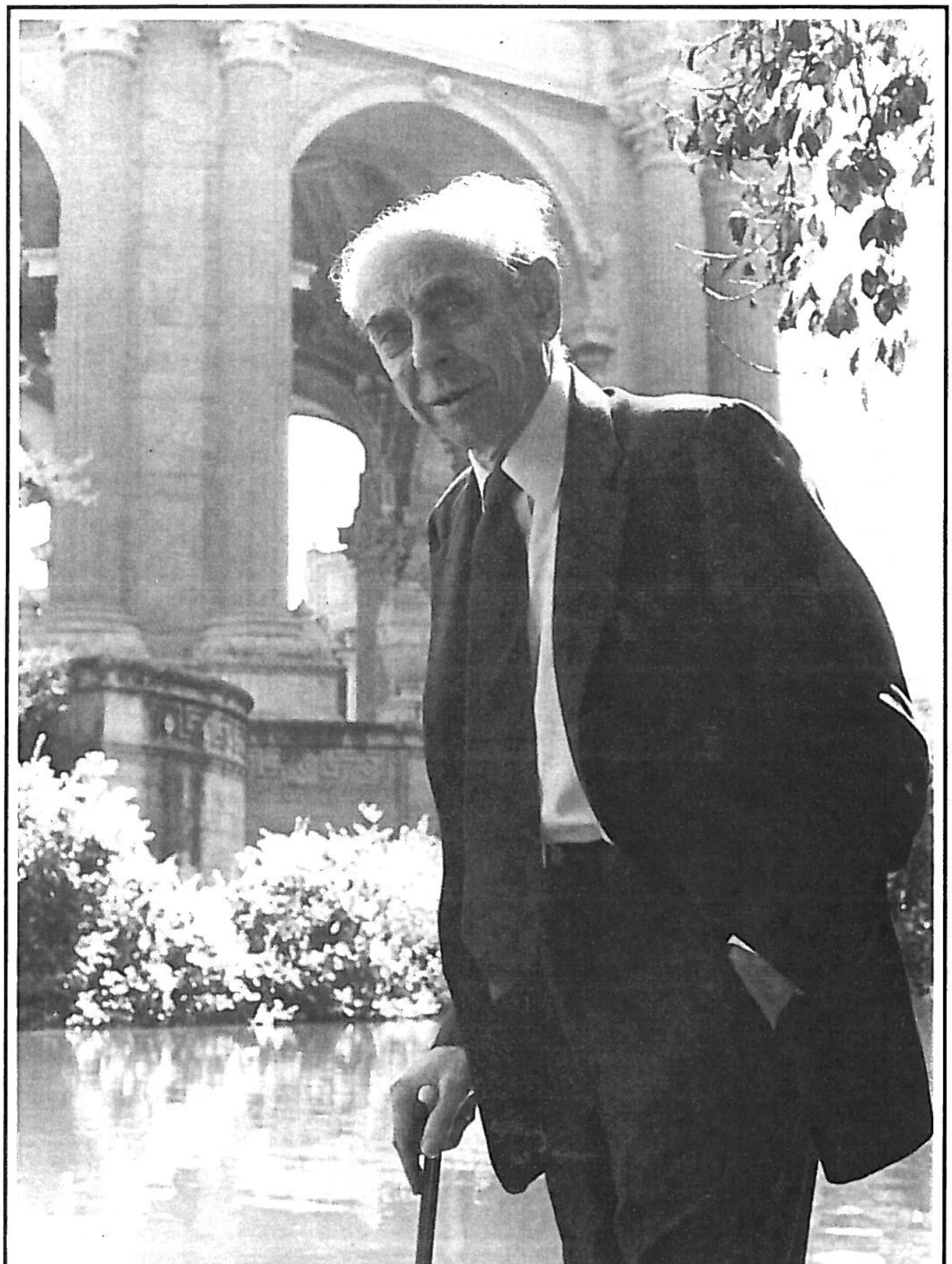
# The Exploratorium

Special Issue, March 1985



Frank Oppenheimer 1912–1985

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Special thanks to **Millie Oppenheimer** for providing the cover photograph and the photographs on pages 2–4 and 28.

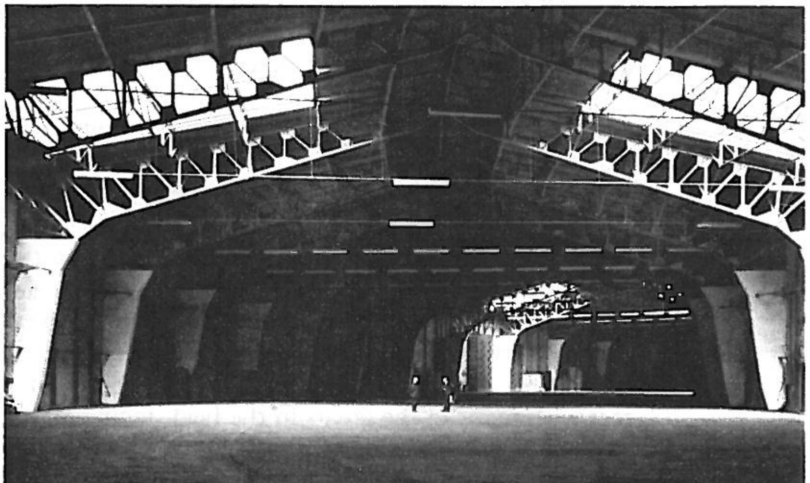
**Illustrations:**
Leonardo da Vinci's drawing of a gear designed to equalize the force of a clock spring: bottom page 10. Brahms' *Sonata for Two Pianos*, Opus 34B, F minor: top page 12. Page from Kepler's *Astronomia Nova*, 1609: bottom page 12.

*This issue of* The Exploratorium *magazine is dedicated to Dr. Frank Oppenheimer, the man we all knew as Frank.*

*Rather than inviting friends and colleagues to share their remembrances of Frank, we decided that the most appropriate portrayal of Frank Oppenheimer is contained in his own writings about the topics he loved: teaching, art, science, curiosity, and playfulness.*

*In this issue we have included a few of Frank's many speeches and articles. Our selection ranges from an address to the Pagosa Springs High School PTA in 1959 to Frank's speech at the 1984 Exploratorium Awards Dinner.*

*Frank died on February 3, 1985. He is survived by his wife Mildred, his children Judith and Michael, and four grandchildren.*



# Dedication to Understanding

## *Frank Oppenheimer*

***August 14, 1912 – February 3, 1985***

Frank dedicated his life to understanding nature and communicating that understanding to others. As he said in a speech delivered a few months before his death, he believed that "If people feel they understand the world around them, or, probably, even if they have the conviction that they *could* understand it if they wanted to, then and only then are they also able to feel that they can make a difference through their decisions and activities. Without this conviction, people usually live with the sense of being eternally pushed around by alien events and forces." Frank's three overlapping careers in science reflected his dedication to understanding: he was a brilliant researcher in nuclear and cosmic ray physics, a distinguished teacher and innovator in laboratory instruction, and the creator and guiding genius of the Exploratorium, San Francisco's unconventional museum of science, art, and human perception.

He was born in 1912 in New York City to a family well-versed in the sciences and arts. His mother was a painter and, as a boy, Frank studied painting. He also studied the flute and became a competent musician. He enrolled in the Johns Hopkins University, and in 1933 graduated Phi Beta Kappa, a top member of his class. He spent a year and a half in the Cavendish Laboratories in England—the laboratory of Sir Ernest Rutherford—working on natural radioactivity with C.E. Ellis. He worked on the development of nuclear particle counters at the Institute di Arcetri in Florence, Italy, and again had contact with many of the greats in the field, including Ochialini and Bernadini. During these years, he continued to play the flute, earned a pilot's license by flying a Gypsy Moth, and haunted art museums, spending so much time at Florence's Uffizi Gallery that he memorized the collection.

On returning to the United States, Frank earned a PhD at California Institute of Technology, doing experiments on artificially induced radiation. He did post-graduate work at Stanford University, where he worked with Felix Bloch on neutron physics.

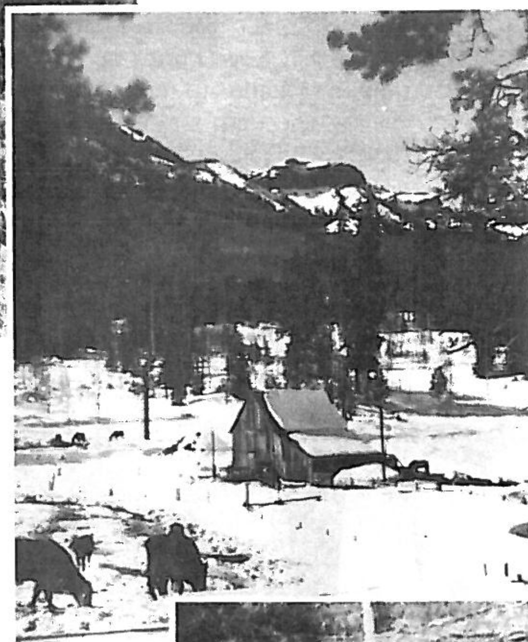
In 1941, Frank began working on uranium isotope separation with Ernest O. Lawrence at the University of California Radiation Laboratory at Berkeley, successfully separating the heavier uranium isotope U-238 from the lighter, fissionable isotope U-235. In 1945, he joined the Manhattan Project at Los Alamos, directed by his brother, J. Robert Oppenheimer. At Los Alamos, Frank was deputy to Kenneth Bainbridge, the physicist in charge of planning and conducting the first test of the atomic bomb.

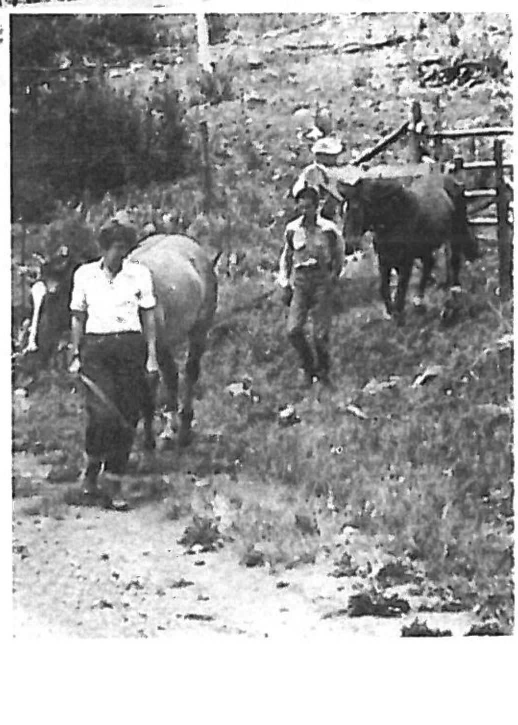
After the war, Frank worked on the development of linear proton accelerators with Wolfgang Panofsky and Luis Alvarez and did some of the first experimental work on the newly completed 184-inch cyclotron at Berkeley. From 1947 to 1949, he was Assistant Professor of Physics at the University of Minnesota, where he did landmark research on cosmic rays.

In 1949, forced to resign from the University of Minnesota as a result of harassment by the House Un-American Activities Committee, Frank was unable to continue doing physics research. For the next ten years, he was a cattle rancher in Pagosa Springs, Colorado. However, banishment from academic physics at the hands of McCarthy did not in any way end his career. On the contrary, it marked the beginning of several new ones.

Frank's passion for excellence and willingness to give himself wholly to whatever pursuit captured his interest made him a successful and ingenious rancher. On the ranch, he was a creative experimenter who liked to make his own tools and find his own solutions. His neighbors elected him president of the local phone company, chairman of the soil conservation board, and representative of the county cattlemen's association. In 1957, he was drawn back into education as a science teacher at the local high school, which had less than 300 students and only one science teacher for all the sciences in all the grades. Frank was a tireless and innovative teacher, eager to share his understanding of science. He took students to the dump and used abandoned auto parts to teach principles of mechanics, heat, and electricity. Frank's enthusiasm for science apparently rubbed off on his students, and two students carried away first prizes at the Colorado State Science Fair.

