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**DESIGNING SCIENCE MUSEUM EXHIBITS**  
**WITH MULTIPLE INTERACTIVE FEATURES: FIVE COMMON PITFALLS**

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ABSTRACT

Interactive museum exhibits are ubiquitous in science centers, and are becoming increasingly popular in art, history and cultural museums. At an interactive exhibit, visitors can act on the exhibit and the exhibit reacts. While there is much theoretical and empirical support for the idea that interactive features in exhibits promote science learning, we believe that serious design problems can arise if an uncritical “more is better” approach is taken to interactivity. This article describes five common pitfalls of designing exhibits with high levels of interactivity or multiple interactive features: (1) multiple options with equal salience, (2) features allowing multiple users to interfere with one another, (3) options that encourage users to disrupt the phenomenon being displayed, (4) features that make the critical phenomenon difficult to find, and (5) secondary features that obscure the primary feature. Examples of each of the five problems are presented, and possible design solutions are offered.

INTRODUCTION

McLean (1993) defines interactive exhibits as “those in which visitors can conduct activities, gather evidence, select options, form conclusions, test skills, provide input, and actually alter a

situation based on input” (p.93). At the heart of interactivity is reciprocity of action, where a visitor acts on the exhibit and the exhibit reacts in some way. Such interactivity is an essential element in the majority of exhibits in contemporary science and children’s museums. The Exploratorium’s founder, Frank Oppenheimer (1968), believed that members of the public would “gain some understanding [of science and technology] by controlling and watching the behavior of laboratory apparatus and machinery” (p. 207); in other words, they would learn by manipulating interactive exhibits. The importance of interactivity is also increasingly evident in exhibits within art, cultural and history museums.

The idea that interactivity should improve visitor learning at museum exhibits has its roots in the philosophies of experiential education (Dewey 1938/1997) and constructivism (Piaget 1957). Dewey proposed an experiential philosophy for education, emphasizing the importance of experiences for challenging or supporting a learner’s previous understanding. Piaget valued interactions with the physical world because they encouraged learners either to assimilate new knowledge into their existing conceptual structure or to accommodate new, conflicting ideas by restructuring their previous understanding. In sum, both philosophies hold that people learn by building their own understandings based on experience, and that educational systems should offer experiences to support learning. More recently, such ideas have been translated and specifically applied to current museum practice (e.g., Ansbacher 1998; Falk & Dierking 2000; Hein 1998; Roschelle 1995).

Research on visitor learning in museums suggests that interactivity promotes engagement, understanding and recall of exhibits and their content (for a recent review, see Schneider & Cheslock 2003). According to Hein and Alexander (1998), “visitors greatly prefer interactive elements” in exhibitions (p.16). In one study, Hein and Heald (1988) found that renovating a diorama exhibition to include multisensory interactive components led to increases in visitor holding time and visitors’ knowledge of the exhibition’s themes. In an art museum study, Richards and Menninger (2000) evaluated specially-designed interactive galleries at the J. Paul Getty Museum and found that holding time was greater in those galleries. Research also suggests that interactive exhibits can be memorable, with many visitors able to describe the thoughts and feelings they had at the exhibits over 6 months after a visit (Stevenson 1991). Borun et al. (1998), after studying families at science centers in detail, explicitly list interactive

design features such as multi-outcome and multi-modal as key ingredients in exhibits that will foster family learning.

In the face of such theoretical and empirical support, one might consider interactive features to be universally desirable characteristics of museum exhibits. One might even adopt a policy of trying to maximize the number and scope of interactive features each exhibit offers, within the usual constraints of budget, space, safety, and so on. However, is it always the case that more is better? Is an exhibit always improved by the addition of more interactive features, or are there occasions when such additions may actually make the visitor experience worse? Below, we list five common pitfalls in the design of exhibits with multiple interactive features. We give examples of each, as well as ways in which the problems could, at least in principle, be solved.

