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EXHIBIT CONCEPTION AND DESIGN

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In talking about exhibit design, I want to avoid a propensity that frequently plagues discussions about teaching, namely: telling people how to teach without any reference to what they are teaching. The way in which one designs exhibits depends crucially on their broad subject matter as well as the detailed content of each exhibit. I will therefore stick to some aspects of what we have learned at the Exploratorium. There we have exhibits on sensory perception, light and optics, sound, resonance and wave motion, electricity, rotation and angular momentum, exponentials, patterns of motion and rhythm, on the nature of heat and temperature, the behavior of gasses and liquids, nerve encoding, marine animal behavior, simple engines and a modest collection of miscellany that exists because it intrigues one or another member of the staff.

This list, and it is not even all inclusive, must sound pretty diverse, but in our minds there is a thread that connects each topic with our starting point: human perception. The Exploratorium is about nature and one of the major accomplishments of science has been to demonstrate that there is a unity to the diversity of nature. There are relatively few fundamental forces, stars are suns, planets and moons fall like apples, electricity produces magnetism and magnetism produces electricity and they both combine to create light. It is hoped that the visitors to the Exploratorium sense this connectedness. This objective may,in our case, be helped by the circumstance that all our exhibits are in one gigantic room. But even if the visitors miss or do not formulate this grandiose idea, it is vital that we ourselves keep it in our mind. A museum can resemble a musical composition, a symphony in which even though the listeners may not be aware of the structure of the piece, they must sense that it exists because the composer was disciplined in his efforts to achieve the coherence of his composition. Museums, at their best, require their creators to be guided by a similar kind of discipline. At the very least one can hope that visitors rarely say to themselves, or to each other,"Why in the world do they have that thing here?"

There are some general precepts that we adhere to: We endeavor, for example, to display multiple examples, in a variety of contexts, of interesting or important phenomena. We have about 18 different examples of resonance and standing waves. There are resonances in air columns, in strings and ropes, in metal plates and rubber membranes, in rods and springs, in water and in mechanical wave machines. We even attempted to illustrate resonances in solids with a remarkable jelly-like substance but unfortunately the only resonant frequencies that would produce an amplitude sufficiently large to be seen with a strobe light were too close to human brain rhythms for prudent display.

We also have over a dozen exhibit pieces on binocular vision and size distance judgments, and almost as many on the role of edge effects and lateral inhibition in the eye. We even demonstrate Von Bekesy'smodel for lateral inhibition in the ear. We have eight different exhibits on gyroscopes and rotary momentum and forces, half a dozen or more pieces on composition of two perpendicular motions including a pendulum, a drawing board, oscilloscopes, and color television sets. We have a section of 15 exhibits on things which grow or decrease exponentially or logarithmically.

There are at least two considerations that dictate having such multiplicities. Science has not only unearthed many intriguing (and useful) natural phenomena, it has also provided us with a conceptual framework for thinking about them. Our concept of wave is much more general than any particular kind of wave. In fact, it takes some doing to perceive the common ground among a water wave, a sound wave, a light wave and a wave of fashion. The best way to know more than a textbooky definition of a wave is to learn through experiences with and reflections on the commonalities among the various embodiments of a wave. It would be much the same with any concept, such as that of a family. Knowing only one family member tells nothing. One needs to know children and uncles and cousins and brothers and grandfathers and mothers, to understand the concept "family". Only then can the concept be extended to include the "family of man" or the chemical family of halogens. Natural history museums and anthropology museums seem to know more about the virtue of multiple examples than do science centers. Too often, these centers will show just one example of refraction, one of reflection, one of interference and one of diffraction and be satisfied that they have "covered" the behavior of light.

There is an additional reason for providing a multiplicity of contexts. Each exhibit on one topic can belong to a different chain of exhibits on another topic. For example, some resonance exhibits also fit into the theme of musical instrument, some into the exponential section and some into the group of those on electrical inductance and capacity, etc. We view a science museum as a collection of props that constitute an interlocking web of mini-curricula that can be used by teachers at all levels, by the visitors who come hoping to instruct their children, their friends or their parents or by our own staff when they use the place for learning or for teaching classes. We are continually filling in and adding on to these interlocking curriculitos and hopefully we will be able to do so for years to come. As a consequence we never have a formal public opening of any but traveling exhibit shows.