In 1959, he was offered an appointment at the University of Colorado, where he eagerly returned to both research and teaching. He initiated and directed research in



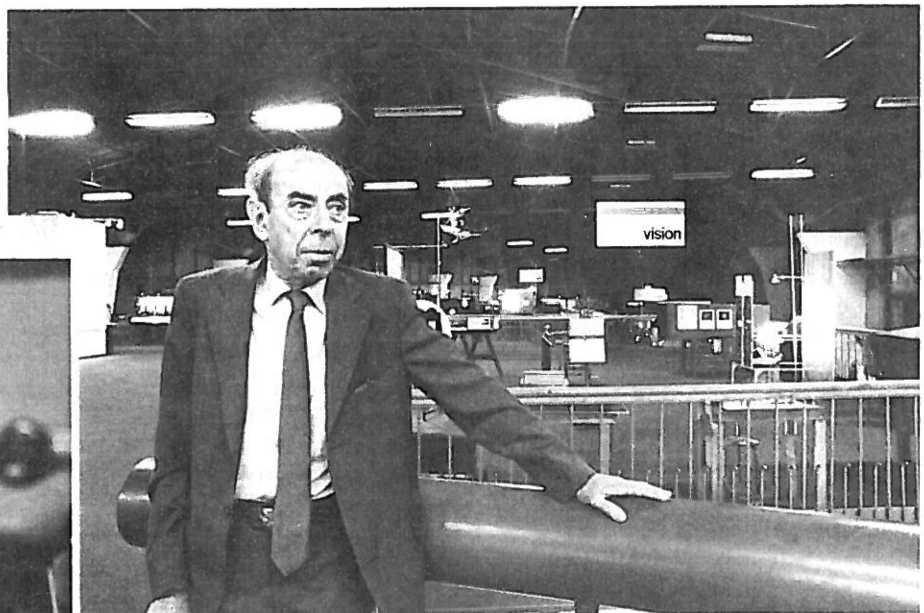


high-energy particle physics. Simultaneously, he became a central moving force in improving laboratory teaching, developing a "Library of Experiments," in which students could explore physical phenomena at their own pace and according to their own inclinations. He was also involved in an MIT-sponsored curriculum development project for high school, junior high, and elementary school science.

In 1965, Frank spent a year in London on a Guggenheim Fellowship. During this time, he explored and studied European museums and became convinced that museums of science were vitally needed for the general public and as a supplement for science curriculum at all levels. On returning to the States, he was invited to do the initial planning for a new branch of the Smithsonian, but he turned it down to work on what he called his "San Francisco project."

In 1968, San Francisco's Palace of Fine Arts, the last remnant of the 1915 Panama-Pacific Exposition, was newly restored. Frank and his first wife Jackie proposed that this cavernous structure house a science museum, or rather, an "Exploratorium." In 1969, with no publicity or fanfare, the Exploratorium opened its doors to display a few exhibits borrowed from NASA and an exhibit on the aesthetics of the Stanford Linear Accelerator. Today, fifteen years later, the Exploratorium contains almost 600 hands-on exhibits designed by artists and scientists.

The qualities that make the Exploratorium special are the same qualities that made Frank Oppenheimer so special: an insistence on excellence; a knack for finding new ways of looking at things; a respect for invention and play; and a lack of pretentiousness. The Exploratorium provides a carefully controlled chaos in which visitors and students freely pick their paths among a subtle and ingeniously




devised science curriculum. From the beginning, the museum's central theme has been human perception, a category that manages to include both art and science. As Frank said, "The Exploratorium introduces people to science by examining how they see, hear, and feel. Perception is the basis for what each of us finds out about the world and how we interpret it—whether we do so directly with our eyes or develop helpful tools, such as microscopes or accelerators, art, poetry, or literature."

The exhibits—often because of Frank's influence—are intriguing, stimulating, playful, sometimes whimsical, sometimes beautiful, sometimes strange, eclectic, or somebody's idea of a joke. Frank insisted on honesty in exhibit building—the exhibits present natural phenomena; they are not rigged to fool the visitor or improve on nature. He also insisted that exhibits and explanations be designed to help visitors achieve the satisfaction of self-discovery. Frank wrote, "We do not want people to leave with the implied feeling: 'Isn't somebody else clever.' Our exhibits are honest and simple so that no one feels he or she must be on guard against being fooled or misled."

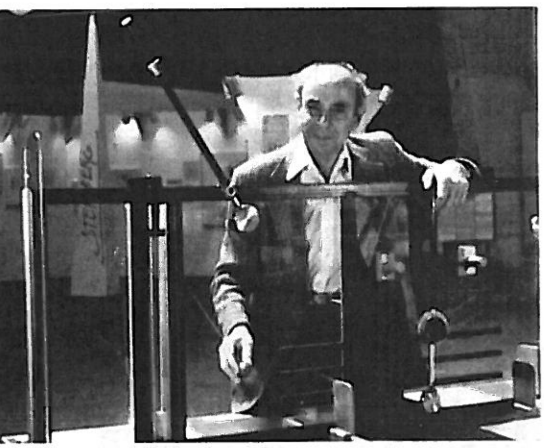
The Exploratorium—with its high-vaulted girder-spanned ceiling, its echoing spaces, and expanses of darkness broken here and there by puddles of light—has been compared to everything from the belly of a whale to a county fair. But perhaps the most apt description was given by Jon Else, a filmmaker who produced an episode of *Nova* about the museum: "The Exploratorium is like the inside of Frank Oppenheimer's brain—that building is a very tall Frank Oppenheimer."

Though Frank is gone, the Exploratorium goes on. A little girl dances through *Sun Painting*, holding her hands up to capture the colors of a shattered rainbow; in the shop, an artist is using scraps of copper and brass to construct a robot that will shake hands; on the museum floor, a group of junior-high teachers cluster around an exhibit, learning how to use the museum as a teaching resource; high-school students from a local school surround the *Downhill Racer* exhibit, completing a homework assignment on angular momentum; in the office, staff members argue about why—exactly—two identical gray stripes appear to be different shades in the *Sliding Gray Step* exhibit. The Exploratorium ticks on, though the man who set the wheels in motion is no longer with us.

Frank will be missed. He was not just the director of the Exploratorium: he was our friend, our teacher, our colleague, our mentor, our guiding spirit. It would be nice to think that the museum might be haunted by him: an irascible gray-suited and gray-haired spirit who wanders the exhibit floor, using his swinging cane to explain the principles of resonance to unsuspecting visitors. And, in a sense, the Exploratorium is and has always been haunted by Frank Oppenheimer. The museum is filled with his ideas, marked by his idiosyncrasies, guided by his philosophy, and touched by his unique view of the natural world that surrounds us all. □

# Recollections

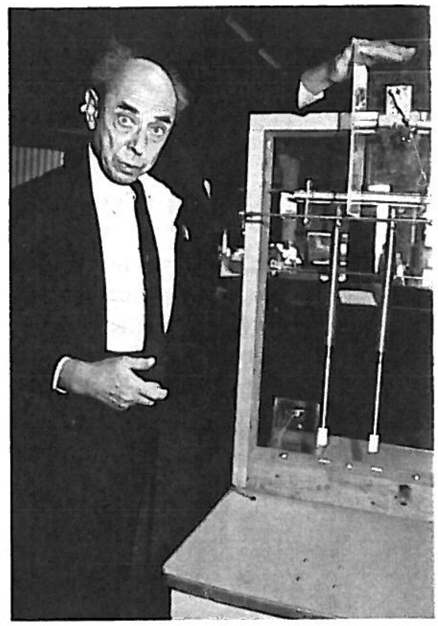
*The Exploratorium staff—and others who knew Frank—remember him for more than his ideas. Frank could be gentle, argumentative, stubborn, courtly, sometimes irascible, sometimes poetic. But above all he was an honest and unpretentious man.*



During the months before Frank's death, the museum roof was being reconstructed. Exhibits were moved so that they would not be damaged by falling pieces of roof. One person remembers walking through the museum with Frank during roof reconstruction. "They were working on the roof and they had opened up the center section quite a ways up from where they should have. Stuff was falling and you could see some guy up there working. And Frank takes his cane and shouts, 'Stop! Stop work!' The guy just keeps on working and Frank yells again, 'Stop! Stop work!' The guy keeps on, and Frank lifts up his cane and says, 'Stop or I'll shoot you!' At that distance the guy couldn't tell the difference between a cane and a rifle. He stopped working."

In "Everyone is You . . . Or Me," an article reprinted in this issue, Frank explains that he builds exhibits that he likes; he designs things for himself—or for people like him. One staffer remembers that sometimes Frank carried this belief to an extreme. People were worried that visitors might hurt themselves on the *Water Spinner,* an exhibit in which a water tank spins rapidly to demonstrate how water in a tank can form a parabolic curve. "Frank got the tank spinning really fast. Then he stuck his head right into its path, and it whacked him—really hard—on the side of the head. I was shocked, but he just straightened up and smiled and said, 'That wasn't bad.'"

As anyone who has gone for a drive with Frank can testify, Frank was a lousy driver. One person claims, "Anyone who'd ridden with Frank knew that he had a guardian angel. You'd be driving with him and he'd be talking and you'd want him to keep talking because he was saying such fascinating things, but it was terrifying because he was looking at you the whole time he was driving down the street." Another recalls, "There were a lot of times that we had special funders and the idea would be to go to lunch. We'd head out to the parking lot and try to head the party off away from Frank's car. But it would never work and we'd end up stuffing everybody in the back of the car and go careening up to Upton's, a local restaurant. I wondered if they gave us money because they didn't want to have to go out to lunch with us again."



Frank never seemed to worry about how people might react to his eagerness to explore natural phenomena. One person recalls, "Two summers ago, we went out to Original Joe's after a performance at the museum, and Frank bought us all beers. We had to drink the beers exactly the right amount so that he could do triple harmonic series on each of the beers at the table and play a tune. Of course we had to drink a couple of beers apiece before we could get it exactly right. And he played incredibly high screeching third harmonics that had the entire restaurant rushing in there to see what was happening."

Frank was concerned with the precise use of the English language. One person recalls, "I had written in a letter, 'It is impossible to describe in such a small space all that this grant has meant to us.' Frank got very mad, and he said, 'Always use words to say exactly what you mean. It's not impossible to describe; say it's very very difficult to describe.' But then I caught him. Later on in the text, he had written, 'an unbelievably competent staff,' and I said 'No, you can believe how competent the staff is.' And he laughed. 'Can I change it to incredibly?'"

Distracted by a big idea, Frank would occasionally forget about little unimportant things. One staff member remembers, "One afternoon, Jimmy walked into the shop carrying this big wad of keys, and he said, 'Have you seen Frank?' and I said, 'Yeah, he's in the office, he's been there about an hour.' And Jimmy says, 'Well, his car was at the curb and the motor was running and door was wide open.'"

Frank was often stubborn and difficult to convince. What made it even more difficult, one staff member says, is that Frank was usually right. "He didn't make a career out of arguing to win the argument," one person points out. "He liked to win—but that wasn't his main purpose. He argued to try to arrive at a solution." The layout of the Exploratorium offices is a case in point, a good example of argument to arrive at a solution. "When we were building the offices here, we had a lot of go-rounds with the architects about how to fit so many people into such a small space. Being modern architects, they were trying to convince us to use modular offices—you know, with low partitions to make little cubbyholes. And they were having a hard time convincing us, so they said, 'You just have to see it.' So we went to the headquarters of PG&E, which is apparently sort of a model office. And there's this gigantic room, partitioned off into little cubbyholes with all these partitions about five feet high. And the architect was talking about how this was the office of the future, and about how this makes people learn to talk softly. Frank was standing there and he said suddenly, really loudly, 'I notice that everyone's being very quiet in here!' All of a sudden these heads start popping up over all the partitions to find out who's shouting. And Frank said, 'See what would happen? I wouldn't be able to yell.'"

Even in sickness, Frank showed an unquenchable love of learning. One person explains, "A few weeks before he died, Frank's leg was giving him a lot of trouble. The doctor prescribed a bone scan. In a bone scan, a radioactive element, in this case technetium, is injected into the blood stream. Technetium acts chemically like the calcium of bones and tends to be absorbed in the same locations. The injection is given in the morning and, later in the afternoon, after the technetium has had a chance to be absorbed, the body is scanned with a gamma-ray detector to see where the technetium has been absorbed. After his injection, Frank wheeled into the office—his leg wouldn't allow him to walk—and got a group of people together to go up on the mezzanine to the *Radioactivity* exhibit. He wanted to see how radioactive he was! So we all went up the elevator and as Frank approached the exhibit the geiger counter started clicking faster and louder until it was obvious that Frank was indeed quite radioactive. In my physics teaching course at State I would be required to sign out a source as hot as Frank. We went back down the elevator to see if Frank was radioactive enough to discharge the *Giant Electroscope* exhibit, but he wasn't quite that radioactive."

Frank's unique view of the world changed the way that many of us looked at things. One person says, "I remember that we were coming back from lunch in his car—and as we rounded the corner of the building here, we noticed that the roofer's trailers and trucks had been removed and there was only one thing left behind, and that was that cart-like machine that heats up the tar. It's dirty, and it's smelly. Suddenly, in this voice that made me think we had just come across a wounded deer in a meadow or an injured bird, Frank said, 'Ah, the poor thing.' And I looked and what he was talking about was this smelly dirty thing."

Frank did not believe in arbitrary rules. If kids wanted to run at top speed across the museum floor, why not let them run? They hardly ever hurt themselves. Besides, Frank liked watching them run. He extended his dislike of rules into every area. One person says, "I remember one meeting where someone was trying to convince Frank to agree to a practical solution by saying 'But Frank, we live in the real world.' 'No we don't,' Frank said. 'We live in a world we made up.'" □

# Teaching and Learning

## Address to PTA, Pagosa Springs High School, 1957

by Frank Oppenheimer

*In 1957, Frank taught biology, chemistry, physics, and general science at Pagosa Springs High School in Colorado. In this address to the Pagosa Springs PTA, Frank describes his motivations and objectives as a high school science teacher, the same motivations and objectives that eventually resulted in the development of the Exploratorium.*

Mrs. Richards asked me to help out with the PTA program this week. Since last week was occupied by tests it seemed impractical to organize any sort of a student demonstration. I therefore decided that it would be useful for me to try to formulate some of my objectives as a science teacher, and that my thoughts on this subject might possibly form the basis of some discussion at this meeting.