## CONTEXT: A NARROW SLICE OF A WIDER WORLD

Before getting to specifics, we need to position this article in the much broader world of interactive exhibit design in museums. There are many ways that interactive exhibits can fall short of creating a powerful, successful visitor experience. Many of these are shared at conference sessions on exhibit design, or discussed in on-line groups, or written up in books and other publications for the museum field. They include such things as poor accessibility (physical, sensory, or intellectual), confusing directions, controls that do not follow cultural conventions (such as turning a knob clockwise to decrease something), unclear feedback on whether the user has made a change to the exhibit, interaction that is so limited or mundane that it frustrates or bores visitors, fragility, lack of safety, and many more. In this article we are not attempting to list common pitfalls of interactive exhibit design in this larger sense.

We are not even attempting to address all kinds of interactive features that exhibits can have. Instead, we restrict our discussion to what we consider “best case” interactive features, because our particular interest is in the complexities that arise when multiple interactive features are combined together in one exhibit.

Specifically, we will limit our discussion and examples to Physical, Adjustable, Relevant (PAR) interactive features. By “Physical,” we distinguish these features from interactivity involving symbolic or computer-based media; we consider only those forms of direct interaction between the visitor and a physical phenomenon. By “Adjustable,” we mean that the exhibit can

be varied in a way that is continuously changing, beyond a simple “on/off” push of a button. By “Relevant,” we mean that the interactivity supports direct exploration of the phenomenon being exhibited, rather than being tangential to it; we therefore ignore cases where an interactive technique is used as a hook to entice visitors to read informational text or graphics. While we have not tested the efficacy of PAR interactive features per se, we focus on them because they are probably the most common and least controversial kinds of interactive features in Exploratorium exhibits.

In choosing examples of exhibits for this article, we have deliberately selected some of the most problematic cases from the Exploratorium’s own collection, rather than presenting examples from other museums. Given this, we wish to note that some of these exhibits have been or are currently being reworked to address the problems described. More details are given in the Design Solutions section later in the paper.

We now go on to consider some of the pitfalls that can arise when multiple PAR interactive features are combined within a single exhibit in an effort to enhance the visitor experience.

## FIVE COMMON PITFALLS

### **1) Multiple interactive features of equal priority can overwhelm visitors—**

Typically, contemporary interactive exhibits are designed to be “open-ended” or “multi-outcome,” meaning that interactions by visitors can lead to a variety of possible exhibit behaviors. Indeed, the PISEC study (Borun et al. 1998) showed several examples of multi-outcome exhibits enhancing family learning by being sufficiently complex to stimulate group discussion.

However, it is possible to create an exhibit that simply has too many interactive options simultaneously vying for visitors’ attention. For example, the exhibit Light Island is an open-ended exhibit that allows visitors to experiment with different behaviors of light, such as reflection, refraction and color mixing. As shown in Figure 1, it is a large table containing a light source in the center surrounded by a variety of optical devices.

