A Case Study of "Planetary Landscapes: Sculpting the Solar System"

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ABSTRACT **This article presents a case study of the design, development and evaluation of a science museum exhibition called *Planetary Landscapes: Sculpting the Solar System*. The exhibition was created by Chabot Space and Science Center in Oakland, California, in collaboration with the artist Ned Kahn. (A slightly smaller version has been traveling to science museums around the country, and has been sent to the Middle East and Asia.) This exhibition affords a chance to explore the work of a gifted artist as he seeks to merge art and science and create beautiful inquiry-based exhibits. The story also relates how a museum design team and an evaluation team sought to support the exhibition design in ways that would augment and not interfere with the expertise of the artist.**

PLANNING THE EXHIBITION

In creating *Planetary Landscapes: Sculpting the Solar System,* Chabot Space and Science Center took a less traditional approach to the design of a science exhibition, bringing in an artist, Ned Kahn, to create aesthetically engaging exhibits. Kahn's work is well-known in the science museum community, and his artworks—including the now-iconic exhibits known as Tornado, Turbulent Orb, and Aeolian Landscape—can be seen all over the world. Kahn was recently awarded a MacArthur Foundation Fellows Program "genius" grant.[1]

The *Planetary Landscapes* exhibition is about the natural geological processes that take place on Earth as well as distant planets, but it largely uses physical analogies to accomplish that lofty goal, placing much less emphasis on scientific explanation than on graphic visual examples. The exhibits provide visitors direct access to an array of natural phenomena—such as mists, vortices, and wind-driven dunes—all of which are small-scale analogs of large-scale planetary forces. Visitors not only observe these analogs but also have an open invitation to investigate these phenomena on their own. The exhibits are a blending of art and science, in which the beauty of the exhibition is intended to enrich the

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visitor experience aesthetically, as well as contribute to a deeper understanding of scientific phenomena.

Case studies such as this are meant to describe a particular instance of something more general. In this case, the focus is on the design, development, and evaluation of an exhibition that melds art and science. The case also examines both the intention and the realization of the effort to provoke visitor investigations into natural phenomena. This article is written by, and from the perspective of, the project evaluators. As evaluators work with exhibit designers, we see how both the thinking and the products of the designer evolve. We also see how visitors of varying ages, experience, and expertise interact with the exhibit prototypes. And we are able to observe the exchanges between the evaluation team and design team. We believe that evaluators are not solely in the business of producing "data," but rather that they have the ability and responsibility to contribute to the field by providing accounts such as this, which tell the story of exhibit design and exhibit evaluation in what we hope is an insightful way.

About the exhibition—*Planetary Landscapes* is a science exhibition that displays complex phenomena in small-scale exhibits in such a way that visitors can make analogies to large-scale planetary forces. Phenomenon-based exhibits like the ones in *Planetary Landscapes,* presented as analogs rather than literal models, are intended to give visitors a sense of the often subtle and complex forces that shape the planets. It is argued that most visitors do not need literal models, or exact replicas of a phenomenon or system, in order to see patterns and similarities between phenomena on Earth and other planets, and to make connections with what they've seen before.

Fog, cratering, static electricity and other phenomena are modeled in the 14 exhibits that make up the exhibition. The exhibits are designed so that visitors can observe and directly interact with the phenomena—experimenting with vortices, the effects of static electricity, turbulence, and vibration. The exhibits are set in substantial, smooth black bases with simple lines. While there is a unifying scientific theme to all of the exhibits, each one is also meant to stand alone. Interpretative aids that accompany the exhibits are designed to be minimal and not to interfere with the visitor's interaction with the phenomena.

INTERACTIONS WITH EXHIBITS

The following three vignettes are a representative sample of the kinds of interactions we observed:

1. At one end of the exhibit hall, at Sea of Clouds, a group of children peer into a gigantic shallow bowl from which clouds emerge and overflow. The children are leaning down to blow on the billowing fog, watching how their breath affects the turbulence in the bowl.

2. Elsewhere in the hall, a man is thoughtfully spinning a large glass orb that resembles, at this moment, a snapshot of Jupiter from outer space. In Turbulent Orb, a band of iridescent turbulence marks the equator of the orb. When the man stops the orb's spinning, the patterns on the globe shift and change as the fluid within the orb redirects its motion.
3. At a third exhibit, Icy Bodies, a mother and daughter are sending shards of dry ice skittering over the surface of a pool of water. As the shards travel, they leave comet tails of mist behind. The mother and daughter appear to be intrigued by the motion of the dry ice shards as they spin and tumble across the surface, creating intriguing and beautiful patterns that look like comets.

Other exhibits are analogous to physical phenomena such as volcanic activity (Caldera, Rift Zone), geological faulting (Tectonic Basin), and lightning and static electricity (Static Landscape). *(See the color pages in this issue for examples of art works and photomurals.)*

The philosophy of teaching and learning—This exhibition is a clear instantiation of an inquiry-based philosophy of teaching and learning. The philosophy emphasizes the importance of direct experience and firsthand learning. Within the museum field, the philosophy maintains that exhibits can provide visitors with a chance to develop their "experiential literacy" through well-designed opportunities for interaction with interesting objects and phenomena.

As stated by Ansbacher, ". . . the experience-based approach [to learning] takes a different route to teach knowledge. John Dewey said, 'One consideration stands out clearly when education is conceived in terms of experience. Anything which can be called a study, whether arithmetic, history . . . or one of the natural sciences, must be derived from materials which at the onset fall within the scope of ordinary life experience.'" And, ". . . in the experience-based approach [to learning] acquiring traditional knowledge is not seen as the final goal, rather, as Dewey said, experience is both the means and the end of education. Knowledge is valued not for its own sake but as a way to understand and enhance our experiences" (2002).