I believe that the major reason that I want to teach is to communicate my appreciation of and skill in science to the children. This motive is a simple motive, not very different from someone who exclaims to a companion while driving down the highway, "Look! There go three elk." I enjoy seeing elk and I thoroughly enjoy being able to understand natural phenomena, that is, being able to explain apparently complicated or new happenings in terms of simpler, more familiar, and perhaps more universal occurrences. I like knowing that the pressure on the walls of this building is due to the momentum of the countless molecules of air that bombard the walls and I dislike not knowing why the steer market was higher two weeks ago than it was a month ago. There are many who have no particular desire to communicate their pleasure in understanding except to a very few and who feel that teaching is a chore which interferes with research. I have at times felt that way, but for the most part I like to tell what I know to anybody who will listen long enough. This rather obscure pleasure of communicating is, I suppose, not unlike the urge of a pianist who, having mastered a sonata, is anxious to play it over and over again to scores of audiences.

I suppose therefore that the first thing I try to do as a teacher is to get my student to understand so clearly some phenomena or device, such as the twinkling of a star or the ring of an electric bell, that they realize that understanding, like eating or making a basket during a ball game, is satisfying and fun. If I can succeed in making understanding seem like fun then I believe that the student will want to understand many things, that is, he will become curious. If I can establish a pattern in a student of satisfying curiosity, by showing him that understanding is both possible and amusing, then perhaps the course I am teaching will have the effect of enriching his whole life. It may also make him a more useful and more sympathetic person.

I believe that another motive I have as a teacher is to prepare the students for further learning. Although I know that in reality many of the students may not learn one more thing about science than they find in my biology course, I find that I teach everyone as though they were going to continue learning the subject. The general science students may take a course in physics; the chemistry students may study chemistry in college; biology students might want to read a veterinary handbook. Thus, as I am teaching, I find that I have in the back of my mind what the content of the next course in the subject will be. I want this next course to be easy for them, but I do not want it to be entirely "old stuff." I find this distinction very hard to draw. Parts of subjects that I do not particularly enjoy, such as metallurgy in the study of chemistry, I tend to under-teach, even though the students may need the knowledge. Parts of a subject that seem to me especially elegant, such as physical optics, I try to teach even to freshmen, though the subject could more profitably be introduced at a later date. But the line is hard to draw because a certain amount of fuzziness and puzzlement is probably good for the more advanced students.

Finally, I try in my teaching to give the students a sense of power to actually do something: to teach them, for example, to get numerical answers, bend a piece of glass, recognize a *Spirogyra* when they see one, or solve an unfamiliar problem. I think that I find this last objective hardest to fulfill.

Yet most people, and adolescents especially, are eager to become proficient in as many things as they can. In fact a frequent interpretation of education is limited solely to the belief that students should learn how to do things. One of the important aspects of sports is that they enable a substantial number of kids to become really good at something: catching a pass or pitching a ball or working with a group. I believe that a great many students enjoy and are helped by algebra because of the delightful opportunity for proficiency it affords in solving equations. Shop work, sewing, writing book reviews, typing, language courses, band and art are all important, not only because of the useful skills they teach, but because in each one a different group of students may find that they can do something well.

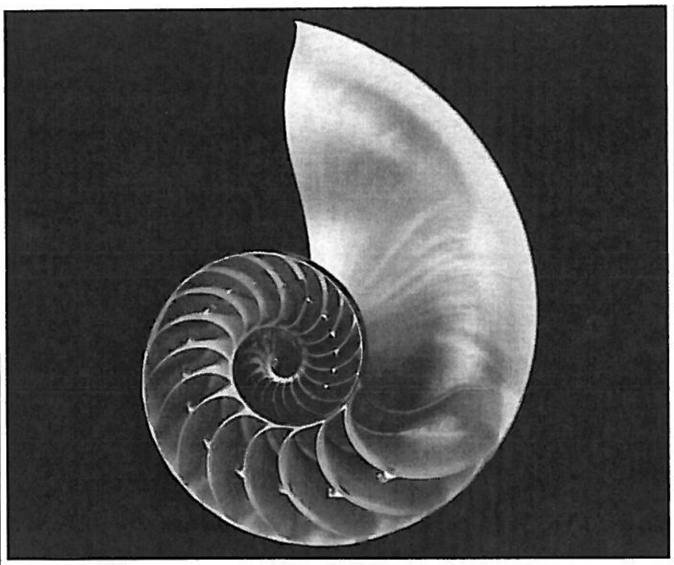
Therefore, as a science teacher, I know that I should allow the students to become proficient in as many ways as possible. There are many techniques in science. There is the manual dexterity of setting up and performing experiments, the mental dexterity of solving numerical problems, the technique of observing the results of an experiment and noticing, for instance, what a leaf or a nerve really looks like. And finally, there are the techniques of plausible reasoning, of putting together known facts and relationships to arrive at new conclusions. Now as I mentioned earlier, it looks as though I will succeed in making an alarmingly small number of my students proficient. Others in school may share my difficulty, but some of my problems are specific to science teaching and I would like, in concluding, to outline them.

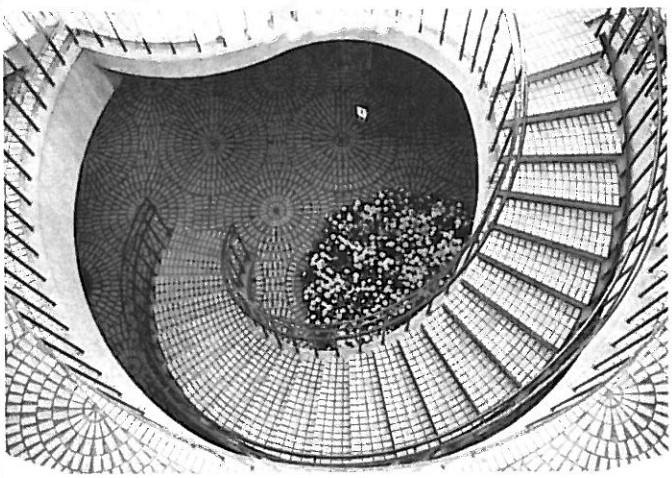
One of the difficulties I encounter is the enormous variation in the initial ability of the students. If I give a test which covers the ground I have tried to teach, and it does not seem to matter which subject or class, the grades usually run from about 20 to 140 out of a possible 160. This range is greater than the intelligence range of the students and must reflect a *cumulative* effect of intelligence, motivation, and health. Since this spread exists very markedly in the mathematical ability of the students, I have difficulty in cultivating problem-solving proficiency in the students. It is as though one had to teach children both how to climb steps and how to pole-vault with just one set of instructions.

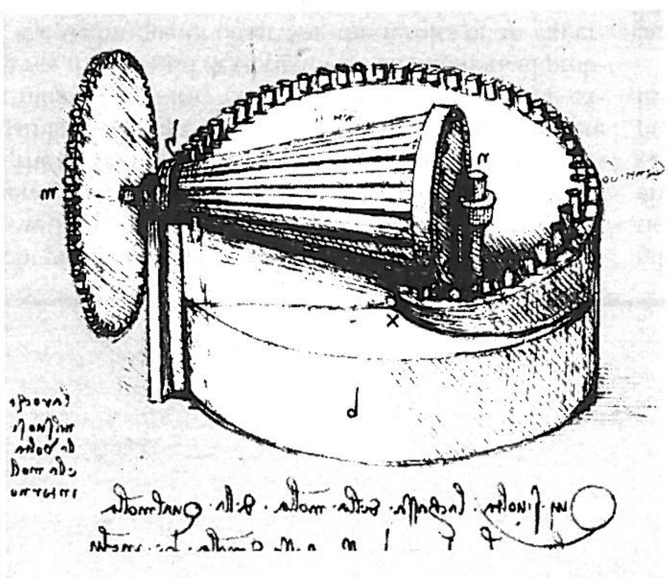
Secondly, teaching the many laboratory skills of science requires either money or time to devise, set up, and supervise the use of the laboratory equipment. I think it is harder to find money than time, but I can't find much of either.

And finally, I do not really know how to teach children to work out problems for themselves. I can give them a problem to work out and say "think." But this procedure is about as effective as saying "wiggle your ears." I cannot tell them how to think, which nerves to use. Alternatively, I can have them follow me step by step as I reason something out, trying to let them get one step ahead of me. But usually the effect is about the same as if I had shown a small child how to saw a piece of wood by standing behind him and making his arms move the saw. The child would know what is required of him and what the motions are, but he still could not do it himself. In short, how does one best teach the most satisfying of all proficiencies: the ability to fashion a new idea.

In discussing the aspects of my teaching—the kindling of curiosity by discovering the pleasure of understanding, the preparation and stimulation for further study, and the satisfaction of becoming adept in the processes of the hand and the brain—I have emphasized the enriching of the student's individual life. It would be easy to argue that these same aspects would make him a more useful scientist. □







# Aesthetics and the Right Answer

by Frank Oppenheimer

*At the Exploratorium, selected artists collaborate with museum staff to produce artworks that are somehow linked to the museum's more didactic exhibits. At a reunion of the artists who had participated in this program, Frank commented, "Art is very much an integral part of what we want people to experience here. If you're going to know about nature, you have to know about how people react to and feel about nature. I think that's what artists communicate." In these excerpts from an article published in* The Humanist, *March/April 1979, Frank describes some of the similarities between artists and scientists and some of their differences.*

Students in physics courses spend a large fraction of their efforts in solving problems and finding the "right answer." The backs of most text books list the right answers for even-numbered problems, and the students feel guilty and stupid if they cannot find the right answers for the odd-numbered ones. In general, physics is considered a "right answer" subject. Its metaphysical implications are widely ignored along with the creative nature of scientific activity.

Students in art classes, on the other hand, although encouraged to be inventive, are rarely aware that artists also find the "right answers." In fact, in the popular view, no one looks to art to provide any answers at all.

Art and science are very different, but they both spring from cultivated perceptual sensitivity. They both rest on a base of acute pattern recognition. At the simplest level, artists and scientists alike make it possible for people to appreciate patterns which they were either unable to distinguish, or which they had learned to ignore in order to cope with the complexity of their daily lives. One can look at hills without noticing that they have a shape until a Cézanne becomes preoccupied with the form of Mont St. Victoire. One can see only a bland flesh color in faces until a Rouault makes one aware of the violent blues and reds and purples that actually appear. Similarly, one can observe the planets rise and set without becoming aware, as Kepler did, that they are moving in elipses about the sun. One can watch falling bodies without sensing, as

Galileo did, that they increase their speed by equal amounts in equal time intervals. Darwin and Faraday, Freud and Marx, as well as Bach and Webern, Giotto and Klee, Shakespeare and Pinter, have all sensitized us to patterns which we might otherwise have missed.

Many artists' sketches, as well as many sketchy reports in the *Physical Review,* simply portray or describe a newly discerned pattern. Even at this level they are important because people rely so heavily on pattern recognition in their personal and social lives. However, artists and physicists do more than discern and record patterns. They use perceived patterns to create additional patterns that are not directly derived from sensory perception. It is as though there were a second level of the neuromuscular system which had the ability to scan the patterns stored in the primary level by means of some, as yet unrecognized, neural mechanism. Eyes and ears enable us to absorb and store the patterns of shape and time that are embodied in our experience. A higher level of perception becomes aware of patterns among these stored patterns. We develop patterns of patterns (called theories in physics, or compositions in painting or music) by selecting from the multitude of stored experiential patterns those which somehow, and often surprisingly, appropriately fit together. It is such patterns of patterns that reveal new insights. It is on this higher level at which we create symphonies from melodies, paintings from sketches, and broad physical theories from empirical summaries or "laws."

These patterns of patterns—the compositions, theories, and works that are assembled by artists and physicists—constitute their most important endeavors. They create an ever-broader framework and mapping of reality; they reassure by creating order out of confusion, separating relevancies from trivialities; they provide a framework for memory, enabling one to reconstruct the experiential patterns without requiring that the infinity of them be stored in memory. By enabling people to share experiences they can also, conceivably, make complex societies liveable. But how do we judge their validity?

In physics, experiential patterns, empirical laws, become validated insofar as they are reproducible and communicable. There is, however, an even more powerful criterion. Their validity is recognized because they have been formulated in ways that suggest how they can be coalesced and synthesized into patterns of patterns. Experiential patterns that describe the flow of heat, or the bending of light in glass have been variously described by physicists at one time or another. Some of these descriptions have led to an ever-expanding linking of patterns, more transparently than have others; they are thereby considered more valid than those which do not lead the way to new insights. It is in this sense that the Copernican pattern for planetary motion is more valid than the Ptolemaic. Both versions describe the motions accurately; both are reproducible and communicable, but Newton would scarcely have been able to produce a theory of gravitation had he been stuck with Ptolemaic epicycles rather than Keplerian elipses. The distrust which physicists express for the occult stems from the fact that each described occult pattern stands by itself as an isolated kind of event, defying any possible integration of conjoining with other patterns to form a recognizable pattern of patterns.