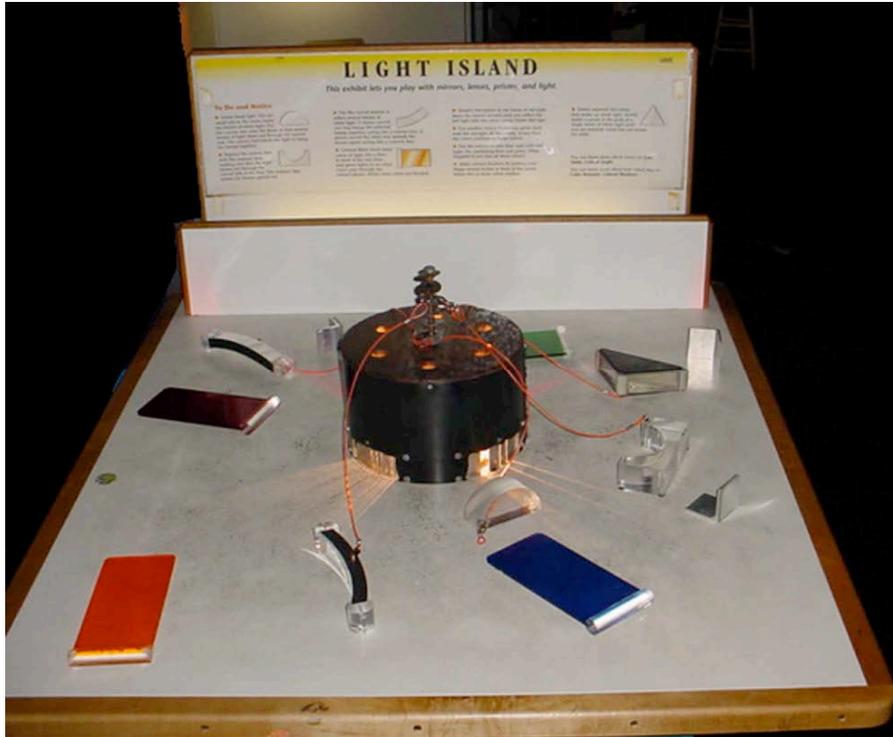


Figure 1. Light Island exhibit. Photo courtesy of the Exploratorium.

Many features of the exhibit combine to make it potentially overwhelming to visitors:

- *Many different elements.* The exhibit contains a light box, convex and concave lenses, several flat mirrors, a curved mirror, a prism, and three color filters.
- *No priority to the elements.* All the elements are approximately the same size, and are located on top of the table, wherever they were left by the last visitor. Many are tethered, thus adding a tangle of wires to the visible elements.
- *Many combinations.* All of the elements can be used either separately or together, leading to an explosion of potential combinations.
- *No obvious “output” area.* To further increase the number of possibilities for interaction, the light can be seen in several places, so there is no clear “stage” for the phenomena. Specifically, visitors can look at light beams on the table-top, on the back screen, or directly with their eyes.
- *No priority in label.* The label offers no help in narrowing or prioritizing the options for interactivity. It is long, discussing every exhibit element in great detail. In addition, all

devices are given approximately the same amount of text space, and the discussion of each element does not build on the previous one.

A small interview study (N=35) revealed that many visitors experienced difficulty with the exhibit. 46% said they had not had any specific thoughts or purposes while using it, 37% spontaneously commented that they or members of their group were confused by it, and 83% said they felt they had not learned anything.

## **2) Interactivity by multiple simultaneous users can lead to disruption—**

It is well known that museum visitation is a social activity, and the large majority of visitors come in groups. It might therefore seem obvious that good exhibits support simultaneous interactivity by multiple users. Once again, the PISEC study supports this general claim, showing that several exhibits evoked increased family learning when they were changed to support several sets of hands or bodies.

However, giving users the option of interacting simultaneously does not always make for a better learning experience. For example, the exhibit Spinning Blackboard allows visitors to explore the phenomenon of relative motion. By drawing lines on a spinning disk of sand, users can make complex and beautiful patterns involving spirals, circles, and waves (see Figure 2).



Figure 2. Spinning Blackboard exhibit. Photo courtesy of the Exploratorium.

Unfortunately, some of the exhibit's features that support interactivity also make it difficult for visitors to create complex patterns:

- *Multiple user access.* Because the disk spins rapidly, any created pattern will extend all the way around its circular surface. But the exhibit is accessible around its entire circumference. When multiple visitors use it simultaneously, it is likely that one visitor will disturb or even erase another visitor's patterns (see Figure 3).
- *Multiple elements.* The exhibit contains various tools for drawing lines in the sand, as well as an eraser stick and several shovels. Multiple elements encourage several visitors to use the exhibit simultaneously.



Figure 3. Multiple visitors interfere with each other at Spinning Blackboard.  
Photo courtesy of the Exploratorium.

An observational study (N=41) showed that fewer than half of the visitor groups successfully made even a simple pattern in the sand such as a circle or spiral. The main deterrent to making a pattern was visitors interfering with each other.

### **3) Interactivity, even by a single visitor, can disrupt the phenomenon being displayed—**

Many exhibits are designed so that the interesting phenomenon is initiated or made more compelling by visitors' interactions with it. However, occasionally some exhibit options are so inviting of interactivity that visitors "get in too close" and unknowingly disrupt the very phenomenon with which they are trying to interact.

For example, the Tornado exhibit contains a ten-foot-tall tornado of water mist swirling and gyrating inside a large metal and plexiglass cylinder (see Figure 4). The floor of the cylinder contains a grate in the center which constantly emits water vapor. Two vertical columns pierced with small holes stand on either side of the mister, blowing air in a counterclockwise direction

around the cylinder. An exhaust at the top of the exhibit draws air and water vapor upward. The result is a beautiful, lively, gentle tornado which reacts to a visitor's touch.