Experiential literacy was also well described by Morrison and Morrison (1984). They discussed the importance of understanding the difference between symbol and substance in teaching science. Philip Morrison noted: ". . . you can't talk about science and remain solely in the domain of symbolic discourse. You require some contact with that substance of which science is a symbolic representation." Phylis Morrison observed how distant from substance many lives have become: "As short a time as a hundred years ago, most people spent most of their time dealing with non-symbolic problems that presented themselves to them as physical problems. The easy example is the child growing up on the farm. . . . That child knew perfectly well how much firewood had to come into the house to deal with one sort of weather at one time of the year, or the problems of

growing things, the problems of mechanisms you used to make growing things easier (1984)." Today this relationship with physical reality is not the norm. The Morrisons argued for the compelling need to make an experiential and challenging connection between individuals today and the natural world.

Those who promote the value of experiential literacy argue that experience has to precede conceptual learning. The root meaning of the word "concept" is from the Latin *con* plus *capiere*: literally to hold together. According to the Oxford English Dictionary, "concept" is defined as "a general idea emerging from a class of objects." Hence, in the science learning domain, the development of concepts, it is argued, comes from the gathering and holding together of related experiences.

Inquiry-based learning philosophy adheres to the premise that conceptual learning ultimately comes out of the active integration of a set of related inquiry-based learning experiences. Experiential literacy suggests that the understanding of science concepts has much greater meaning when conceptual understanding is grounded in rich personal experiences of phenomena. According to Ansbacher, " . . . knowledge and understanding cannot be delivered whole into peoples' minds. . . . To achieve understanding, an individual *must* engage in his or her own inquiry cycle" (1999).

Resonance, for example, can be understood as a concept: the large response that occurs in a system when the frequency of the driving force matches the natural frequency of the driven system. But this definition can be grounded in multiple and diverse examples of resonant phenomena clearly and intriguingly presented in well-designed exhibits. Similarly, visitors might be able to read about tornadoes, but it is argued that both their understanding of and their interest in the phenomenon are likely to be greatly enhanced by the opportunity to interact with a range of vortices in well-designed exhibits.

Evaluators are often asked, "What do people learn in science museums?" We think this question misses important dynamics of learning if the question is construed only in terms of what information people take away from their visit.[2] Rather, advocates of experience-based learning believe that learning must be much more broadly construed to include the haptic, kinesthetic, visual and other sensory aspects of peoples' experiences.[3] We believe that in science museums, the heightening of experiential literacy is often felt to be a goal that is equally as important as the transmission of factual information.

In speaking of the need for direct experience, Ned Kahn, the artist in charge of designing *Planetary Landscapes,* said:

> I want to give people a chance to experience a phenomenon. . . . Just to have a direct sense of the phenomenon, I think, is a very worthwhile thing. A lot of our general educational process is mediated; it is mediated through the teacher or through books or television or computers. My own philosophy is that it has become rarer and rarer that people have this opportunity to just use their senses as they directly interact with a phenomenon—and then to build intellectual structures on top of that sensory experience. . . . I want people to have this foundation of a sensory understanding of nature.[4]

Those who advocate for a sensory encounter with natural phenomena often prefer

to begin the design process by invoking whatever personally interests an artist or designer. The expectation is that this standpoint of passionate engagement will present itself as more interesting and enticing to visitors than a theoretical approach, once the exhibition arrives at its final form.

The first author of this paper recalls a question put in 1978 to Frank Oppenheimer, founding director of the Exploratorium, about what makes a good exhibit. Oppenheimer responded that good exhibits come out of the interest and engagement of the staff making them. When designers play with the exhibit, trying "just one more thing," then the likelihood of success is high. Conversely, if the staff makes an exhibit that is intended to be "good for visitors," but that does not interest the staff, then it's not likely to be a good exhibit.

Kahn acted on similar assumptions during the design of *Planetary Landscapes.*

The converse may also be true: that when designers are weighted toward the theoretical, audiences feel something is missing. The study team observed that one of the exhibits, Cratering, was uninteresting to and somewhat frustrating for visitors. This exhibit is a Plexiglas cylinder, about one-quarter full of a fine white powder. Visitors lift a rod and drop it into the powder, making craters. Museum scientists had wanted to have an exhibit that showed the phenomenon of impact cratering—an important idea to include in a discussion of forces that shape planets. Kahn tried several approaches, but ultimately was unable to come up with a way to show cratering successfully. It was not a phenomenon or concept that enlisted his own interest or curiosity, and—maybe for this reason, at least in part—the resulting exhibit was less than engaging for visitors.