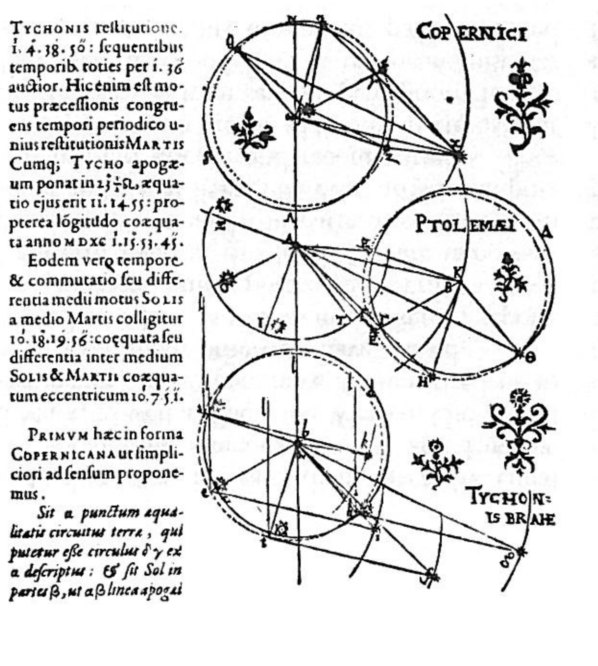
Scientists not only concentrate on perceiving patterns, but they continually transform and reformulate them, or redetermine what aspects of a pattern they consider "signal" as opposed to "noise." Eventually some particular formulation becomes recognizable at the higher level of pattern recognition, and the creative work, once again, begins to move on.

In physics, these patterns of patterns are selected as valid by using both aesthetic and correspondence criteria. Theories that are structurally simpler and that at the same time include more elements of the primary pattern are chosen. They appear more elegant. Maxwell, for example, created a truly elegant pattern of patterns which included virtually everything that had been observed about electricity and magnetism.

But a theory such as Maxwell's may have blank spaces, as though it were an assembled jigsaw puzzle in which everything fit, but in which there were still some holes. Holes could mean that the puzzle was incorrectly assembled. But more commonly, the holes represent missing pieces; they suggest that if one looks in the box or in the trash basket or under the table, one will find the missing pieces. One keeps looking and looking, and if one finds the missing pieces, one is convinced that the puzzle was assembled correctly. It is validated. However, if, as quite frequently happens, the search enables one to find too many pieces, one is forced to assemble the puzzle over again. The theories of physicists are obviously not framed by neat, rectilinear borders as are the puzzles bought in a store. Physical theories usually have boundaries with the jagged jigsaw shapes exposed, and which occasionally enable one to join two independently assembled puzzles. Actually, the imagery of a jigsaw puzzle is misleading. In the composite pattern of patterns of a physical theory, the pattern of individual pieces is not apparent. The composite is not necessarily representational. One has only an idea and a few equations which are less like a jigsaw puzzle than like a group of chromosomes containing all the information in some coded form which, through appropriate transformations, can represent each of the patterns incorporated into the theory. Newton's expression for gravitation, Maxwell's set of five equations, Dirac's quantum mechanics, or even the familiar $E=mc^2$, constitute such coded patterns of patterns. One considers them valid because they represent so much of what has been observed and because they keep leading us to new parts of reality.

The primary-level patterns that artists perceive do not necessarily stem from a different source than those that intrigue physicists. They involve shape, sound, light, motion, and an ever-increasing range of natural phenomena; but the process of formulation, representation and abstraction of these patterns by the artist differs from that by the physicist. The physicist represents patterns in a way that will facilitate his particular way of synthesizing patterns of patterns, often relying on mathematics, which is a step-by-step procedure to discover whatever elements fit together.

Great works of art also constitute a synthesis of experiential patterns and involve a process of selection. Some things fit together, and others must be excluded from the composition. Sometimes the fit is recognized by established rules of form and structure, but usually there are no formulated rules and the synthesis is holistic and intuitive, but far from arbitrary. The artist, consciously or unconsciously, decides that some things are mistakes and must be done differently. The sure hand of Picasso or of Fermi makes few mistakes, but, more commonly, constant decision-making and choosing between alternatives is a characteristic of both artistic and scientific endeavors. The patterns of patterns created by artists are deemed valid, as are physical theories when, often after many false starts, they succeed in concordantly combining the multiple elements of nature and experience. Artists as well as scientists must transform or reformulate observed patterns in order to be able to perceive this concordance. Both artist and scientist combine elements of experience which no one else had conceived of as belonging together.


The works of artists are valid because they lead, as do physical theories, to the revelation of things that are happening, but which have not previously been perceived. In art, these revelations frequently apply to relationships and feelings within ourselves, to those patterns which involve a sense of order and disorder, or feelings of peace and anxiety, or even meaning and purpose, the introspective parts of reality. These relationships are not contained in Maxwell's or Dirac's equations, but they are not forbidden by them. Works of art not only enable people to form associations among previously experienced feelings, but they also generate new feelings from the juxtaposition of familiar ones.

Artists and scientists can observe the same patterns, but they frequently arrive at complementary syntheses of them. Most of us, for example, were intrigued as adolescents by the thought that love was merely endocrine chemistry. Certainly the poetic and the chemical descriptions of love refer to the same reality, but endocrine chemistry and falling in love cannot be bridged by any overlapping set of perceptual experiences. The appropriate starting point for the model must be determined by the way in which a question is formulated. In general, the renditions of art and science share this complementarity. Within this framework, the confirmed emotional revelation of artistic composition establishes validity just as surely as the revelations of theories in physics. Both are surely required to fully know nature.

The validity of art arises because through it we can recognize the way in which all the processes of nature, including those that arise within ourselves or that stem from other people, affect our consciousness and our emotional well-being. Art is not valid merely to decorate our surroundings with statues in the plazas of skyscrapers, any more than science is valid because it provides the conveniences of electric shavers. Surely they must both be required if we are to learn how to survive in a changing world—a world that we ourselves keep changing, but that would also change even if we were not here. □

# Adult Play

by Frank Oppenheimer

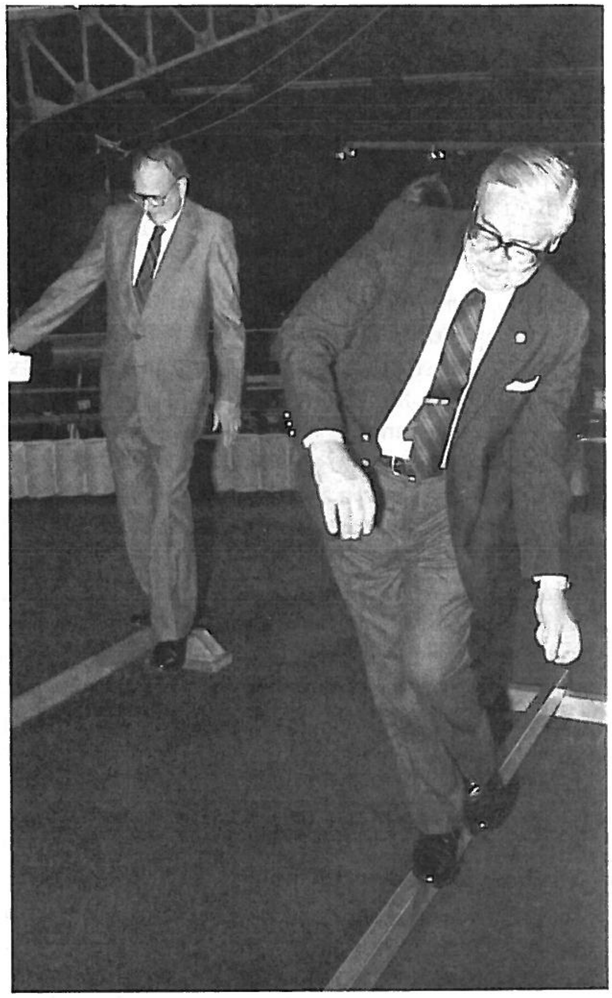
*Frank wrote this article for the February/March 1980 issue of* The Exploratorium *magazine, which was on the topic of play. That same issue was dedicated to the memory of Jackie Oppenheimer, Frank's first wife and co-founder of the Exploratorium, who died of cancer as the magazine was going to press. It might have seemed inappropriate for that commemorative magazine to deal with such a light-hearted topic, but the consensus at the Exploratorium was "Jackie would have liked that." The article captures an important aspect of Frank's attitude toward work and learning.*

When we were planning this issue of *The Exploratorium* magazine some months ago, we thought of taking photographs of a crane operator knocking down a wall with a huge steel ball. It seemed to us that anybody who had ever seen this activity would like to get a hold of that swinging ball and play with it for a while. We asked our staff photographer to photograph this activity in San Franciso; we would also talk with one of the operators to see if he ever had this sense of playfulness that we associated with the wrecking ball. Immediately after these discussions the photograph of the Minneapolis grain elevator appeared in the *San Francisco Chronicle.* The photograph confirmed our notion that it was indeed a playful activity, and we contacted the Minneapolis ball-and-crane operator. Contrary to our expectations, the operator perceived what he had done as getting publicity for his firm.

Despite the operator's perception of his own activity, we see it as something which matches our conception of playfulness—that of using a prop of society out of the context of its designated purpose, which in this case is to knock things down. The imaging of a face on a grain silo certainly seems like play even though it was justified as publicity.

This example illustrates the difficulty in distinguishing adult work from play. The distinction can become very blurred when people get paid for play. One of the more productive employees of the Exploratorium said to me some years ago that he felt confused because what he was doing much of the time in the machine shop was just playing around with no particular purpose. He didn't see why he should be paid for doing that, even though his playing around sometimes resulted in the birth of wonderful and instructive exhibits: exhibits whose major purpose or form was in no way conceived at the outset of the playing around. My brother, when he was a young man, said his teaching made him feel that he was giving somebody their money's worth, whereas almost none of his research calculations had anything to do with anything. It seemed hard for him to justify his being paid for just doing research.

Whether it is exhibit-building or research or sculpture, so much time is spent just playing around with no particular end in mind. One sort of mindlessly observes how something works or doesn't work or what its features are,



much as I did when, as a child, I used to go around the house with an empty milk bottle pouring a little bit of every chemical, every drug, every spice into the bottle to see what would happen. Of course, nothing happened. I ended up with a sticky grey-brown mess, which I threw out in disgust. But much research ends up with the same amorphous mess and is or should be thrown out only to then start playing around in some other way. But a research physicist gets paid for this "waste of time" and so do the people who develop exhibits in the Exploratorium. Occasionally though, something incredibly wonderful happens.

But if people get paid for playing, does it then become work? The recognition of adult play can become very difficult. In some instances, the playfulness is obvious. For example, there are times while driving that I keep time to radio music with the accelerator and the brake to produce a quite remarkable motion of the car. It's true that this activity is manifestly playful. It uses the automobile out of the context for which it was designed, but it is also an extremely trivial example of adult play.

The problem of talking about adult play becomes difficult because there are some people who are never playful in their work or their studying. I once asked Bob Karplus, a professor at U.C. Berkeley, a question that I had asked many people without getting a very satisfactory answer. I asked, "Are there any things which a young person must learn before it is too late to learn them?" There has been much emphasis on how *early* a child can learn to write or to spell or to add, but my question seems not to have attracted much attention. There may very well not be anything which one has to learn before it's too late to do so. But Bob answered, "Maybe people have to learn how to play before it's too late." He said he had observed college students over the years and there seemed to be a large group of them who never played in their studying or in their life, whereas at the other end of the spectrum an equally large group of students were continually playful. The ones who were never playful never seemed to learn how to be playful. It was an interesting answer, I thought, and would bear some looking into, for it is clear that the kind of playing that is so fruitful in art and science and in getting accustomed to life or change is an extremely vital aspect of all human endeavor. If the ability to play is inadvertently denied to a large part of the population, it would be worth finding out why.

Certainly, many Exploratorium exhibits have been born of play and have been built so that they can be playful for the people who come here. But even in this enterprise, I've noticed that as the staff gets larger and the institution grows older, it becomes more and more difficult to get people to be playful. Exhibits are now usually made from scratch out of raw stock through elaborate machining and welding, whereas in the early days we improvised by finding something that was made for some other purpose and using it to construct an exhibit. We even set out purposeless exhibits such as a vibrating timer and called it an *Adjustable Plaything*. But it's been a long time since we've set out an exhibit with no particular purpose in mind.