Figure 4. Tornado exhibit. Photo courtesy of the Exploratorium.

Unfortunately, some of the exhibit's design features, undoubtedly meant to increase interactivity, encourage visitors to use the exhibit in ways that actually disrupt the tornado:

- *Open, large scale construction.* The exhibit is open on two sides, has a strong opaque floor and is large enough for several people to get inside. This may suggest to visitors that they should actually enter the exhibit and stand or move where the tornado is forming (see Figure 5).
- *Hidden mechanisms.* The blow holes on the two metal columns are small and discreetly located, and there is nothing in the design or label to suggest that they are responsible for the rotation of the tornado.



Figure 5. Visitors running in circles disrupt the phenomenon in the Tornado exhibit.  
Photo courtesy of the Exploratorium.

Anecdotal observations indicate that many visitors, particularly children, enter the exhibit and run in circles. In a small evaluation study, we interviewed 30 such visitors and asked them about their behavior. Fully 27 (90%) of these visitors thought that by running in circles they were helping in the formation of a tornado. When visitors act on this mistaken belief, they often block the air holes in the column and actually inhibit a tornado from forming. Some visitors realized this during the interview, and expressed frustration with the design of the exhibit. For example, one visitor said, “Wait, look, we were wrong. When no one is in there it really goes. You expect that it's you making the thing happen...there should be a sign.”

#### **4) Interactive features can make a critical phenomenon difficult to find —**

One assumption behind the belief in multi-outcome exhibits is that most of the possible outcomes will be interesting to visitors, thus encouraging further exploration. This assumption

fails in cases where the essential phenomenon of an exhibit is only present in a small part of the “searchable space” available to the visitor.

For example, the exhibit Live Beating Cells displays live cells from a dissected chick heart (see Figure 6). Despite the absence of cellular connections from nerves, such cells beat spontaneously and can be seen on a monitor connected to a microscope. Remarkably, cells that are in direct physical contact with each other spontaneously synchronize their beating, and this too is visible on the monitor. Visitors have two ways to interact with the exhibit: they can move the specimen around to view different areas of the culture flask under the microscope, and they can adjust the focus to sharpen anything of interest they find. Unfortunately, only about 20-30% of the cells in a normal heart will spontaneously contract, and these are typically found only in scattered pockets throughout the specimen. To help visitors find such cells, exhibit developers added a small map of the entire culture flask, updated daily to show the recommended places to look.

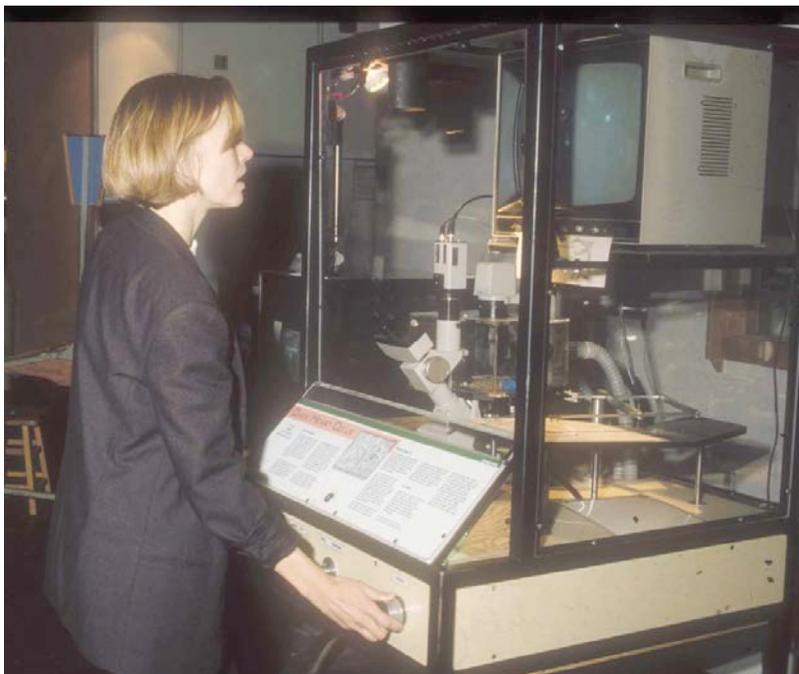


Figure 6. Original Live Beating Cells exhibit. Photo courtesy of the Exploratorium.