The blending of art and science provides multiple avenues to inquiry. The artist looks into a phenomenon in a particular way that is different from a scientific process. Both approaches complement each other in terms of increasing access to the phenomenon. Neither the artistic perspective nor the scientific perspective, taken alone, provides a full view. Oppenheimer described the importance of this blending:

> Art is included in exhibits 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 geologists. 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.[5]

The creative process—Kahn is an artist with a keen interest in the natural and material world and in creating "windows on that world" so that others can share in the kind of discovery-making in which he excels. He was an Artist-In-Residence at the Exploratorium from 1982 to 1996 and spent years working with Frank Oppenheimer. Kahn has a background in science, having studied botany and environmental science at the University of Connecticut, but his interest is not in pursuing science with an academic focus. Rather, he has been, throughout his life, more of a tinkerer and explorer of nature. For example, he recalls, "Even from the early days, I was really interested in motion. I'd come home

with springs and ball bearings and I'd kind of glue and bolt them all together . . . making found-object sculptures. And I would design them so that they would all spin or wobble on a spring. Even from my early days I was really fascinated with motion."[6]

Kahn's exploratory processes of exhibit design reflect his strong love of the aesthetics of nature and his belief in the power of observation to draw people into their own investigation. He sometimes creates exhibits that are deliberately ambiguous (in their physical characteristics) in order to stir the observer to explore and ask his or her own questions. These kinds of questions can then lead visitors into their own inquiries of the phenomena that Kahn presents so artfully.

In the first step of the exhibition development, the artist and the design team came to an agreement about the domain, the general goals, and the overall vision for the project. *Planetary Landscapes* was originally called *Bringing the Universe down to Earth: Demystifying the Forces that Shape the Solar System.* It was conceptualized by Ned Kahn and Mike Reynolds, project scientist and principal investigator. They proposed to the National Science Foundation that ". . . using Kahn's unique and imaginative approach to exploring the larger forces and processes that shape planets, the exhibition will invite visitors to draw on their general knowledge of this world, focusing on familiar earthly phenomena—volcanoes, whirlwinds, wind storms, avalanches—and consider them in a larger context." Reynolds and other Chabot staff wanted to bring the aesthetically engaging work that Ned does into the service of conveying a basic and important theme in astronomy: there are forces that occur repeatedly on Earth and other planets that dramatically and fundamentally shape the way those planets appear and function. They wanted to create exhibits that encouraged visitors to observe and inquire about the phenomena in an open-ended way. They also wanted to provide a context for their observations and questions that would open visitors' eyes to the nature of forces that shape the solar system.

In step two of the process, the artist removed himself to his own laboratory and began to play with the key phenomena. In this approach, exhibits arise most vitally from the phenomena themselves. As the artist sees something beautiful, intriguing or provocative, he may start to "have a conversation" with it—to explore it in an open-ended way, asking: "What is this thing? What does it do and how does it act? What am I interested in? What do I want to capture and portray?" Kahn explains:

> I don't have any specific predetermined educational goals . . . really, all my work evolves from me playing around with phenomena and finding something that intrigues me. I show it to my kids and other people I know and when enough people seem intrigued by it, then I feel like I am on the right track . . . sometimes I will make things that are intriguing to me and everyone else shrugs their shoulders. . . . So a lot of things fall by the wayside. . . . That is how I start off.

The artist, thinking more like a scientist, then might ask himself: What are some of the scientific principles these phenomena suggest? What analogies can be drawn? Here the artist is shifting his perspective slightly and exploring the way in which some important physical principle or process is illuminated by the phenomenon. He may start to

imagine how those principles or processes might be revealed in the exhibit format, allowing viewers to see something they may not have seen before, while at the same time leaving room for them to make their own discoveries. Thus, he is working to make the learning of a principle or a process very accessible—but never mandatory. He is providing visitors with multiple opportunities to explore scientific concepts in a way that will broaden and deepen their "experiential literacy." When asked what kind of experiences he wanted to create for viewers, Kahn explained:

> [M]y hope is that people would just be intrigued with nature—seeing a real phenomenon like this gives people an opportunity to make their own associations and create their own theories about what is going on . . . . One of the things I try to do as an artist is to make things somewhat ambiguous, so the exhibit essentially becomes a conversation piece. It is a piece of nature, it is something that I have built, but something other than me is actually sculpting the nature and shape of what is in the exhibit—it is being sculpted by its own dynamics. . . . I like the fact that people have to exercise their minds to figure out what is going on and hone their own observational powers. With something like this, if you spend an hour looking at it, you start noticing subtler and subtler details. . . .

About *Planetary Landscapes* in particular, Kahn said, "[I]n the traditional Zen garden, there is a lot of emphasis on framing views of nature. . . . I had the image of that sort of aesthetic, but I wanted to create framing views that would apply to the world of planetary phenomena. So, each exhibit—each artwork—is in a sense a window, a portal, a view . . . and each one presents in that window a kind of a landscape . . . and some of these landscapes are familiar and some are bizarre."

Interpretive scaffolding and the role of evaluation—The evaluation team became involved with *Planetary Landscapes* after the exhibits themselves had already been prototyped and largely completed. This was deliberate, if a bit unusual. In this case, we did not want to interfere with the creative process of a skilled artist. (The danger lies in a conversation like this one: "Hello, Mr. Michelangelo, we are here to do formative evaluation on your ceiling painting. We will have you change it based on visitor feedback.") The formative evaluation work focused less on providing feedback to Kahn, and more on helping to develop the interpretive materials that surround the exhibits.

The design of *Planetary Landscapes* incorporates graphics, signs, programs and other materials that enhance the exhibits and make possible a deeper, richer visitor experience. This layering of interpretive information is often referred to as "scaffolding." There were two ways that the design might let visitors "fail" in using the exhibits. First, visitors might not achieve the intended inquiry experiences, because they lacked some guidance that could have helped them form and pursue their own questions. Second, the exhibit could be overly structured so that information rather than phenomena became the foreground, thus lessening the beauty and the chance for individual experimentation.