We,of course, also think of the Exploratorium in other ways than as a collection of props for teaching mini-curricula. It is a place for sightseeing, a woods of natural phenomena through which to wander. Sightseeing is more than pleasurable, it can build the experiences and the intuitions on which other opportunities for learning rely; it can arouse curiosity and, in a broad sense, it can help people determine where they are going and where they will want to make their home. Many of the scientists who visit the Exploratorium have attributed the fact that they are scientists to their early experiences in the Museum of Science and Industry in Chicago.

In addition to providing opportunities for sightseeing and for providing a library of teaching props, a museum can, in an overall way, make very deep, lasting impressions on its visitors. It can reestablish the visitors' confidence in their own ability to understand and to learn. It can give them a sense of roots in the past, it can help them realize that human beings and human acts are a part of nature. More simply, it can engender a comfortable familiarity with aspects of culture that they may have rejected as inaccessible or as undesirable. It is hard to predict or to assess these general effects. One woman told us that after being at the Exploratorium she went home and, for the first time in her life, put a plug on a lamp cord. Nothing in the Exploratorium could have instructed her how to do so. She must have felt that since she had made sense of some of the difficult ideas in the museum, she could make sense of other things as well.

The Audience

There is one piece of oft-repeated advice to which we have not paid the slightest attention. Over and over again I have been lectured at by exhibit designers with the statement "You have to decide who your audience will be". We do recognize that it is essential that neither I nor the staff are bored by our exhibits, that we learn something as we make them and that we enjoy showing them to people, especially our friends and colleagues, over and over again. The best physicists that I know usually learn something in the place and are also delighted by some of the things they already know because the presentation is novel, illuminating or beautiful. But as far as we can determine there is no age limit, no training limit nor any cultural limit to the range of people who use and enjoy the place. Preschool groups and old-folks-home groups come and come back. Mentally or sensory retarded groups repeatedly come and special classes for gifted students use the place as the basis for a variety of projects. It is one of the few formal institutions that attracts teenagers.

There are two things misleading about the statement "You have to decide who your audience is". In the first place it is possible to make many, if not most, of the exhibits so that they can each individually be appreciated and enjoyed on a variety of levels. Secondly, it is ridiculous to think that every visitor should be able to appreciate or enjoy every exhibit in the museum.

Most science centers have several hundred exhibit pieces. We have over 400, the Franklin Institute has over 600. How many of these should one expect a visitor to become memorably absorbed with in a two or three hour visit? How many paintings in the New York Metropolitan do you specifically want to go back and see on your next visit - 6? 12? 14? 48?

We have one exhibit that I have never seen an unaccompanied person spend time at. It is an exhibit on images of point sources produced by holographically made zone plate rings. But the exhibit is there if anyone ever asks how a standard holographic image is produced. We, and the Explainers, can take them to this "unused" exhibit on zone plates, and occasionally knowledgeable visitors also use it to explain holograms to their companions.

Not only should one not expect a visitor to become absorbed in very many exhibits, the atmosphere of the museum must be adjusted in such a way that people are relaxed about missing or not understanding something. I was especially delighted by one example of such relaxedness: We have painted over one of the skylights in the building to keep the optics section dark. However, the seagull feet puncture star-like holes in the paint. On one occasion I overheard a middle-aged woman saying to her companion as both looked up at these holes, "Well, I suppose that if we knew more, we would know what the little lights meant". They were perfectly happy as they went on to play with other exhibits.

An important general consideration of the Exploratorium stems from the central values we place on art. Many museums involve artists to help with the appearance and the graphics of their exhibitry. We have used artists in a parallel capacity to that of science teachers. Each contributes exhibits that deal with roughly the same domains of nature. We have, for example, many detailed didactic exhibits on the dispersion of light into colors but we also have the magnificent, constantly changing Sun Painting that was created by an artist using a pallette of pure hues that are extracted from the sunlight by an arrangement of long prisms and narrow mirrors. We have holograms purchased from artists displayed along with our didactic treatment of holograms and diffraction. Art is included, not just to make things pretty, although it often does so, but primarily because artists make different kinds of discoveries about nature than do physicists or biologists. They also rely on a different basis for decision-making while creating their exhibits. But both artists and scientists help us notice and appreciate things in nature that we had learned to ignore or had never been taught to see. Both art and science are needed to fully understand nature and its effects on people. The art in the Exploratorium is therefore blended with the science as a part of the overall pedagogy. These works, that derive primarily from aesthetic considerations, undoubtedly also play a crucial role in our ability to attract a universal audience. We need to do more along these lines, but we are slow in doing so because we only accept those artists whose interests mesh with the broad thematic content of the museum.