For visitors lacking any prior knowledge of microscopy, there were several problematic features of the exhibit’s design:

- *A small region of the searchable space where something compelling happens.* Over most of the flask, synchronously beating cells could not be seen.
- *Additional ways to miss the critical experience.* Because visitors also had access to the focus control of the microscope, they could fail to find the synchronous clusters due to incorrect focusing. These two interactive features (location and focus) had a sadly multiplicative effect on the difficulty of locating the critical phenomenon of the exhibit. Yet the focus was deemed a necessary control if the visitors were to be able to move the culture flask across the microscope's field of view, because it was impossible to keep the sample perfectly flat across its entire surface.
- *A subtle phenomenon.* Heart cells are not familiar objects, and the cells were difficult for non-specialists to identify at all, within the grainy fluid sample. Furthermore, the beating effect was often subtle: visitors might need to watch a cluster of cells carefully for several seconds in order to determine whether they were seeing beating or not. This made the search even slower and the cells even more difficult to locate.

Observations of visitors' struggles and frustrations over a period of years led the developers to a series of rebuilds of this exhibit, all constrained by budgetary limitations as well as design considerations. In the latest version of the exhibit shown in Figure 7, both interactive options (location and focus) were removed entirely.

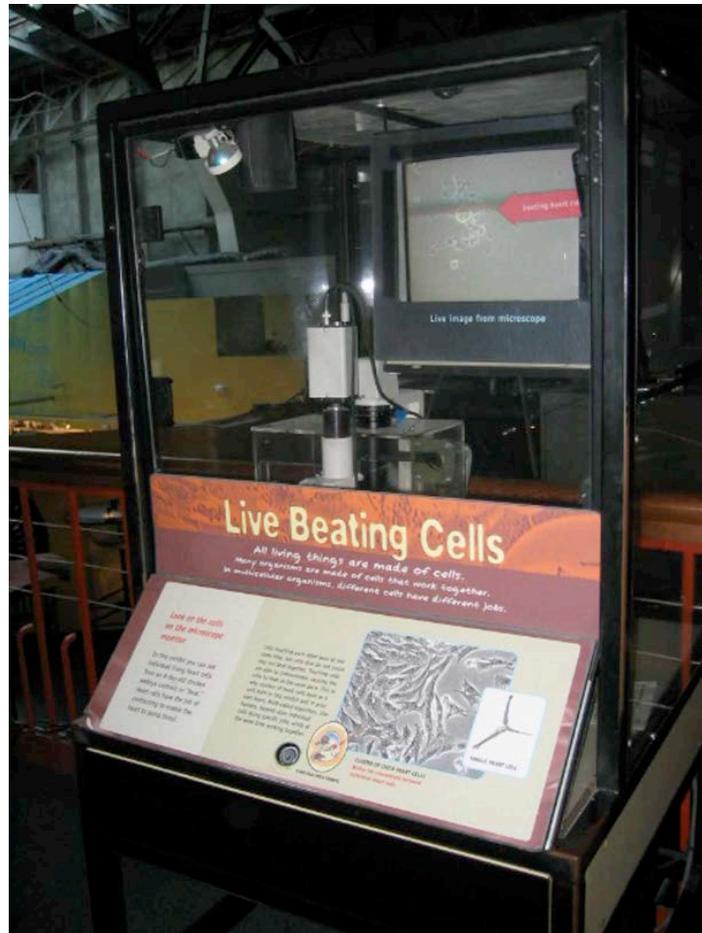


Figure 7. Revamped Live Beating Cells exhibit, with interactive controls removed.  
Photo courtesy of the Exploratorium.

**5) A secondary interactive feature can displace visitors' attention from the primary one—**

Sometimes an exhibit has a simple, powerful interactive experience at its core, but it then becomes more complicated as additional interactive features are added. This often happens in cases where the extended exhibit can display phenomena not previously possible. At the Exploratorium, a desire for more interactive features is driven in part by the institutional need to use the exhibits as teaching tools in facilitated workshops.