The design team was faced with the significant challenge of creating scaffolding for

an already well-designed artistic exhibition, and enhancing the visitor experience while not getting in the way of a direct encounter with the phenomena. It was important to avoid precluding the direct firsthand learning of those who were confident and curious, while providing material to assist those who needed more help to initiate their interactions and to interpret what they were seeing and doing. As Ansbacher stated: "For experience-based exhibits . . . educational value lies in the visitor's engagement with the exhibit; it is intrinsic in what visitors see and do. Labels may be used to facilitate visitors' engagement with the exhibit and to extend the experience and connect it to other aspects of their lives, but the label's role is clearly a supporting one" (2000).

The team included project staff, scientists from Chabot, and staff from Gyroscope. The evaluators provided feedback along the way as the design of the scaffolding evolved. The artist and design team thought together about what they wanted for the visitor experience, asking themselves how to highlight the phenomena, the design of the exhibits, and the ideas. The evaluation team facilitated a process of identifying and articulating the potential for each exhibit. What was possible with this exhibit? What could be noticed? What experiments might the visitor try? How might they explore and learn? After documenting the "theory of action"—that aesthetic, phenomenon-based, relatively unmediated exhibits can provide a rich experience in science inquiry—the evaluation team then explored the degree to which the intention of the designers was, in fact, realized. A "lab" setting allowed the team to watch visitors use the exhibits. The observers noted which activities—out of all the rich possibilities—visitors discovered on their own, without the assistance of the creators. The evaluation team then worked with the design team to create materials that would help visitors improve their explorations and discover more of the possibilities within each exhibit. Finally, in a summative evaluation, the evaluators compared what the exhibit creators had intended with what visitors discovered in the completed exhibition. We describe each of these steps in more detail below.

Exploring potential through interviewing the artist and scientists—The exhibit designer has an intention for each exhibit and seeks to make each one as rich as possible for all the visitors who come to view it. Each exhibit can be used in multiple ways, can portray multiple phenomena, and can illustrate multiple ideas. Exhibits that are well-designed have a kind of logic or "theory of action" behind them. To varying degrees, different exhibits have different ways in which they can generate certain experiences and certain kinds of learning. Accordingly, within the design of each exhibit there exists a potential richness and educational value. By trying to map out the full range of experiences that each exhibit might afford a visitor, evaluators are able to create a framework of expectations for the optimal use of each exhibit by a range of visitors.

For *Planetary Landscapes,* we asked the artist and the primary scientist to participate in a conversation with the main evaluator about each exhibit and the collection as a whole. The evaluator played the role of interviewer and asked the others to describe in some detail the steps visitors might take, the patterns or processes they might notice, and the scientific meaning they might make by using the exhibits.

For example, here are excerpts from our discussion of the Caldera exhibit. Kahn pointed out how air bubbling up through sand between two sheets of glass creates the impression of a cross-section of a volcanic landscape. Pools of air and sand, like underground magma chambers, rise up through the denser substrate and erupt on the surface. Calderas form and collapse as the user changes the rate of air flowing through the sand. At high flow rates the entire mass of sand becomes a water-like fluid even though no water is present.

Standing in front of the Caldera exhibit, the evaluator asked: "Then there is no water in here, but the steady air is flowing up through the powder—is that what we are watching?" He pursued questions about what he observed: "This seems like water, but it isn't, of course . . . so what is the analogy? What is it that flows up and what is it flowing through? In other words, we have air flowing through glass beads here, but with a real volcano, what do we see that is flowing through what in a real volcano?" Finally, he asked questions about the anticipated visitor experience: "What would you hope for—say, a fourth grader who came in and was on a field trip, or with her parents. What kinds of things would you want her to take away from this exhibit, either scientifically, experientially or artistically? What is your hope that someone might be able to do or discover at Caldera?"

The scientists explained: "This is a spectacular demonstration of magma flow. You see bubbles closer to the bottom, as they flow up. Of course they break up because you are using this material as almost a lubricant in a sense to move the bubble along and it breaks up and is least resistant . . . . As the magma erupts over the sides here, it 'cools,' [and] the analogies to a volcanic flow are absolutely spectacular. Again if you look at dormant volcanoes on other worlds, you will see this sort of coning. Of course if you were to shut [the air] off, you would see this sort of drop in the center of the crater, and it is just a spectacular analogy to what you see in real nature."

Interviews demonstrated that there was certainly overlap between the artistic perspective and the scientific perspective. At the Caldera, Reynolds described the exhibit from an artistic perspective: "This is just a spectacular piece. You talk about the beauty of things in nature, the subtle colors and changes, the shapes, this is quite spectacular, so I am kind of drawn to the art that is demonstrated here, the beauty of sculpture. . . . It amazes me, not just the science but the beauty of the [phenomenon] itself. It is very complicated, too. And when you start talking about the little squiggles and such as that, it is very, very nice to see. . . . I think it is really a wonderful piece both artistically and scientifically."

Kahn described the same exhibit from a scientific point of view: "[You can see] erosion and also some of the way some of these fractures occur, the way materials naturally develop [they create] very complicated fractures which makes fault lines so maddeningly difficult to analyze and predict. They are incredibly complicated, the way Earth and the way other planets' crust fracture and break . . . [like] the ice of Europa. . . there you have convection that is being driven by gravity, by these tidal, squeezing, constant squeezing and releasing of the moon."

Watching visitors and designing scaffolding—Videotaped interviews were conducted with Ned Kahn and Mike Reynolds (and segments were selected for eventual inclusion in a

kiosk in the exhibition). In addition, the evaluators and the design team held "lab sessions" where visitors from a range of potential audience groups came together to experience the phenomena in a direct or "raw" format. The purpose of this phase of the evaluation was to conduct an inquiry into the primary experiences of the visitors, so that scaffolding for the exhibition would be informed by the interests and needs of a range of real users.