The Design of Specific Exhibits

The creation of virtually every one of our exhibits has involved multiple stages of decision making about how best to demonstrate a particular idea or phenomena, about how much variation to provide for the basic variables and about how much random irrelevent behavior to retain in the design. In the Gray Step exhibit, there is really only one thing that the visitors can do. They can move a rope that covers the boundary between two seemingly identical white rectangles to one side. When they do so, one rectangle looks uniformly dark gray and the other a uniform white. The effect is so remarkable that a visitor will repeat the procedure over and over again. In this case, we do not need to provide any other activity. Invariably the visitors will also read the"What is Going On" graphics. (We did, after the exhibit was on display for several years, add a white card with two widely separated holes punched in it. An Explainer can now use the card to show that the identical uniform-looking rectangles are not uniform. Each half changes from light to slightly darker across the rectangle. The rope hides the discontinuity between them, the step that goes abruptly from dark to light.) The exhibit as it stands is a good one and does not need anything more. We do however have nearby another exhibit, a rotating vertical cylinder with vertical black and white stripes that illustrates the same effect. The first exhibit was copied after one in Edwin Land's research laboratory and the second version was suggested by one at the MIT teaching laboratory.

Although the single activity of the Gray Step exhibit is satisfactory, many of the single activity exhibits in our electricity section are extremely disappointing. One of these, Motor Effect, which we really tried to make effective,was conceived to demonstrate the force that a magnetic field exerts on a wire carrying a current. We used an array of radar permanent magnets that we got from the dismantled accelerator at Cal. Tech. They create a magnetic field of over 2000 gauss within a gap of 1½" with pole pieces of area 2" by 10". A very flexible rubber covered wire about 1" in diameter lies just below the pole pieces until the visitors step on a mat-switch. Then a current of 200 amperes makes the wire pop up through the field. If one tries to push it down, one can feel the magnitude of the force. The direct current through the wire is not completely smooth so that the wire feels vibrant to a visitor when he or she touches it. When the current flows, the large rectifier lights up to indicate electricity and the required large transformer is clearly on view. However, when I first showed this exhibit to a very knowledgeable member of our graphics department she said:"The lid of my garbage also pops up when I step on a little lever". Over and over again I have watched visitors step on the mat-switch, feel the force on the wire, shrug their shoulders and move on with an expression of "so what". We do not know how to make the exhibit (and several other analogous basic electrical exhibits) more captivating, more beautiful or more instructive.

The only thing that has occurred to us is to use an entirely different attack. We have built a vacuum system with a cold cathode generated electron beam that is made visible by introducing a small flow of helium into the vacuum. The beam is about ¼" in diameter and 18" long.One can deflect it with a hand-held magnet or steer it with a joy stick connected to electrostatic deflectors. This beam, of about eight kilovolts, can be directed to turn a radiometer, to impinge on a thin foil and make it red hot, to light up a fluorescent screen or to fall on a Faraday cup that is connected to an external milliameter. We call the exhibit "Electric Currents with the Wire Removed". We still have trouble with the stability of the focused beam, but when the beam behaves as we intend it to, the visitors are intrigued and captivated, and we often observe people explaining it to each other. The glow of the beam, the elegance of the glassware and of the internal gadgets render the exhibit really quite handsome. When its performance is debugged, it will make a very good exhibit.

Sometimes we can figure out how to revive or reconstruct a dud exhibit. Our exhibit Convection Currents provides an example. The exhibit was conceived by one of our staff members who was developing an exhibit to demonstrate that the temperature of boiling water and the steam above it remains constant no matter how fast the water boils. At one point, while heating the rectangular glass water boiler tank, he noticed the shadows of the rising hot water that were produced on a wall by a nearby clear light bulb. These convection currents shadows were worthy of a second exhibit so he made another identical tank, put a clear light bulb behind it on a long table and a frosted screen in front of it. He mounted a small helical calrod in the water. The viewer could vary the temperature of this heater and watch the convection current patterns by standing in front of the frosted screen. The exhibit worked, but it was extremely unsatisfactory. The screen was too small and the water rose further in the tank than could be projected onto the screen. The calrod coil was too wide so that the convection shadows (schlieren) appeared fuzzy and unduly irregular. The calrod started to rust so that it was painted with epoxy. But the epoxy prevented the water from wetting it properly. The magnified projected surface of the calrod looked bumpy and ugly because of the air bubbles that adhered to the epoxy.