For example, Fading Motion (formerly known as Sand Trail) is an exhibit in which a pendulum drops sand onto a moving belt, to create a record of its movement (see Figure 8). The primary activity involves moving the pendulum, releasing or holding it, to create interesting patterns on the moving belt. The funnel at the tip of the pendulum, which holds the sand, must

also be periodically refilled with a small plastic shovel; this activity is highly compelling to small children. Secondly, the belt speed can be adjusted, and this is something quickly understood by visitors. Almost parenthetically, visitors can adjust the degree of damping of the pendulum's motion; the top end of the pendulum rests in a bath of oil, whose effective depth may be adjusted by rotating a dial. The effect of changing the damping is not immediately obvious: one must release the pendulum and watch it carefully over several oscillations to notice that increasing the damping makes the "swing" die out more quickly.

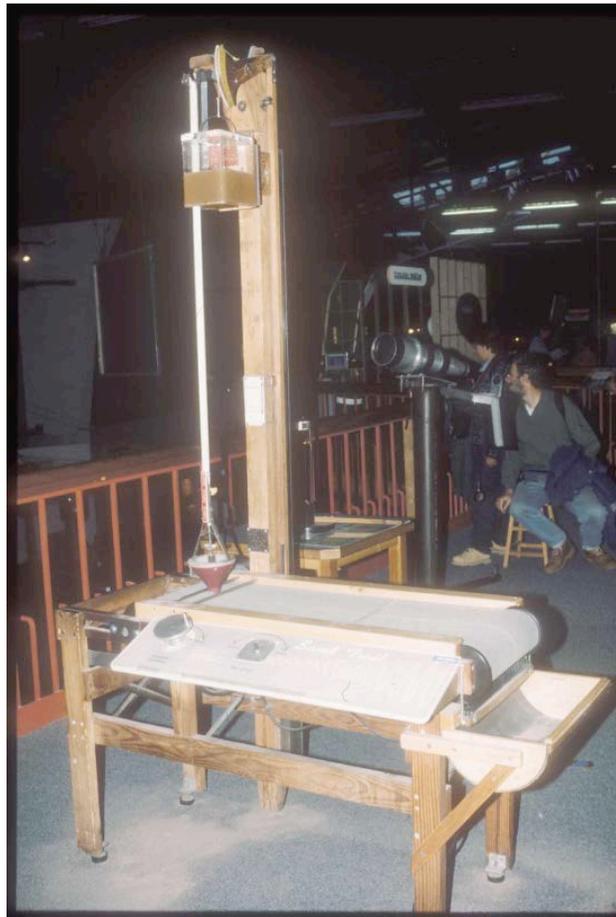


Figure 8. Original Fading Motion exhibit (formerly known as Sand Trail).  
Photo courtesy of the Exploratorium.

The exhibit suffered from the following features:

- *A control with no obvious effect.* The damping dial, although interactive, did not do anything immediately obvious.

- *Secondary options taking focus away from primary activity.* The damping dial was the largest control on the exhibit, and occupied the prime location on the left of the main control panel. The dial controlling the belt speed was smaller, to the right, and more difficult to turn (see Figure 9).