I can only conclude that it must require an inordinate amount of self-discipline for adults to remain playful in their work. It seems to me that although a lot of people do play games together, being genuinely playful is frequently a solitary kind of activity with private justifications that are socially incommunicable. One can never manage to justify any particular act of playfulness, but only recommend the value of playfulness in general. □

# Everyone Is You...Or Me

by Frank Oppenheimer

*Frank often described the Exploratorium as a "woods of natural phenomena." In this excerpt from an article published in* Technology Review, *June 1976, Frank talks a little about what makes a good exhibit, an interesting addition to the trees in the woods. Whenever Frank built an exhibit, he strove to design it for people like himself—curious, energetic, enthusiastic, and willing to learn.*

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In my youth I used to wander in the mountains. I would gain a feel of the terrain and gradually build up a reliable intuition of how to get from here to there and back again. Always, on these expeditions, I would discover special places—a tiny area, the only one, where fairy slippers grew; a pool in a rushing stream that was deep enough to swim in. Invariably I would find myself excitedly climbing some promising knoll or uppermost peak. Suddenly a whole new vista would open up, showing a great expanse of prairie, a hidden lake in some inaccessible canyon, an entire new ridge of peaks.

As a result of these solitary expeditions, I would tell friends what I had found and would want to show it all to them. Somehow it was especially important that they see the view, often at a special time of day—perhaps precisely when the sun was setting. But we would start late or they would be unable to walk as fast as I. I would point to the place where I had found the fairy slippers, but we would walk on by. We would reach the top, and the view would be well worth the effort and the hurry. But gradually I began to realize that there was something wrong with these revisiting expeditions. Although the view far outweighed anything along the way in wondrous and memorable experience, the events along the way had been an integral part of the trip for me, and would also have to be so for the people I wanted to bring pleasure to. If the trip was spoiled through hurry or painful effort, then no one was moved to go searching for views on his own.

When I was teaching physical science to high school students, I felt the same kind of thing happening. The course was certainly an improvement on my mountain expeditions. It cleared the trail, mapped out switchbacks when the grade was too steep, and built bridges or steps when the terrain was impassable. But for those who built the course and came to know it well, it was crucial to reach the panorama of the final chapters, which put together everything that had gone before and opened up grand new vistas. From the vantage point of Bohr's model of the atom, one could look down and see where one had come from and how different and tiny everything looked down there. One could look out at new terrain that begged for future exploration. But in order to reach the vantage point soon enough, the trip had been spoiled. There was no opportunity to explore unexpected and pleasant nooks along the way.

The Exploratorium—or any good museum—is a response to the problems that beset both my guided tours in the mountains, and teachers who feel they must "cover the ground." At the Exploratorium we've invented a new style of exhibit to do it.

Consider our audience as contemplating a tree. Science museums all describe themselves as having interactive, involving, hands-on exhibits. But they misunderstand the implication of the terms they use. A tree has no push-buttons, no cranks, no manipulative parts; but there are a lot of ways of interacting with it. One can look at it, lie under it, climb and feel it. One can watch the leaf buds unfold, mature into deepening greens and then oranges and reds until they fall off. One can study the bark, the cambium layer, the root hairs, extract sap, learn about photosynthesis. One can hear the rustle and watch the swaying in the wind. One can draw or photograph the tree, carve initials on it, chop it down, or just stand and watch the sunlight diffract around the edges of the leaves. One can even learn its name.

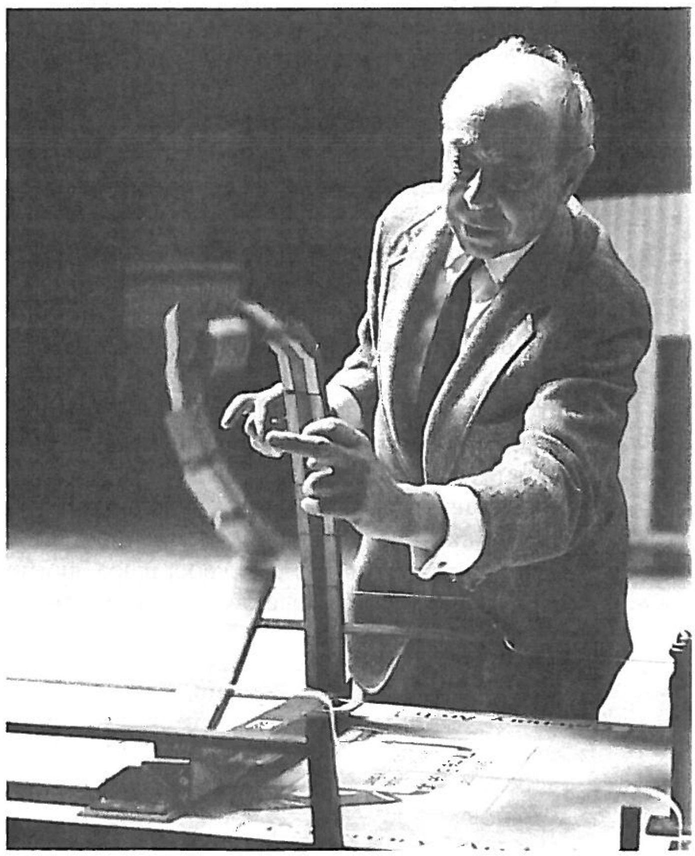
Our exhibits do not have quite this versatility. For one thing, we do not want people to chop them down; for another, the time scale is more defined: at most, half an hour at any one exhibit piece, often much less. More importantly, however, we conceive most of our exhibit pieces as props to link a pedagogical chain; frequently the links are common to several different chains. Thus, the *Relative Motion Swing*, which has a swinging table beneath a pendulum of the same period, can be used in many contexts. One can use it in talking about vectors, about polarized light, about Lissajous figures, about phase, amplitude and frequency, about damping, about kinetic and potential energy, about frame of reference and relative motion. For each of these topics this exhibit is but one link shared by several other chains of exhibits, which may intersect at other links as well.

The fact that we use this exhibit for these multiple but specific purposes limits the versatility of people's interactions with it, but not as severely as one might imagine. True, visitors cannot disassemble and rebuild the exhibit. True, we have not made provision for the visitor to vary the swing periods of the table or the pendulum. (The clearest pedagogy arises when the two motions swing synchronously. If either were readily adjustable, most visitors would not take the time to make the two motions synchronous and thus would not perceive the most delightful effects of relative motion.) On the other hand, we have not designed out all possibilities of variation. Although the pendulum swings most readily at right angles to the table, it can also swing parallel to the motion of the table with a very different and not commensurate period. The table itself can be made to vibrate perpendicular to its swing and, thereby, modulate the basic pattern of relative motion.

People use this exhibit in many different ways. Some just give the table a push as they walk by—but then, so do I. Others make everything move every-which-way producing a noisy, unintelligible relative motion pattern. I enjoy doing that too. Many people very systematically let the table and the pendulum swing at right angles to each other, trying to reproduce the indicated circles and diagonal lines of relative motion, learning about relative phases and amplitudes by trial and error. There are some visitors who know all about what the pendulums are "supposed" to show. They use the exhibit to instruct their friends and children—and I also use it that way.

This is a very good exhibit. I enjoy playing with it myself, and I enjoy showing it to you—no matter who you are; it is an exhibit for everybody. Many decisions went into its construction. It is versatile; visitors can find systematic things to do with it with relative ease; and one can obviously invent activities that are "out of context," clearly not part of any preconceived syllabus. The exhibit has other virtues as well. It is made entirely of hardware-store parts: pipe, perforated angle iron, cable and turnbuckles, springs, etc. The hinging involves a short section of pipe rolling on two rods for the proper motion of the pendulum and a rocking motion from one rod to the other for the playful motions. The main defect in the exhibit is that, although there is elegance in the design, there is virtually none in the craftsmanship. Perhaps it was built in too much of a hurry.

Certain attributes of exhibits—their beauty, their multiple linkages with different themes, the inclusion of extraneous possibilities for intervention and discovery—have proved to be important to the overall effectiveness of the museum. There are other general practices that are important. In particular, when we make an effort to illustrate some process or behavior that is pervasive in nature (refraction, resonance, or sensory lateral inhibition, for example), this behavior is presented in many exhibit pieces. Each illustrates the same underlying process in very different contexts. For example, wave motion is a powerful abstraction that could not be perceived from any single

type of wave. But the concept can take shape by observing the effect of light waves and water waves and sound waves, of waves on an oscilloscope, and waves in a string or a flat plate.

One of the great virtues of museums stems from the possibility that visitors can, by themselves, achieve a very satisfying understanding through abstraction from multiple and contextually different examples. Many museums fail to provide this possibility because they show only a single representative example of each effect or process.

The remarkable feature of the process of individual discovery, whether of detail or of generality, is that the first taste of success can be addicting. For some obscure reason we, as teachers, are committed to turning on addicts. But potential addicts are not programmable; one never knows who they are or when they are vulnerable. We argue among ourselves: if we do not tell people what they are supposed to find, many will leave with a sense of frustration, but a few will have become addicted to finding more than anybody knew was there. How many frustrated people is one addict worth? Since there is no going back if one gives away too much, we tend to lean toward the more radical answer to this arguable question. And we do have a large number of addicts who come back for more.

The Exploratorium is a good museum because of the care and thoughtfulness with which the exhibits have been conceived, designed, and assembled. But many of the people who visit us stress, and perhaps exaggerate, the importance of the general ambience of the place. Some aspects of this ambience may be essential to our purposes. The remarkable spaciousness of the Palace of Fine Arts hall is certainly unique. It is also vital that we do not fragment the space with walls that define subject matter boundaries. Since we want visitors to explore and invent in a way to which they are unaccustomed, we avoid the usual plethora of written and verbal commands as to how they should behave. We also resist making rules whose sole purpose is to reduce the amount of work or decision-making required of the staff.

The most important aspect of the ambience of the Exploratorium may stem from the fact that visitors are never subjected to judgmental discomfiture. They do not feel compelled to decide whether they are supposed to learn something from an exhibit or merely enjoy themselves. If they stand before an exhibit and say, "Gosh, my eight-year-old child could do that," this remark is made approvingly. It is not the familiar disparaging or derisive statement that is heard in an art gallery. Nothing in the setting, label, or symbolism suggests to the visitor that he must decide whether an exhibit is truly great art or great science or an outstanding intellectual achievement of the human mind. It is in this one respect—and only in this one—that we may conceivably fool the people because many of the things they look at really do reflect the extraordinary quality of somebody's achievement and imagination.

Even in this respect, though, I doubt that we really fool people. They are certainly aware that the Exploratorium is not a trivial place. But we do nothing that would make people feel uncomfortable with non-triviality; else why do so many teachers bring students, why do so many students bring back their parents and families and friends? And why would those few adults who come alone invariably express regret that they do not have their children or grandchildren with them?

I suspect that everybody—not just you and I—genuinely wants to share and feel at home with the cumulative and increasingly coherent awareness of nature that is the traditional harvest of scientists and artists.

The exhibits that we have designed, the thematic emphasis on perception, and the general atmosphere of the Exploratorium go a long way toward making this sharing possible for an indescribably diverse population. There is a great deal left to do and learn in order to complete what we have started. As we mature it also seems ever more important to us that we learn how to integrate what happens here with learning and enjoyment that takes place at home, in the city and country, and in schools. In the meantime, it is wonderful and rewarding to just wander around the floor, watching, listening to, and occasionally talking to the visitors. Perhaps each of us is in some way everybody, and the surest way to delight others is to find what is a delight to ourselves and to the people we are fond of. □

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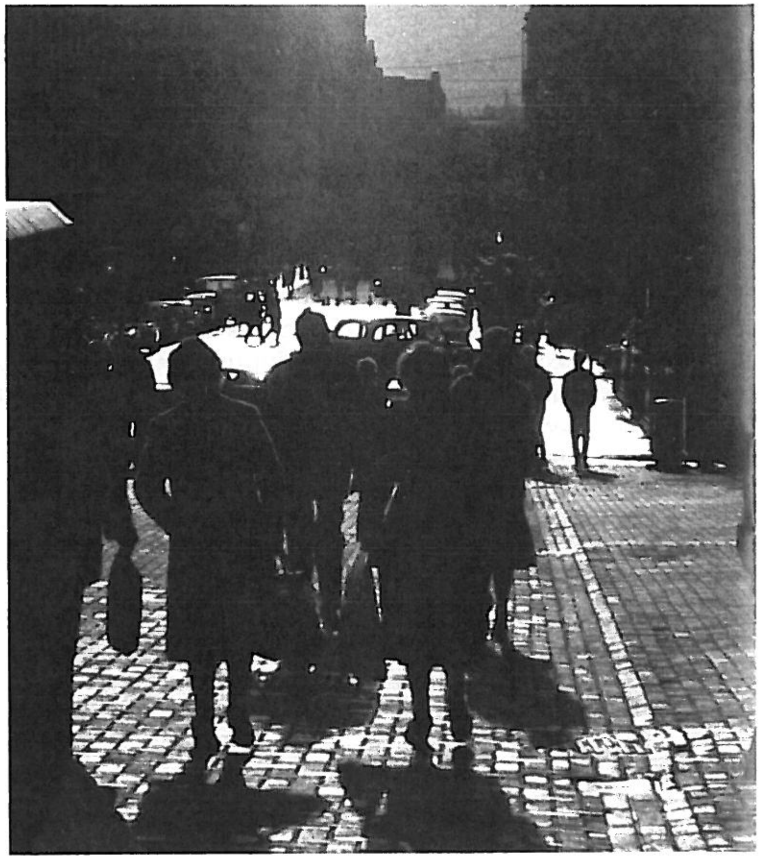
# Fear

by Frank Oppenheimer



*During the last few years of his life, Frank collaborated with K.C. Cole, former Exploratorium staff member and noted science writer, on a book to be titled* The Sentimental Fruits of Science. *This brief discussion of fear and how it affects people's behavior was excerpted from one chapter of the manuscript.*

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Today people in most parts of the world are still threatened by natural disasters, earthquakes and famines, epidemics and floods. But by far the most dreaded and most menacing aspect of our environment stems from its human component—the activities of people like ourselves. We are now afraid of nuclear bombs and handguns in the same way that people were afraid of comets and smallpox. But we are not threatened directly by the nuclear bombs in the missiles. The bombs are as harmless as a car in a garage. We are threatened by the people; by some crazy fool or some zealous patriot or reformer who may "push the button." We are fearful of the people who drop the napalm and spray the mace, and of the people who shoot each other in dark alleys.