In two- to three-hour lab sessions, we invited several groups representing potential visitors of various kinds: elementary and middle school students, schoolteachers, the general public, and Chabot educators. Each group had from six to ten people. We observed as group members explored the exhibits in an open-ended fashion. We then walked through the exhibits with them and asked them to "think out loud" about questions such as: What do you like about this exhibit? Is there anything here that is confusing to you? What does this remind you of? What do you think this exhibit is about? In some sessions we also showed the visitors early prototypes of signage and labels, and introduced sample activities, so that we could consider how much scaffolding, or additional supporting information, visitors might want or need in order to have the best experience of the exhibits. Finally, we sat with each group and asked people to reflect on the exhibits as a collection and discuss whether they could see common patterns and themes, whether these phenomena were interesting to them, and what questions they had.

We discovered great value in having the designers and educators (and in some cases, the artist) be present at the lab sessions, and participate in real-time learning by watching visitors directly interacting with the exhibits and with us. By seeing for themselves what was most interesting for visitors—what they wanted to know more about, and what was confusing to them—the designers and education staff gained firsthand knowledge of the interactions between visitor and exhibit.

As visitors encountered these exhibits, it was possible to see the extent to which people could interact with the phenomena and to determine whether their interactions were as rich and productive as those envisioned by the artist, designers, and scientists. When there was a gap— that is, when visitors could not achieve the potential of the exhibit on their own—we interpreted this to mean that there was a need for scaffolding. Then, by watching visitors and listening to our debriefs, the design team was able to think about ways to develop scaffolding that they felt would help visitors, but that would not interfere with their direct interaction with the exhibits.

It is important to be clear about this minimalist approach. Because the scaffolding was designed with the goal of keeping the phenomena in the forefront, the materials and processes that were interesting to visitors remained the primary experience, the thing first encountered by visitors. Thus the scaffolding was meant only to enhance the experience, never to replace it. The goal was to further the inquiry of visitors and to help take them deeper into the phenomena.

In the spirit of these highly experiential exhibits, the graphics were deliberately set up to be strongly visual, with very little text so that they did not intrude on the exhibits. The analogical connections between the small phenomena displayed in the exhibits and the massive and very distant planetary phenomena were suggested through beautiful photomurals of planetary landscapes.

The museum and design team originally had wanted to create common scaffolding for each exhibit (a photomural and a "Science Card"). However, as the result of visitor feedback, the team decided that some of the exhibits needed more scaffolding. (For example, the design team created a book of illustrative photographs and information about static electricity for the Static Landscape exhibit.)

Comparing intention and reality—In this last step of the evaluation (which happened after the exhibits had been installed in three different science museums), we were looking for the final congruence between the visitor experience and the design vision. That is, in the summative evaluation we wanted to compare what was actually happening on the exhibit floor with the estimated potential visitor experience.

From interviews with Ned Kahn and Mike Reynolds, the evaluators created a "matrix" for looking at the visitor experience along key dimensions that mattered to the artist and museum design team, and that reflected their values. We pulled out key concepts, connections with everyday life and with planetary phenomena, and other important ideas that Ned and Mike had discussed. We laid out these main ideas for the whole exhibition, as well as for four particular exhibits that we wanted to look at more closely.

To focus the study we looked at four exhibits that were identified by project staff either as particularly good examples of the blending of science and art, as especially intriguing to people of all ages, or as having the potential for generating misconceptions. These four exhibits were Turbulent Orb, Jovian Cloudtops, Caldera, and Tectonic Basin. (A sample visitor rating sheet for Caldera is duplicated here in the Appendix.)

This evaluation process gave us information about the successes and weaknesses of each exhibit and provided the opportunity for exhibit staff, as resources allowed, to further develop and refine the design of the scaffolding. It also provided general lessons about the role of visual media in scaffolding and about how a minimalist approach can best support the goal of inquiry.

In the completed *Planetary Landscapes* exhibition, the interpretive scaffolding is mutually reinforcing and multi-faceted, including signage, photographs, descriptions of the phenomena, programming, and other media. Analogical connections between the small-scale phenomena and the large-scale, planetary level are highlighted visually on large photomurals, and in more detail in a brochure that visitors can read while they are in the exhibition or at a later time. The photomurals have images of the exhibits as well as large photos of their phenomenological counterparts on Earth and other planets. There are dramatic and colorful pictures of cratering, comets, dunes, volcanoes, faults, streams, convection, cyclones, lightening, dust devils, turbulence and clouds.

The designers of the scaffolding—especially the photomurals—intentionally created a look that would not override the exhibits, both in terms of the aesthetics and the amount of information. Chuck Howarth of Gyroscope explained the strategy: "As we designed the photomurals, we intended to respond to Ned's approach to the exhibits, in that the graphics are strongly visual with very little text. We were trying not to intrude on the exhibit, and to not be didactic. So we created an almost entirely visual connection, where the title on the photomural is most likely to be noticed—that is, 'crater' suggests a

topic but is not explanatory. The titles are meant to serve as points of contact with the artworks, as opposed to explaining the phenomenon."

The photomurals served as a strong link that let visitors make connections between the visual evidence in front of them and the forces that shape the Earth and other planets. According to Gyroscope staff, "The photomurals were designed to create a connection—where the interactive exhibits took on different meaning than they would have if they stood alone. That is, without the graphics, there was no reason for people to see them as being about phenomena happening in space. So, the graphics established the analogy—the invitation—for seeing the exhibits in front of them in a different and expanded light."