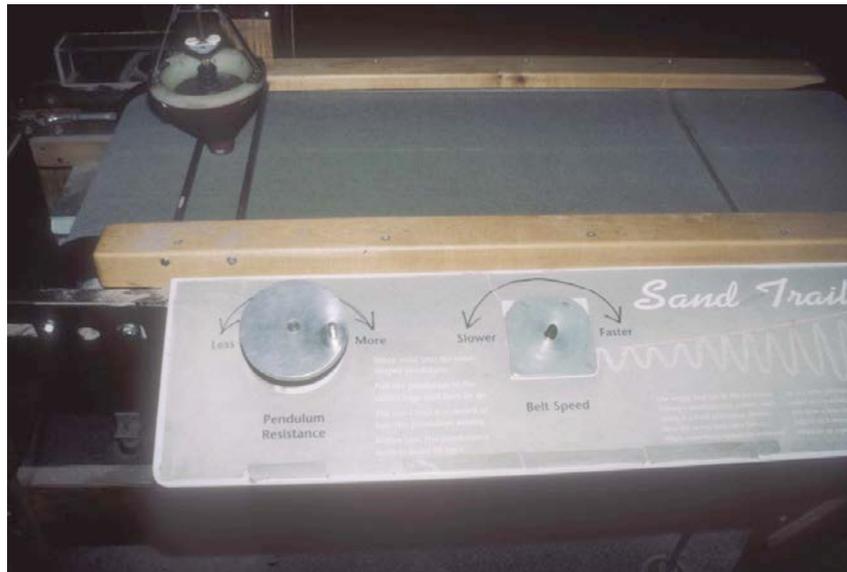


Figure 9. Control knobs on original Fading Motion exhibit (formerly Sand Trail). The large dial on the left controls the damping mechanism, while the small knob on the right control the belt speed. Photo courtesy of the Exploratorium.

Perhaps unsurprisingly, informal observations showed that most visitors began their exhibit interaction by turning the damping dial and waiting for something to happen. When nothing seemed to make any difference, some gave up and did not explore further. Following a small formative evaluation study, the exhibit was redesigned so as to reduce the salience of the damping mechanism, as shown in Figure 10.



Figure 10. Revamped Fading Motion exhibit, with damping control removed and belt drive control made more salient. Photo courtesy of the Exploratorium.

## DESIGN SOLUTIONS

For many exhibits, the problems listed above can be regarded as interface issues, and can be solved through relatively minor changes to the exhibit's label or physical affordances. Less commonly, a complete rebuild is required to solve the problem. Here we list three specific responses to an exhibit that suffers from multiple interactive design features that are poorly integrated:

## **1) Limit functionality—**

It may be possible to change the exhibit interface to limit the number of interactive options, without limiting the quality of the visitor experience. For example, the Tornado could be changed so that visitors were physically unable to climb inside (by raising the base of the tornado to chest level, or installing thin plexiglass strips across the access points) or so that visitors were theoretically able to climb inside but found the idea unappealing (if the base were made to appear transparent, fragile or difficult to navigate). Such changes would not interfere with the Tornado's access to visitors putting their hands and arms into the heart of the tornado and seeing it respond in a variety of ways. In fact, guiding visitors toward interacting with their hands rather than their whole bodies might reduce frustration and even deepen the experience by shifting it to something more focused and rewarding.

In an extreme case, Live Beating Cells was rebuilt to drastically limit the number of interactive features it offered visitors. The rebuilt version removed both the focus and movement options for visitors, creating an exhibit that could only be watched, but which was finally reliable in showing all visitors synchronously beating live cells. The principal cost to the museum was that the exhibit now requires periodic adjustments by staff to ensure that there are beating cells visible on the monitor at any given time, since the cells die off at different rates and in different parts of the sample.

## **2) Segment functionality—**

Some exhibits could be rebuilt by splitting them into multiple “stations,” each of which supports a limited range of visitor interactivity. For example, Light Island could be recreated as a series of separate stations to explore different behaviors of light, such as refraction, reflection, and color mixing. Each station could include a central light source and a small number of objects relevant to that exploration, and the stations could be conceptually linked via design cues such as physical links, adjacencies, repeating structural features, and labeling. Evaluation studies at other exhibits with multiple stations suggest that this format may ameliorate the problem of having too many interactive options at equal levels of priority. Of course, this strategy only works if visitors find the individual stations engaging as stand-alone exhibits.

In the case of Spinning Blackboard, the exhibit is slated for a rebuild to create multiple stations, each with full functionality but with limited visitor access. A formative evaluation study (N=111) showed that limiting the number of visitors who can use this exhibit simultaneously may improve the experience: the number of patterns created by each group increased significantly. Along with this segmentation into stations, additional interface changes may also be helpful. For example, informal observation suggested that when access to the exhibit was limited, parents were often the ones excluded. An evaluation study (N=493) in which a label was added to provide parents with challenges they could pose to their children re-involved parents and significantly increased group holding time.

### **3) Create a hierarchy of salience—**

In some cases functionality does not need to be entirely removed; it can merely be made less obvious to visitors. For example, in reworking Fading Motion we did not remove the oil bath that served as a damping mechanism, because it was positioned high above the moving belt, in a discreet location. However, we removed the associated damping dial from its prime position on the control panel. At the same time we enlarged the responsive belt-speed dial, and placed it prominently on a white control box where it is now seen and used early in the visitor's exploration of the exhibit.