Since science has dispelled our fears of much of our natural environment, one wonders whether or not it can also dispel the fears originating from that part of our environment which consists of other people. Is there any way in which the solution of the social problems can be simplified by scientific and technological developments? Can we protect ourselves against the violence of people by understanding them? Can we invent the societal analogs of lightning rods and vaccines?

There is no better example of how a vague but pervasive fear of little-understood phenomena can create chaos and terror than our fear of war. Fear of war is vague because most of us do not have a specific enemy in sight. Our enemy is not really defined as the Soviet Union or as Iran or China or some terrorist or some madman. For we don't know what a war could be about or what might trigger it. But for the past thirty-five years, we have behaved most astonishingly towards this diffuse threat.

Much like our superstitious ancestors, we run around doing everything we can think of to prevent war, even things that are incompatible with each other. We adamantly claim that we should act tough, then we turn around and decide to act sympathetically and promote detente. We make certain that we are armed to the hilt, and then we attempt to work out disarmament treaties. We use the CIA to assassinate and influence, but we also act humanely through loans, the Peace Corps, and disaster relief. We give food, and we take food away. We arrange cultural exchanges and economic agreements, and then we countermand them. We rely on the balance of terror to deter war, but continually unbalance the scales with more terror. Along with these "deterrents" that are supposed to stabilize international relationships, we engage in repeated acts of denunciation and hostility that increase rather than reduce tension.

Fear of war is typical of the vague terrors that invariably eventually result in irrational and ineffective behavior. We have no theoretical understanding of war, of its causes, or of how it can be triggered or where it will start or how it is connected with economic and political actions—or even what problems it could conceivably solve.

We, in our country, think of war as an external threat which, if it occurs, will not be primarily of our own doing. And yet we obviously also believe that the avoidance of the disaster depends in some obscure or at least uncertain way on the details of how we behave. What elements of our behavior are decisive: Our weapons production? Our world prestige? Our ideas of democracy? Our actions of trust or stubbornness or secrecy or espionage?

We have, for the past thirty-five years, staved off a war. Since our behavior has involved all these elements, we can only keep adding to our ritual without daring to abandon any part of it; we have not the slightest notion which parts are effective. One of the reasons that the United States and other countries have become so consumed with international coercion is that our efforts to preserve the peace are unwarrantly complicated and costly of time and resources. Since we don't understand what is required, we invoke every suggested alternative.

Like so many other people, I find myself really scared that there will be a war. But on many other issues, I do not feel as frightened as many of the people around me seem to be. Perhaps my life as a physicist and teacher has encouraged me to believe that understanding will enable us to react appropriately. I am therefore not as scared of radioactivity or of city streets or of running out of fuel or of the effects of burning carbon fuel or of fouling the ozone layer with fluorocarbons or of nuclear wastes. These are all valid, specific things to worry about. But I feel that somehow we can and probably will learn what is important and what we need not bother with and what to do or not do.

The fact that I feel this way does not mean that I necessarily trust the people who are now making the decisions about these things. Yet I do feel differently about these threats than do so many other people. Why? It is because I've had a taste of success in trying to understand nature, and because I, along with many colleagues, believe that the world (including war) is, in principle, understandable. But nobody acts as though they believe that war is understandable. As a consequence, national policies, ours and others, seem to be based solely on voodoo. No wonder we fear.

The vague fears are themselves, of course, a potent danger. It is well known that fear can provoke normally harmless people to behave in violent ways. Most cases of police brutality can be traced to frightened police; dogs and horses detect fear in people and become much more dangerous to those who are afraid of them than to those who are not. Fear of pain in childbirth can increase the actual pain, and fear while diving or rock climbing can cause dangerous accidents. Fear of a stockmarket crash often leads to panic behavior and economic disaster.

But nowhere is fear now potentially more disastrous than in the case of war. The more each country fears the others, the more nuclear weapons proliferate. Each country fears a surprise attack. The world is increasingly like a saloon in an old-time Western: people crouch behind the furniture whilst silent desperados eye each other for the least sign of motion. Today fear is the cocked hair-trigger of our silos that could start the futile agony of a World War.

Understanding is not always sufficient to quell our fears. When I was twelve years old, a beloved adult friend died of blood poisoning after he accidentally scratched himself with a needle. People understood all about streptococcus then, but had no defense against it. They used a variety of ad hoc treatments that sometimes worked and sometimes didn't. Until antibiotics were discovered, signs of blood poisoning were thoroughly frightening.

If we are to protect ourselves against the dangers of other people, then we need not only understanding, but also social invention and experimentation that can provide immunities from the things that people can do to each other. We need the social equivalent of ships that protect us against the waves and the antibiotics that protect us from disease. The role that science may play in this process isn't yet clear, but certainly the social sciences have not been as helpful as one might have hoped. A large part of the reason for this lag is that social scientists are dealing with much more complex phenomena than are physicists. But the lag in the social sciences is also due to a profound misunderstanding of what the physical sciences have done and can do, and what factors have been responsible for their impressive successes. □

# The Practical and Sentimental Fruits of Science

## Fifteenth Anniversary Awards Dinner Speech, November 1984

by Frank Oppenheimer

*In December of 1984, the Exploratorium held its Eighth Annual Awards Dinner. The year also marked the museum's fifteenth anniversary. At the dinner, Frank spoke on "The Practical and Sentimental Fruits of Science." The complete text of his speech is reprinted here.*

Thank you all very much for coming. I also want to thank the staff of the Exploratorium. Because of our roof reconstruction this place was open to the rainy atmosphere over the weekend when seven thousand people came. Then, to compound the mess, it rained all day yesterday. Yet the entire staff conspired and worked to make this place look as nice as it does tonight.

I was extraordinarily honored when Bill Hewlett let us honor him at this dinner. It is for us a great privilege to be able to do so.

I'm not going to talk about the Exploratorium. I resist the temptation to do so because I want to talk more broadly about science. There are some aspects of science that I think are not generally understood. In the first place, when people talk about civic cultural institutions they do not usually include science museums as part of their image of culture. Before we started this place, I noticed that universities would have museums of art, geology and anthropology exhibits, but rarely museums of the physical or biological or social sciences. Yet when we describe older cultures, we always include their world view. When we think of the Druids we are impressed by how well they had recorded the seasons and how well even earlier people had recorded eclipses and tides. We show their tools and their technology; we talk about all their myths about nature and include all these as a part of what we think of as culture in distant civilizations. But these are also part of the culture in our civilization. One of the reasons that physics, chemistry, and biology are not assimilated into our view of our culture is that these subjects are taught primarily as vocational ones. Furthermore, they are taught unimaginatively and are not integrated with other aspects of our culture. I hope this situation can change. It would be good to come back to the days in which physics was thought of as natural philosophy.

The basic objective of science is to discover, understand, and unify what's happening around us, whether in living things or inanimate things. Very often people talk about the scientific method, but I believe that the way of understanding in science has a great deal in common with the way of understanding anything. Yet there are a couple of very special things about science that are not part of its methodology really, but which are crucial to its progress. One of these is that if you are genuinely trying to understand what's going on around you, then there's no point fooling yourself, or, for that matter, fooling any of your colleagues. Within the scientific community there is a tradition that anybody who fabricates data is completely ostracized. This tradition is one of the basic tenets of science, and science has traditionally been one of the very special strongholds of that tenet. I wish it also applied to politicians and advertisers, so that they would ostracize people who willingly and deliberately fabricate data.

One of the nice things that is true of the Exploratorium is that people trust it. We don't "rig" any of the exhibits; the exhibits do not show things artificially. The natural phenomena are there, and the visitors can ask questions of the exhibits. The exhibits can then answer these questions because they behave according to nature.

There's another very special property that is true of the pursuit of science and essential to its ability to flourish. It has to do with the fact that the effort and activity of trying to understand something can be, and often must be, separated from, divorced from, the process of trying to accomplish something, and from the business of doing, of making a living, of constructing. A great deal *is* learned in the process of doing, but one can rarely stop the doing in order to look into some unexpected behavior more closely or to follow the side-dreams of one's curiosity far enough to complete the understanding. I know that during World War II, when we were working on the separation of the readily fissionable isotope of uranium from the more abundant one, we were in a hurry. We couldn't stop to

***The basic objective of science is to discover, understand, and unify what's happening around us, whether in living things or inanimate things.***

look at all the new things that we saw. We had to start with a gas discharge, like a neon sign, but through the gas of some uranium compound. These discharges produced separated beams of the two isotopes. These beams started as extraordinarily small currents, just tenths of microamperes, but eventually ended up in factories that produced hundreds of amperes of uranium ions. We ran into trouble. When we tried to increase the current, we got violent random fluctuations in what was happening—"hash" we called it. But we couldn't stop to examine the nature of discharge plasmas; we just had to try something different. If our change made the current larger, we did more of the change; if it made things worse, we did less of it. There was no way of getting the job done and at the same time trying to understand the phenomenon.

I had the same kind of experience when, during the 1950's, our family was farming. We planted a certain wonderful grass: Amur wheat grass that was selling at a dollar fifteen a pound for the seed. We decided to grow the seed as a cash crop. We plowed up eight acres of virgin soil and got a wonderful harvest that filled our granary with sacks of the precious seed. *But not one seed was fertile.* However, we couldn't stop growing the grass to understand why. Besides, by the next year there was no point in understanding it since the price of the seed had dropped from a dollar fifteen to thirty cents a pound. And so we just continued to have a good hay crop, but without ever having a seed crop.

Bringing up children provides another example of the impossibility of combining research and activity. For example, I have always wondered whether major and minor keys had something special about them, the minor one being intrinsically sad. So after my daughter was born, when I was happy or we were dancing, I would sing or play music in a minor key, and when we were sad, I'd play music in the major scale. But it wasn't a very good experiment because there were too many outside influences: other people sang songs which sort of destroyed my experiment. Whether you are bringing up children or teaching or farming or developing products, it's very hard to really look into things at the same time. The very special thing about science is that one isolates the business about finding out about something from the business of doing it. Of course, many very fundamental properties of nature have been discovered in the course of trying to get something done, but the establishment of separate research environments in which people are paid just to find things out has been a key element that has made science flourish.

The experiments with cosmic rays that Dr. Panofsky mentioned when he introduced me provide an interesting example of the way in which the course of fundamental research can fruitfully be redirected in midstream. In 1947 the Chairman of the University of Minnesota Physics Department, Jay Buchta, had brought together a group of physicists to study cosmic rays at very high altitude. The General Mills Corporation was developing huge balloons that could carry an eighty-pound payload to an altitude of one hundred thousand feet (about twenty miles). These balloons made it possible to adapt standard instruments to the study of nuclear reactions using very-high-energy cosmic rays well before the high-energy accelerators of today had been developed. We accordingly built a cloud chamber that enabled us to successfully photograph nuclear interactions. But the most surprising results came from a stack of photographic plates that we had added to the payload. These plates did not show incoming cosmic ray hydrogen nuclei (protons) very well, but they did show, when developed, heavy dark lines that were the tracks of fast moving, highly electrified particles. We had made a discovery! These tracks were due to the presence, in the incoming cosmic rays, of the nuclei of all the elements: carbon, oxygen, iron, etc. Up to that time, only the nuclei of hydrogen had been observed in incoming cosmic rays.

This discovery immediately turned around the direction of our research. We began to study the origin of cosmic rays and what happens to them as they move in our galaxy. Our thrust became more involved with aspects of cosmology than with the study of nuclear physics.

Another manifestation of the central role of separating research from problem-solving is illustrated by a controversy that raged during the nineteenth century concerning the age of the Earth. From purely geological evidence, sedimentation rates, etc., geologists concluded that the Earth must be well over one billion years old. But this age contradicted evidence provided by the high temperature of the interior of the Earth, hot springs, molten lava, etc. The Earth radiates this heat to cold outer space much faster than the sun keeps the planet warm, so that the Earth would cool fairly rapidly, in about one one-hundredth the time claimed to be the age of the Earth by geological evidence. The solution to this problem could not have come from either the geologists or the physicists of the time. The solution came from a completely different kind of research at the beginning of the twentieth century: the study of radioactivity. There is enough uranium and thorium in the Earth's rocks to keep the Earth warm.