Further scaffolding is provided in the laminated Science Cards, which provide more information about the scientific principles of the exhibits. Finally, the scaffolding includes the contributions of carefully trained floor staff, who work with visitors to interpret and explore the exhibits more deeply.

This study of *Planetary Landscapes* suggests that the use of analogs and the scaffolding strategy basically function well together. We found many visitors were, in fact, intrigued by the phenomena and made associations with other experiences. Some people connected Rift Zone with the bubbling mud pots they had seen at Yellowstone Park. Others noted that the mist creeping over the edge of the pan in Sea of Clouds was similar to the fog that flows in over the Bay Area's coastal hills. The key here is that the salient aspects are strongly similar to other phenomena people know well. There is a small danger that some visitors will mistake the analog for the phenomenon itself. (For example, with Tectonic Basin—which is analogous to faulting, but not a direct model of it—there is the possibility that people will think that faulting is a result of vibration.) We found visitor meaning-making enhanced through the analogies they were able to make.

FINDINGS FROM THE SUMMATIVE EVALUATION

Summative evaluation sessions took place at Chabot Space and Science Center, at the North Carolina Museum of Life and Science, and at the Orlando Science Center in Florida. The evaluators had a range of tasks, including naturalistic observation, timing of visitors, exit interviews, and in-depth reviews of four key exhibits (Turbulent Orb, Jovian Cloudtops, Caldera, and Tectonic Basin). The primary focus of the observations and interviews was on the extent to which visitors did or did not have to use the scaffolding materials, and how much that scaffolding influenced their enjoyment and understanding of the phenomena. (The findings summarized here are primarily from the summative evaluation at the Orlando Science Center in Florida.)

The beauty of the phenomena and the aesthetics of the exhibits engaged visitors—The primary strategy of this design approach was to provide visitors with an intriguing firsthand encounter with beautiful phenomena. And indeed, our studies bear out the success of this intention. Even without looking at any of the signs or supporting materials, the vis-

itors wanted to observe, manipulate, and talk about the vortices, the shifting sands, and the swirling liquids. It was not the scientific ideas that lead them into the exhibits; rather, upon entering the exhibition visitors were awed by the aesthetic and artistic qualities of the exhibits themselves.

> I liked the exhibit with the fan and the dunes [Aeolian Landscape]. I like the way they form, like the blower, when you blow it, it forms a pattern, like it forms a sculpture. . . . And I liked the spinning glass circle . . . [Turbulent Orb]. I think it was pretty cool, the way you could spin it and stop and it would keep on going. I think it was a pretty neat thing to see. . . .—Teen male

> It's pretty artistic, and I think visually it is more interesting, definitely. —Adult male

Visitors found some exhibits in the collection to be particularly dramatic and engaging—Visitors seemed to be most interested in exhibits that were dramatically beautiful or showed some effect in a particularly aesthetic way. They liked exhibits where they could make beautiful effects through their own manipulations. Examples of exhibits that were particularly attractive (and reported as "favorites") were Icy Bodies, Sea of Clouds, Tectonic Basin, Jovian Cloudtops and Caldera.

The physical placement of scaffolding turned out to be very important—In all the contexts where we observed *Planetary Landscapes,* many visitors felt the photomurals were placed too far from the exhibits.[7] Even in the traveling version, where the kiosks with photomurals were quite close to the exhibits, visitors often had trouble seeing that the kiosks related to them. This made it difficult for visitors to make the initial connection, and then they had to work—in some cases more than they wanted to—in order to go back and forth between exhibit and photomural.

> It took me three or four times before I figured out the connection between photomurals and exhibits.—Adult male

> The text illustrates each section, but I would suggest having it more close by each object; that would be better.—Adult male

A middle school science teacher noted:

> If there isn't signage with the exhibit you will lose a lot of exploration and knowledge—I would hate to see that. The photomural should be with the exhibit.

Overall, the exhibition's minimalist design worked well for most but not all visitors—We found that very few people used the brochures or Science Cards that provided more detailed scientific information. However, the photomurals seemed to help visitors understand the exhibits and make appropriate analogies to earthly and other planetary phenomena.

> I go and look at the exhibits and if I don't understand, I can go back to the murals and find out.—Adult male

> [The photomurals] give examples, they are nice. I didn't know that there were dunes in California; I thought they were only in Colorado. It shows you the Mississippi River.—Adult female

However, not everyone looked at the murals. Of the 30 visitors we observed and talked with in our mediated study of the four key exhibits, we estimated that only about 33 percent presented either "some" or "a lot" of evidence that they were interacting with the murals in some way (for instance, looking at the pictures for long periods of time, talking about them with others, going back and forth between murals and exhibits, and so on).

When we asked visitors in exit interviews about the explanatory information in the exhibitions, some visitors were satisfied with the amount and level of guidance:

> The signs are a good level for an adult. I would have read more if I weren't chasing a four-year-old. —Adult female

> They gave me examples of what this is—like in the desert—at my age you can understand what [the signs] are talking about.—Teen female

A few visitors specifically appreciated the minimalist design:

> We were immersed in our own observations, so I didn't pay attention to the signs, nor do I have a need for explanation. Experimenting was what I enjoyed. Maybe if the exhibits were different—if there were less to do—I would want [more] signs.—Adult male

> For me it's enough information, but maybe not for others. The first time you don't understand—but then if you spend more time, you can appreciate what they're trying to display.—Adult male

Only a few visitors specifically wanted more information:

> There should be more stuff for kids to help them understand. This is for adults, not for kids. It doesn't have anything they can combine here with what they do in their real life.—Adult female

Most visitors were able to relate their experiences to similar earthly phenomena—The alternative—seeing the phenomena as abstract processes that have no analog in nature—did not seem to occur.