We put up with this exhibit for many months and then completely redesigned it. We made a much thinner tank and used a one inch long ¼" diameter horizontal heating element. We placed a shielded point source light in front of the tank on a slide so that it could move from about four to fourteen inches away from the glass wall of the tank. The shadow image of the convection current stream was projected on a broad expanse of a wall a few feet behind the tank. The rod that supported the calrod extended a short distance above the top of the tank. It could be moved,but initially its motion was frustratingly restricted because someone was worried that the visitor might knock the heater against the wall of the tank and break the glass. I did not like the feel of this restricted motion and wanted to be able to stir the water with the calrod to see what could happen. The mounting was therefore changed so that the calrod could not move sideways and hit the glass but could have considerable motion parallel to the glass. We ran a string from the protruding calrod support over a pulley to a ring on the side of the tank. It was quite pleasant to pull the string and stir the water. The exhibit now has an intriguing operational aesthetic. It is both entertaining and instructive to move the light and observe the change in scale of the shadow on the wall. When one first turns the heater on, a thin warm layer forms around it that does not rise, a kind of "inversion". With a little more heat, the warm water breaks away from the heater, it rises smoothly for a few inches and then develops two swirls,one each side,rotating in opposite directions. With full heat, there is much turbulence and if one pulls the string up and down one observes threads of warm water that appear throughout the tank and persist for a surprisingly long time. It is not as easy to produce a uniform mixture by stirring as I had supposed. If one waits, with the heater off, till the threads have disappeared and then stirs again, the threads reappear. We were puzzled by this reappearance until someone pointed out that, after the heater had been on for a while, there is a gradual temperature increase from the bottom to the top of the tank that remains static. It becomes rearranged when one stirs the quiet tank and the shadows show the resulting inhomogeneities. The exhibit now is lovely, instructive, and as so often happens when one makes one's own exhibits, full of both aesthetic and phenomonological surprises for the exhibit creators. The exhibit is so "nice" that, instead of putting it where it belongs in the section on Heat and Temperature, we leave it between the main entrance and our office so that visitors can see it when they first come in and so that we can readily play with it and show it to friends. In describing this exhibit I have discussed only its operation and have left out an equally long description of all the little problems and decisions that were involved in its fabrication.

In many instances removing unpleasant frustrations in the operation of an exhibit can be much simpler. One staff member built a large, adjustable but very rugged Michelson Interferometer. One could test the sensitivity of the instrument by watching the motion of the interference fringes that resulted from a very light pressure on the steel plate on which the interferometer mirrors were mounted. After doing so, I wondered how thick the steel plate was. I put a finger from one hand on top of the plate and tried to put a finger from my other hand underneath it, thereby using my hands as a crude set of calipers. But I was frustrated in doing so by a piece of plywood that blocked my lower hand. The problem was solved by raising the steel plate above the box on which it was mounted so that the visitors could see that the plate was made of ½" thick steel.

In some ways an exhibit resembles a play or a musical composition. A tension is built up by something in the exhibit that elicits curiosity, or an interesting task, or a lovely effect, and then the tension is resolved as the result of aesthetic or intellectual payoff. If either component is missing, either the creation of tension or its relief, the exhibit is unsatisfactory. The creation of tension should not involve flamboyance or the high signal strength of traditional advertising. It should be a quiet affair, for if every exhibit shouts, "Hey Come and Look at Me," the museum will become impossibly tiring for the visitors.

Although the two exhibits described above, the Gray Step and the Motor Effect, can be used in just one way, most of our exhibits can be used in many ways by the visitors and they are often used in an ingenious fashion that had not occurred to us when building them. When visitors can invent ways to use an exhibit they get a sense of discovery that is much more satisfactory than if they merely discovered what we thought they were supposed to discover. They stay with the exhibit for longer times and usually, but not always, end up by observing the behavior that we hoped they would when we conceived the exhibit. The exhibit Bernoulli Blower provides a clear example of such versatility. A large blower supports a ten inch rubber ball on a stream of air. The Bernoulli force is great enough that the visitors can feel the tug when they pull the ball out of the air stream. If they tap the ball it will oscillate. They often attempt to toss the ball so that it is captured by the stream. They lift up their sweaters and let the air blow on their stomach. They lean over and let the air blow their long hair. They tear off bits of paper and watch them in the air stream. They try suspending other objects in the stream and sometimes they move off to the side and have a game of catch.