This pattern of discovery—the bringing together of two initially completely independent domains of basic research—is characteristic of progress in both the practical and the sentimental fruits of science. It is clearly shown in the invention of lasers, semiconductors, and super conductors, and in the many roles that nuclear energy can play both on Earth and in the stars.

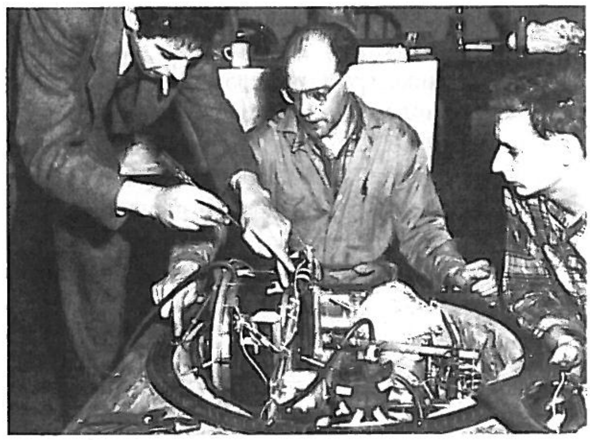
In general, what science has done through its wandering explorations is to discover things that were happening in nature that nobody knew were happening. These newly discovered phenomena—whether they have to do with semiconductors, radioactivity, induced emission, or electromagnetic waves—have provided the raw materials for new invention. Virtually every newly discovered natural behavior has opened up a plethora of new inventions. On the other hand, without this continuing insertion of fresh raw material, we become stuck. We then go 'round and 'round in the same path, both technically and philosophically. It was largely this lack of "raw material" that caused invention to be mired down before the scientific revolution, before people had the privilege and were even paid to go off into a corner and look into nature apart from actually getting something done.

So our support of basic, almost playful research has to continue. Too often it is not understood how this special, or, if you want to call it so, this ivory tower nature of science is crucial to any sort of progress.

There are industrial labs that have this academic quality. The Bell Lab has had such a reputation, and many other industries have followed suit. But for the most part, industries can only afford to do research to get a limited domain of particular things done; they can't wander all over the map because they have noticed something that aroused their curiosity.

There is another aspect of science that has caused much confusion, especially among the lay people and even, I think, among the scientists themselves, especially the social scientists. Scientists are now very often asked to predict what's going to happen. But I see no reason why they should be particularly good at doing so. The confusion comes from the parlance of science. We say that a crucial test experiment for a theory comes about because the theory "predicts" something, and then you find it. But what these theories predict is not the future: they do not tell what's going to happen. When Einstein predicted that light bends as it goes by the sun, he didn't predict something that was going to happen in the future. It was something that was happening all the time—that always had happened and always will happen.

Most crucial experiments, most predictions of theory, are not predictions of what's *going to* happen; they are



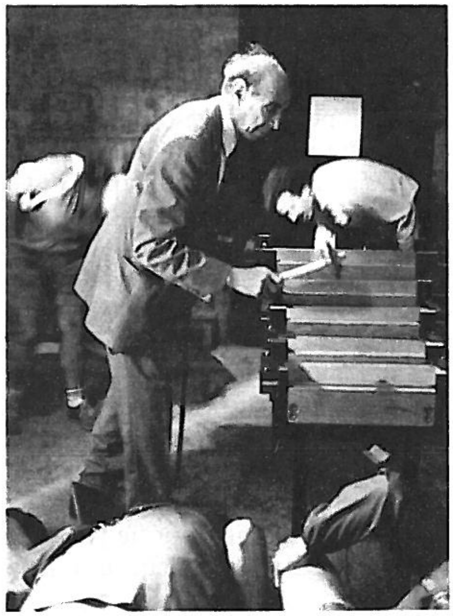
***The very special thing about science is that one isolates the business about finding out about something from the business of doing it.***

predictions that if you look at the right time, in the right way, and with the right instruments, you will find what *is* happening. In this sense the theory helps you discover new things that are going on in nature. But the word prediction has led people to think that one's understanding of nature is going to let us know what actually will happen in the future. Science can tell what is happening, what has happened, often what can happen, and sometimes even what cannot happen because of the conservation of energy or some other very broad principle, but it hardly ever can tell, purely from understanding, what *will* happen.

Yet a by-product of science *has* contributed to our ability to predict and therefore, indirectly, to our sense of security (people have always wanted oracles). In fact, most predictions are based on pattern recognition rather than on understanding. People could predict the tides long before they knew anything about gravity. Prediction is based primarily on observing patterns often enough that one can assume those patterns will repeat again and again. Such repeatability is the basis of our predictions, whether connected with child-rearing, the mode of operation in committing a crime, the course of a disease, or the changes in business cycles.

How does one observe patterns? One has to use one's senses, and it is science that has provided the raw material of natural phenomena that has enabled us to invent ways of extending the range and sensitivity of our senses. This extension of our senses involves our ability to see through things: it has to do with weather satellites, with the perfection of microscopes, telescopes, and infrared binoculars. All kinds of ways of seeing, hearing, sensing motion or detecting molecules have been invented. These have vastly expanded the acuity of our senses, our ability to observe patterns, and therefore our ability to feel a little more secure because we think we know what's going to happen.

The people who can do this observing are not necessarily using science to observe patterns. We are all reasonably good pattern recognizers and some of us are uncannily good. Doctors must be very good pattern recognizers; artists are pattern recognizers; the people who watch radar and observe what's happening with airplanes don't have to know any science to discern the patterns of approaching airplanes. So I think scientists on the whole should be a little more humble. They should understand that it isn't their scientific training or knowledge that enables them to predict what's going to happen. If the scientists say that such and such a thing *can* happen, they may well be right. However, they rarely have any compelling scientific justification for saying that something *will* happen. I don't think they have any special right to say that. But if they *do* say it *can* happen, whether it's a nuclear winter or destruction of the ozone layer, then the public, although it cannot be sure it's going to happen, should nevertheless be alert to this possibility and be prepared to react quickly to prevent it from happening, especially if it is catastrophically irreversible, as is the case with nuclear winter. It is in this sense, I think, science and understanding can provide a real service, but I am



***So our support of basic, almost playful research has to continue.***

really worried by the fact that many scientists too often believe that they can tell us what *will* happen.

The discoveries of science have clearly done more than extend the senses and thereby improve our ability to discern patterns. These discoveries have also enabled us to invent tools that enable us to do what we want to do, whether through the use of computers, lasers, electric motors, or airplanes. Furthermore and very importantly, science has enabled us to construct protective environments that shield us from the ravages of nature. We don't really control nature, but we do have air conditioners, ocean liners and space suits that—rather than change the climate, the ocean or outer space—frequently enable us to live in a protective mini-environment where we do have control. These practical fruits of science—the extension of the senses, the tools, and the mini-environments—have really made a huge difference in the way people live now compared to the way they lived two hundred years ago.

But science has done a lot more than that. It has changed the way we feel about ourselves, and our broad notions of how we fit into nature. Our understanding of the history of the expansion of the universe and the formation of galaxies and stars meshes with our understanding of the evolution of living organisms and of the Earth. All of these form an interconnecting view of change and development. Furthermore, our detailed knowledge of the workings of nature has changed what we fear and the way in which we fear. We no longer think of lightning strokes, earthquakes, or floods as punishments inflicted by angry gods. Such events only rarely have any connection with human behavior. We understand enough about nature that we know how to react to and in some cases protect ourselves from lightning and floods. We certainly do not have to rack our souls trying to determine what we did wrong and why we are being punished. In general, our understanding enables us to simplify our actions and choices because we know in advance which of all the possible reactions we can take are relevant. This simplification of response, this ability to substitute specific fears for vague terrors, can bring to us a sense of peace and order. Certainly this process is manifest as a sentimental fruit of science in the way we now react to the inanimate world.

But unfortunately we are still filled with vague fears. It often seems to me that the total amount of human fear may be constant. For although we are not as filled with haunting fear of earthquakes, bacteria, or lightning, many people are increasingly scared of what people can do to each other, whether by using guns and clubs in the streets, or with nuclear bombs or carcinogenic food and environmental pollution. Too often our collective responses to the fears of what people can do to each other are irrational, mutually incompatible and confused. For the most part, people are barely able to distinguish which of all the possibilities for inflicting human terror are most threatening.

Perhaps social scientists can use what they discover about the behavior of people and societies to provide the raw material for inventing institutions that protect people from people and which, at the same time, provide social tools that enable people to satisfy their innate physical, mental, and emotional needs. Whether they can do so is not yet clear. Certainly, social scientists have developed many new tools, social indicators that, so to speak, extend the range of our collective social acuity for observing patterns. Improved pattern recognition enhances our ability to foretell the future. But this ability is not very well developed even in the much simpler domain of the physical sciences.

Unfortunately, many social scientists have concentrated on using their ability to predict the future as a test of their understanding and the reliability of their instruments. But they too rarely use observations and measurements primarily in order to get a better understanding of what is actually happening in people and in societies. There is one outstanding example of social invention that may have been the result of such deeper social understanding. During the seventeenth and eighteenth centuries, French philosophers developed the notion that it is impossible to govern a populace without having at least the implicit consent of the governed. This insight led to the recognition that such underlying consent could and should be expressed as overt consent, and thereby led to the constitutional inventions that rely on popular suffrage.

On the other hand, I find that the general use of the Stanford-Binet IQ test provides a counter-example to my admittedly somewhat speculative example of constitutional invention. Almost immediately after its development, the test was used to help judge how well students would do in college, etc. Certainly measurement is an important and usually essential step in the development of the sciences, but the ability to predict what is *going* to happen is a poor indication of the quality of the fundamental sciences. The IQ tests have not really illuminated the nature of intelligence any more than Galileo's invention of the thermometer in the sixteenth century gave insight as to the nature of temperature. This insight was not arrived at until late in the nineteenth century. And temperature is a much simpler concept than intelligence.

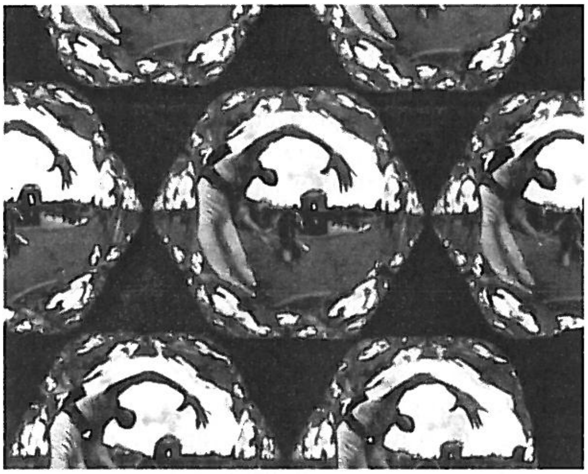
It is such considerations that lead me to believe that the pursuit of the fundamental social sciences can eventually provide the raw material for social inventions that will significantly reduce our currently paralyzing fears of what people can do to other people by "pushing the button," by local and world-wide lawlessness, or by the coercive nature of police and militarily dominated governments.

There are many important sentimental fruits of science, two of which I would like to touch on before closing: the unity of nature and the meaning of heresy.

One of the most elegant and satisfying achievements of science is the discovery of widespread unity in nature. For example, every atom of carbon in each galaxy, in each star, has the same properties and emits exactly the same color of light as does our earthly carbon. The diverse phenomena of nature do not require the assumption of diverse forces or causes. Electricity and magnetism are coupled, and together they explain the existence of radio waves, light, and X-rays. The aurora borealis is not very different in origin from the light given off by a TV screen. Lightning is equivalent to the shock to your fingertip when you touch a doorknob after shuffling across a rug on a dry winter day.

The list of phenomena that can be explained by virtue of electromagnetic forces is almost endless. But there are still many gaps. Gravity and electromagnetism continue to defy unification despite the many attempts by Einstein and others to do so. But there has been progress in other directions: nuclear radioactivity and electromagnetism, it appears, are the result of the same underlying forces, the electro-weak force. Our detailed awareness of the overall unity seems to be expanding. As more and more is discovered about nature, more and more of it fits together.

This unity is a sentimental fruit of science more than it is an immediately practical one. It removes for us any sense of frivolous arbitrariness about the behavior of nature. This quest for unity, this reduction of the number of different kinds of explanations or causes that are needed in order to account for observed diversity, started a long time ago—perhaps with the atomic postulates about matter conceived by Democritus and the Greeks.



***One of the most elegant and satisfying achievements of science is the discovery of widespread unity in nature.***

A contrary trend is manifest in so-called "pseudoscience." I have heard people claim that if they were in Fresno and had bad thoughts about the plants in their home in San Francisco, the plants would be wilted when they returned home. Such behavior on the part of the plants belies everything that I know about long-range action at a distance. No matter how often the experiment was repeated, I would not believe that there was any cause-and-effect relationship between the bad thoughts and the wilted plants.