> At Dust Devil: This is like when we were in a river, canoeing; the force of the water was like the wind. It blows things around. I've been sucked down in a whirlpool, but we popped out.—Child male

> We're going to Hawaii—I told my daughter we'd see a volcano. And Sea of Clouds is like clouds in the sky up above the islands, when seen from an airplane.—Adult female

> I've seen sand dunes [like Aeolian Landscape]. We go riding in them all the time.—Teen male

To varying degrees, people made broader planetary connections—Sometimes they made these connections strongly; sometimes they missed them altogether. Explicit photographs seemed necessary so most visitors could make the connection between the small-scale, very real phenomena in front of them and the large-scale, quite distant geological processes happening on Earth and other planets. The images on the photomurals helped to illustrate the planetary connections by showing a photograph of the exhibit (for example Aeolian Landscape), next to photos of similar phenomena on Earth (dunes in Death Valley) and on other planets (blowing ice formations at the Martian poles). (Some photomurals are reproduced in the color pages in this issue.)

Many visitors were able to begin to make connections, but many insights were implicit and almost intuitive rather than concrete. When asked what these exhibits are about, visitors gave the following kinds of responses:

> I think this exhibit [Turbulent Orb] is meant to be Venus. There are volcanoes on Venus, so it should look like a big ripe peach.—Child male

> The exhibits are about atmospheric conditions here and elsewhere.—Adult female

Other visitors were not able to make the leap between Earth and other planets.

> Most are related to Earth, our own Earth. . . .—Adult male

> Disasters. Lightning causes disasters, volcanoes cause disasters.—Adult female

> Weather patterns. . . . Fog, sands that are shifting.—Adult female

> I saw turbulence, clouds. . . . I have no idea what it's about.—Adult female

Most visitors extended the phenomena to some kind of analogical connection, often to their own personal experiences, but also to planetary forces. Of the 30 visitors rated in the in-depth study of four exhibits, about 68 percent showed "some" or "a lot" of evidence that they made connections between the exhibits and their own experiences. About 74 percent showed "some" or "a lot" of evidence that they made connections between the exhibits and other similar phenomena. About 80 percent exhibited "some" or "a lot" of evidence that they interacted with or understood the forces that affect planetary landscapes.

A small minority of the exhibits did not work as well as others, or were not accessible—Not surprisingly, visitors were less interested in the exhibits that, according to them, "don't work." These included Convection Cells, Cyclone, and Static Landscape. It is important to note that, in most cases, exhibits that visitors perceived as "not working" were those where the phenomenon was not responding quickly in that particular environment. Thus, their definition of "working well" corresponded strongly to the essential features of this approach—where visitors have direct firsthand access to beautiful phenomena that they can manipulate and learn from on their own.

For example, in Static Landscape—viewed as a prototype at Kahn's studio—small metal balls demonstrated quite dramatically the effects of static electricity. However, in all three other locations in which this exhibit was observed, the balls were significantly less active and visitors did not understand what they were (not) seeing. And with Convection Cells, the changes were so subtle, and happened over such a long period of time, that visitors gave up on it:

> I don't understand the electric one [Convection Cells], that one dealing with convection stuff, because I am touching it and nothing is happening, so what does it really mean?—Adult male

The exhibits sparked independent inquiries as visitors tried out experiments—Often, in small ways, visitors noticed things, raised questions, made conjectures and checked out their ideas with little experiments or tests. This was evidenced by the fact that, in many cases, visitors spent quite a bit of time at exhibits, even waiting in line to use them, and by the observations they made and questions they had.

> I got to wondering, what is actually in that globe [Turbulent Orb] to make it look like that? I love the colors. It's white and there is dark orange and then it gets black, kind of. I have no clue what's going on. Like the other one [Jovian Cloudtop] you spin it and it all turns dark and when you stop it, it just kind of forms down.—Teen male

> It's [Rift Zone] boiling. It shoots out of the ground. It has to be boiling water or it wouldn't come out from the magma chambers. This isn't as hot as a real geyser. [But is it boiling water?] I think so . . . [He touches the exhibit—which is, in fact, cool—to "confirm" that it is warm.]—Adult male

> I was trying to understand the water [Cyclone], the one at the end there with the crank, and I was doing it and now I am thinking, I am going to create a vortex with the air. And then everything on the bottom picked up. It created a big cloud. I'll try it again slower, because I really cranked on it. Everything gets in motion and keeps going.—Adult male

> At Caldera: I was sitting for a long time. I know the switch now. I wanted to see it slow and watch it and I guess there is a clog in one of the jets. It is not fully mixing.—Adult male

SUMMARY THOUGHTS ABOUT THE VISITOR EXPERIENCE

How well the minimalist approach supports and enhances the visitor experience of exhibits like *Planetary Landscapes* may to a great extent depend on the stance of the visitor. That is, people who are attracted to an experiential learning style, who have more time, and who are interested in careful observation are more likely to feel satisfied with a minimal amount of signage and explanation.

At the Caldera exhibit we spoke at length with a man and woman who turned out to be mathematicians. When we learned this, we were less surprised by their detailed observations and insights:

> There is aesthetic and intellectual appeal. You see the changing, swirling colors—the geology and natural shapes. Then you see that [the artist used] tiny sand pieces to look like water. Then, you realize that's what happens when lava bubbles in a volcano—and erosion under the sea [looks like this]. . . . These are about random processes—large-scale geological features. They demonstrate what the Earth does, its geological progressions.