Our exhibit Critical Angle is flexible in a different way. In many ways the exhibit is completely standard. It uses a Leybold 8" by 1½" plastic semi-cylinder and two Leybold light sources. However, one of the sources has the cylindrical lenses removed in order to produce a diverging beam which canbe focused by the large semicircular lens. The broad beam makes a very pretty pattern as the light converges in a caustic whose curvature is due to the spherical aberration of the wide lens. The other light source produces the narrow "ray" of a beam that it was intended to make. We have added a short 1" diameter lucite cylinder tied to a string that the visitor can place in the ray to steer the light toward any part of the lens. The visitor can, as is customary, observe the path of the light on the white formica table top below the lens, but the ray also impinges on the white rear wall of the exhibit. One can see the rainbow colors disappear one at a time as each color reaches the critical angle. I have seen similar exhibits in other museums in which the activities allowed the visitors are much more restricted. In one display, the semicircular lens was constrained to rotate only 180°, presumably to insure that the visitor did not miss the total internal reflection effects. I found the constraint maddeningly frustrating. In fact in general, it is important to allow the variables in an exhibit to change enough so that the interesting effects disappear. One learns as much or more about an effect by its disappearance as by its appearance.

The Ideas for Exhibits

Many, many visitors ask "Where do the ideas for these exhibits come from?" Our answer is: "From many, many different sources". A good number of the exhibits are adaptations of quite standard laboratory or lecture demonstration equipment. We learn about them from our own experiences as instructors or students, from wandering around to other museums, research labs and universities and from published reports. Other exhibits originate because, while wandering around town or through our junk drawers, we encounter some material, a gadget, or a phenomena that clearly illustrates something we want to show. The Glass Bead Rainbows, the Eye Shimmer Poster, the Walking Beats, the HiQ Spring, the Adjustable Plaything and the Shoe Tester are examples of such "found" exhibits. Some exhibits are spin off results from staff discoveries as they work on a completely different exhibit. Such are the exhibits Mirrorly a Window, the Cheshire Cat or the Brine Shrimp Ballet. Sometimes we have to search hard and long and even put the matter aside for a year or so, before we find a technique for showing some particular effect. We tried Ouzo and Pernod in water to show the preferential scattering of blue light by fine particles but the particles gradually coalesced. We had to await a staff member's discovery that the right kind of gelatin would make a good Blue Sky exhibit.

The most interesting developments can result when we ask ourselves questions such as, "What is the most basic thing we want to show about nerves?", and then: "How can we best demonstrate that nerves encode the intensity of their stimulation by increasing the frequency of the neural pulses they transmit?" I believe it was Professor Kennedy's neurophysiology laboratory at Stanford that came up with the idea of using a Crayfish Tail to show this effect. When asked "how can we best show that a large resonant response can arise from repeated, properly timed tiny pushes or pulls", we invented the giant 400 lb. Resonant Pendulum exhibit. When we asked how can we best show that matter absorbs and re-emits light, we subsequently decided to develop a group of exhibits on phosphorescence and fluorescence. A very large number of our exhibits arise in this way. We first try to decide what kind of effects or ideas are fundamental to an understanding of some aspect of science or nature. Then we sort out which effects are easier to understand if they are demonstrated rather than read about. Finally, we grope around for ways to effectively and captivatingly illustrate such effects. Outsiders who learn about what we are searching for will frequently help. Phil Morrison called from MIT to tell us of the exponential behavior of a Bouncing Ball, Luis Alvarez sent us an article on a sequential array of long focal length lenses. Occasionally a staff member will read about some work in a journal or newspaper and contact the author. We gather a group of experts in linguistics, for example, or in visual perception. Invariably the group provides us with a great raft of ideas to work on.

Since, as an ongoing process, we are expanding exhibit curricula and filling gaps in the ones we have, we have been able to afford the luxury of being responsive (albeit also selective) to the continual flow of ideas and of actual exhibit pieces that visiting scientists, teachers and artists bring to us.

I have used the exhibits in the Exploratorium as illustrations because I know them so well. But this paper is not about the Exploratorium. It is about some of the very many considerations that govern the way in which exhibits can be conceived and designed in any science museum. My discussion has not touched questions of safety, or maintenance, of handicapped person accessibility, of fabrication techniques or of the all-important graphic labeling. I have restricted the discussion and the examples to some of the basic considerations of exhibit pedagogy and have primarily stressed the flexibility, patience and willingness to discard and start over again that exhibit development requires. I have used these examples to suggest the kind of discipline that is required on the part of exhibit creators if the audience is to be relieved of the constraints on exploration and behavior that have done such damage to the learning process in other contexts.

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