At the Exploratorium we have tried to express this unity in two ways. We have set up the exhibits in sections—Electricity, Light, Animal Behavior, etc.—with each section showing multiple examples of a particular kind of behavior. But there are no walls between these sections. And exhibits on reflection, for example, occur in the Light, the Sound, and the Resonance sections.

In addition to our exhibits, our quarterly magazine, *The Exploratorium*, promotes the idea of unity. Each issue is about a single topic treated from several different points of view. The issue on bicycles, for example, had articles about their construction, their stability, their history and social impact, the most modern improvements and efficiency, etc. I believe that most of the science magazines do a disservice to the cause of science by including in each issue a hodge-podge of unrelated topics in the hope that they will attract more readers. In doing so they belie the important sense of unity that science can bring to all of us. The simplification of our view of the world that comes with understanding how things fit together may be one of the most important emotional and sentimental fruits of science.

The other sentimental fruit of science that I want to touch on briefly is a change in our view of heresy. This is a change that has developed during the twentieth century and that has had a very profound influence on the way that we think about nature. The change has come about through the study of the tiny scale of atomic and subatomic matter, of the huge scale of cosmology, and of the incredibly complex interlocking interactions encountered in biology. These are domains of nature in which the details are completely removed from our ordinary experience. The problems first appeared in the study of electrons and of light. A great list of experiments showed conclusively that electrons behaved like the particles and light like the waves of everyday experience: like BB shot on the one hand and water waves on the other. But an equally valid long list of newly performed experiments that asked questions in different contexts showed electrons behaved as do familiar waves and that, in other experiments, light arrived in small bundles of energy as does a BB pellet. It makes no sense whatsoever to say that light is both a wave and a particle, that it spreads out in all directions like a wave and also travels in one direction and lands in a certain spot with a splash! In some contexts, beams of electrons behave like waves and *are* waves; while in other well-defined experimental contexts, electrons behave like and *are* particles. Neither statement or view is a heresy.

There is a mathematics of electrons that can describe their behavior in these different contexts, but there is no way of making sense of this duality of description that can be based on ordinary human experience. With people, there also appear dual descriptions that are contradictory and can only be valid descriptions when applied in very different contexts. There is no mathematics with which to bridge the gap between these dual descriptions, but our experience with electrons and light indicates that there must be bridges beyond our experience. For example, *neither* the statement "there is no purpose that is fulfilled by people" nor the statement "everything people decide to do is for a purpose" need be considered a heresy. From a cosmological point of view, there would not be any difference if there were no people in the universe. On the other hand, it is impossible to talk about human beings or to properly describe them or ourselves without using the idea of "purpose." We are always (or almost always) doing things for a reason, even building Exploratoriums.

There are many other value dualities that apply to people, and to me it has made a profound difference in my thinking to know that such dualities are required even in describing inanimate nature. I can be reassured that thoroughly contradictory ethical statements need not, either one of them, be a heresy when applied in the appropriate contexts. This possibility does not imply that there are no ethics or distinctions of right from wrong, but it does imply that we can mollify some of the fiercest intellectual battles of the present and the past. We need to recognize the need for contradictory but equally valid descriptions of matters that are not and never have been part of human experience. By accepting this need of dual and incompatible descriptions, we have greatly simplified our view of ourselves as being embedded in a concordant view of nature. For this relief we can, in large part, thank Niels Bohr and those who worked along with him.

In conceiving the Exploratorium we have had these sentimental fruits of science in mind, but we do not present them as such. However, we have been doing things for a purpose. If nothing else, we have created a delightful woods whose "trees" are parts of nature, through which many people have had an opportunity to wander. We have also enabled people to understand these "woods" by their own exploring and by teaching each other.

If people feel they understand the world around them, or, probably, even if they have the conviction that they *could* understand it if they wanted to, then and only then are they also able to feel that they can make a difference through their decisions and activities. Without this conviction people usually live with the sense of being eternally pushed around by alien events and forces. I believe that the Exploratorium does help create or renew this conviction for very many people and that, especially for young people, it builds a desire to understand. I sense also that this is happening when I hear adult visitors tell me, "I wish that science had been taught this way when I was a kid." What they are telling me is that now, after a lifelong rejection of the subject, they could in fact have understood it. The conveying to our visitors a sense that they can understand the things that are going on around them may be one of the more important things we do. This sense can then so readily extend to all aspects of people's lives. The intellectual apathy that I am told now exists among young people may have come about because these youths have never been convincingly taught the wonder of understanding or learned that when one does understand, then each person, as an individual or as a member of a group, can feel that they can make a difference. I do hope and think that we are contributing in this way.

Thank you. □

***If people feel they understand the world around them, or, probably, even if they have the conviction that they* could *understand it if they wanted to, then and only then are they also able to feel that they can make a difference through their decisions and activities.***

# Living a Fruitful Life

## Speech to the Graduating Class of Pagosa Springs High School, 1960

by Frank Oppenheimer

*In 1960, Frank delivered a speech to the graduating class of Pagosa Springs High School, a small Colorado school where Frank had been the sole science instructor from 1957 to 1959. Portions of this speech, which dealt with how to live a rich and fruitful life, seem particularly appropriate to this issue of* The Exploratorium.

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I am grateful for the life I have lived. It has certainly not been as full as the lives of some people, and yet it has probably been richer in experience and in a sense of accomplishment than the lives of many.

I think that part of the sense of having lived a full and a rich life comes from an ability to continually take things seriously, but not too personally. This feeling stems from a willingness—even a determination—to become deeply involved in what you are doing, but not obsessed by it.

I want to put a little more meaning into the phrase "taking things seriously." Perhaps I can best explain what I mean by talking about myself. I would say, for example, that I took my teaching in this school seriously. First of all, I thought it was an important job. I felt that if you learned some science, you would be able to lead better lives. And I felt that by trying to do a good job of teaching, I might have some effect not only on you individually but also on the school and the community. The teaching involved a lot of work and planning and I had to learn new things, not only about the subject matter, such as the names of the various geologic epochs, but also about how to present ideas that I was, at first, not able to get across. I stopped thinking of myself as a rancher or a nuclear physicist and thought of myself primarily as a high school teacher and wanted to be a good teacher. I wanted you to understand the things I enjoyed understanding, such as why a star got hot and stayed hot. I wanted you to get satisfaction from being able to do some of the things I found pleasure in doing, whether blowing glass or solving a problem. I felt an enthusiasm for the whole process of teaching.

Now let me give you another example, in retrospect a quite trivial one. At about the time I graduated from college, I took coffee seriously. I read about coffee and found out where and how it was grown and roasted. I wandered about New York City looking for coffee import houses, bought my own grinder, and learned to tell the difference in taste between Mocha and Java and Guatemalan and Brazilian and Costa Rican coffees. I drank my own mixtures and occasionally served them to my friends, each type of coffee for the proper time of day. Undoubtedly my friends thought I was nuts, but I thought of myself as a connoisseur, an expert. Now, twenty-five years later, I can chuckle at my former self. But obviously at the time it was not a trivial interest, or I would not now recall it so vividly.

I do not want to relive my life for you, but I would like to mention, for the purpose of example, a few more of the things that have absorbed me. During the War, it seemed enormously important to me that America develop an atomic bomb as quickly as possible and before anybody else did. Now the making of atomic bombs seems repugnant and evil to me. Before the War, I worked hard and long to help support the Spanish Loyalists against the fascist invasion of France. After the War, I gave speech after speech on the need for nuclear disarmament. During my years here in the Basin, I put my heart into my ranch, trying to make it a better one. I derived pleasure from the flourishing crops and animals, and I learned the sick feeling that comes when one fails in helping a heifer to deliver a live calf or sees four or five cows dying on the range from having eaten larkspur.

Before coming here, I was in Minnesota for a couple of years. I remember how exciting it was when, with our high-altitude-balloon experiments, we discovered that not only hydrogen, but the atoms of all the elements were in the cosmic rays coming from outer space.

In thinking about my life, I arrived at some ideas about what was necessary for a fruitful life. First, you become involved in projects that you can put your heart into. They seem important. What happens, the outcome of your efforts, must make a difference to you.

Second, the outcome must have, directly or indirectly, a wanted effect not only on you but on something outside you, on other people or on science or on a ranch or on a business.

Third, your project must involve some effort in doing, and especially in learning and experimenting.

Fourth, you have to really commit yourself by being willing to stand for something and represent the kind of person to yourself and to others that is not inconsistent with what you are involved in. In this sense, taking something seriously often means that one is conscious of acting a role.

Now this subject of acting a role is a tricky one. There are many people who are thoroughly obnoxious or pathetic because they are continually acting the role of someone they would like to resemble but cannot. The standard cartoon about insane people shows them pretending to be Napoleon. I am not going to try to answer the question of when and to what degree role-playing is proper and appropriate. But I know that to get much out of what you are doing, you have to act the part and be consistent with its restraints and customs. But I cannot draw for you the fine line between devotion and obsession or between sanity and insanity. It seems that one's ability to draw this line in any actual situation is connected with the fact that one can take what one is doing seriously without at the same time taking oneself too seriously.

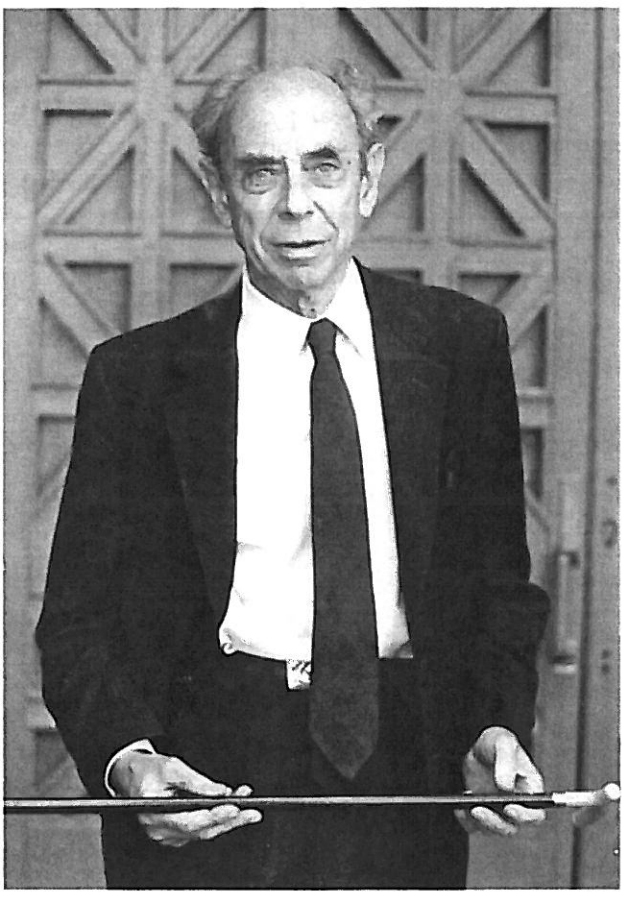
It is not easy to explain why people take things seriously. If one thinks deeply and objectively about anything, even life itself, it can appear trivial. One can argue that our actions make a negligible difference to a universe that is billions of years old and a billion light years in diameter. But such thinking is somehow irrelevant to the way humans act. I am aware of the immensity of the cosmos and yet I can take things seriously. So can you.

I do not want to imply that I have no sense of values, and that everything is of equal importance to me. Some kinds of pursuits and exploits that I could have at one time put my heart into, now seem unimportant to me, but other, perhaps somewhat more channeled interests, have appeared in their place. I do not know what will capture my devotion in the future, but from past experience I have some confidence that it will be caught.

For you, I hope that there is another domain that will attract you. Throughout one's life, one sees the perpetuation of innumerable injustices in human acts, both at home and abroad. Usually, one feels powerless to do anything about them, but I recommend to you that when an opportunity to intervene for justice arises, either for you alone or in concert with others, you take these opportunities seriously and consider them important.

I have gone a little astray from my main purpose tonight, which was merely to remind you that you have a long life ahead of you and to say that I hope it will be a good one. I have talked about just one small aspect of how you live your life, but I think it is an aspect over which you have some measure of control and also one that you might not have been aware of. I recommend that you be willing to become deeply involved in lots and lots of things and that you let yourself, perhaps even force yourself, to do the things that you think are important and that you can take seriously.

I make this recommendation to you because I believe that if you do, then even in the face of considerable adversity you will feel, as I do now, grateful for having lived. □



For more information—

*Additional writing by Frank Oppenheimer and further description of the Exploratorium and its exhibits are available in a recent publication from the Exploratorium.* ***Working Prototypes—Exhibit Design at the Exploratorium*** *describes the Exploratorium's process of exhibit design and construction. For more information on* ***Working Prototypes*** *and other Exploratorium Publications, write to the Exploratorium Store, 3601 Lyon Street, San Francisco, California 94123, or call (415) 563-3456.*

*The Frank Oppenheimer Fellowship Fund has been created at the Exploratorium. Donations to the Fund will support fellowships for national and international staff exchanges and study residencies to further the development of science museums as educational resources.*

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