Ironically, the museum setting itself may work against visitors taking the time to focus on an exhibit and do their own inquiries. Making observations and coming up with one's own questions in the context of a science museum visit is not always easy. Often visitors are there as part of a larger group that may be pressuring them to keep moving, or they visit an exhibit as they wait for a theater show, or they are caring for young children and so cannot focus on an exhibit for any length of time. There are also many different exhibits, and rooms full of exhibits, competing for attention.

To achieve the potential of these exhibits—to observe things carefully and to inquire into these phenomena—a visitor must invest time and patience. Often the effects of manipulating the physical events are small and difficult to see. The potential described by Kahn and Reynolds in their interviews with us is fully achieved only by the visitor who works at the exhibit for some time. And Chuck Howarth at Gyroscope, when reflecting on the philosophy embodied in *Planetary Landscapes,* talked about inquiry-based science museums as "challenging places" for visitors, in that visitors are expected to be much more involved in shaping their own learning experience than in other contexts. "The whole approach is challenging, and asks visitors to do more. That doesn't mean they are bad exhibits. You know this approach will frustrate some people and free up others. . . ." Not surprisingly, then, visitors were often enchanted by the exhibits, but most missed the more subtle opportunities afforded them. One visitor said it well: "It takes multiple visits—you go and then you come back—you read some and look some."

It was a challenge for us to document the inquiry process at these exhibits, since the interactive aspects are more subtle than in many other science exhibits. Much of the inquiry probably happened on an aesthetic, visual, and intellectual level, yet we have found that visitors often lack the vocabulary, and sometimes the confidence, to share their thoughts with researchers. While visitors may have engaged in their own investigations to

satisfy their personal curiosity, it was difficult to document their precise questions and the specific learning that occurred. Often their experimentation was quick, tacit, and nearly invisible.

Planetary Landscapes is a good example of an approach to exhibits that emphasizes intrigue and experiential literacy. It would be hard to make the case that most visitors walked away with the ability to explain planetary forces. But it may also be that visitors had very strong visual and tactile memories of the phenomena, their beauty, and their connections to other experiences. Many people most likely left with a better intuitive sense of the phenomena they were observing, and perhaps even some important notions about how these phenomena model geological and atmospheric processes on Earth and other planets.

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NOTES

1. See http://www.macfound.org/programs/fel/announce.htm for more information.
2. Multiple articles about experience-based theories of education are available at http://www.scienceservs.com/id13.html.
3. Haptic perception involves both tactile perception through the skin, and kinesthetic perception of the position and movement of the joints and muscles. For example, if we hold a cube, we perceive it through the skin of our fingers and the position of our fingers.
4. Conversations were between Ned Kahn, Mike Reynolds, and Mark St. John in January and April 2000.
5. See http://www.exploratorium.edu/about/air.html.
6. From an interview with Kahn in 2002 on EGG–The Arts Show, a product of WNET, New York: the Educational Broadcasting Corporation, http://www.pbs.org/wnet/egg/205/kahn/.
7. In the permanent exhibition at Chabot, large photomurals were hung on the wall around the gallery where the exhibition is housed. In the traveling version, the slightly smaller photomurals were placed on three-sided kiosks which were placed throughout the gallery.

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Appendix A

Sample Visitor Rating Sheet: Understandings, Connections, Personal Inquiry, Affective and Aesthetic Experiences in Relationship to an Exhibit (Caldera).

Understandings and observations* Ratings: 1–Did not understand/observe. 2–Infer they understood from some evidence. 3–Clearly demonstrated/said. ?–Not enough information/conflicting evidence. N/A-too young, too impaired, not observed, etc.

1. Notices/understands mechanism—air is being pumped into a powder of glass beads.
2. Makes observations about the material (related to color; related to behavior—erosion, fracturing).
3. Notices that when air stream is strong, the mass of sand seems fluid—this creates flow.
4. Notices that the darkness of sand relates to its density.
5. Notices/understands other (describe).
6. Expresses or demonstrates confusion or misunderstanding (e.g., that liquid is involved).

Connections* Ratings: 1–Did not make connection(s). 2–Made some connection(s). 3–Made multiple connections. ? and N/A—same as above.

1. Makes connections to similar phenomenon outside museum (e.g., volcanoes, magma chambers).
2. Makes connections to Rift Zone exhibit.
3. Makes connections to other *Planetary Landscape* exhibits.
4. Makes connections with own life.
5. Makes another connection.

Personal inquiry* Ratings**:** 1–Did not happen. 2–Happened in a limited way. 3–Happened at a significant level. ? and N/A—same as above.

1. Extends own scientific understanding/learns new concepts.
2. Carries out own inquiry.
3. Asks thoughtful questions/makes analogies.

Affective and aesthetic experiences* Ratings: 1-Did not seem to happen. 2-Happened in a limited way. 3-Reported significant affective/aesthetic experience. ? and N/A—same as above.

1. Appreciates and is excited about solar system, and phenomena within it being strange, complicated, beautiful, having order and disorder.
2. Has aesthetic experience around the exhibit (beauty, grandeur, flow).
3. Appreciates the integration of art and science.

*The major categories, as well as the indicators of visitor understanding, and experiences that are rated within each category, were derived from interviews in which the artist and director of the Chabot Space and Science Center described the ideal, or "best case," visitor experience.