We used a similar approach in reworking the label for Light Island as an interim measure, while it awaits rebuilding. From among the myriad possible explorations a visitor could carry out, we selected two and wrote them into the label as challenges. For example, we asked, "Can you make the light reflect all the way around the light source in the center?" This serves to give visitors a clear starting point in their exploration, and highlights the mirrors as primary objects within the larger collection.

### **FINDING THE "SWEET SPOT"**

It may be that each exhibit has its own optimal set of interactive features: too few and the exhibit fails to engage visitors, but too many and the experience is confusing, disrupting or overwhelming. A recent study by Allen & Feinstein (2003) compared three different versions of

a microscope-based exhibit, *Glowing Worms*. The first version incorporated a video microscope and living material that visitors could manipulate by changing the lighting options, focus, and dish location. A second version reduced the options available to visitors; a third version eliminated all interactive options, using recorded video clips to provide optimal views of the worms and their behavior. Observations (N=180) showed that visitors who saw an interactive version stayed longer at the exhibit than those who saw the video version. In addition, interviews (N=150) revealed that the two interactive versions of the exhibit were significantly more enjoyable than the video-only version, and that visitors who saw an interactive version were able to reconstruct more relevant details of their experience than those who saw the video version. There were no significant differences between the experiences of visitors who used the more interactive version and those who used the less interactive (but still living) version. This study suggests that, at least for one exhibit, having some form of interactivity with live animals was key, but adding more did not improve the experience or enhance learning.

## CONCLUSION

Many science centers and other museums are committed to designing interactive exhibits as an effective, fun, and compelling educational medium. However, sometimes there is “too much of a good thing” when it comes to interactive features, particularly when the features do not work together harmoniously. Each exhibit warrants individual consideration and evaluation to find its optimal degree of interactivity, in the service of a powerful and relevant visitor experience.

In trying to optimize the interactivity in exhibits, the Exploratorium staff sometimes use a framework with two aspects: initial and prolonged engagement. By initial engagement, we mean the degree to which a visitor can determine how to approach an exhibit and how to get started.<sup>1</sup> By prolonged engagement, we mean the degree to which an exhibit offers opportunities for sustained explorations, challenges, and experimentation. We try to build our interactive exhibits, particularly those that showcase interesting physical phenomena, to support both initial and prolonged engagement.

Finally, we recognize that exhibit development is irreducibly complex, and though design principles may serve as tools to help us become more reflective practitioners, they are unlikely to

provide simple prescriptions any time soon. For this reason, we want to emphasize the importance of conducting evaluation studies in all phases of exhibit development. Many development budgets include funding for summative evaluation, conducted at the end of the process to determine the degree to which a project met its goals. However, we believe it is vital to devote a considerable portion of the evaluation effort for formative and remedial evaluation. Such studies, even with sample sizes as small as 10 or 20 visitors, can expose hidden problems with interactivity and suggest possible solutions. Although our staff members are experienced and know many effective design principles for interactive exhibits, we are sometimes surprised by the results of such studies. Often, the full complexity of an exhibit's interactive features can be seen and understood only through the eyes of our visitors.

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#### REFERENCES

- Allen, S. and N. Feinstein. 2004. *The effect of physical interactivity on visitor behavior and learning*. Manuscript in preparation.
- Ansbacher, T. 1998. John Dewey's experience and education: Lessons for museums. *Curator* **41**(March): 36-49.

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<sup>1</sup> The Science Museum of Minnesota (Sauber, 1994) calls this "early assured success."

- Borun, M., Dritsas, J., Johnson, J.I., Peter, N.E., Wagner, K.F., Fadigan, K., Janguard, A., Stroup, E., and A. Wenger. 1998. *Family Learning in Museums: The PISEC Perspective*. Philadelphia: PISEC, Franklin Institute.
- Dewey, J. 1938/1997. *Experience and Education*. New York: Simon and Schuster.
- Falk, J.H., and L.D. Dierking, L.D. 2000. *Learning from Museums: Visitor Experiences and the Making of Meaning*. Walnut Creek, CA: AltaMira Press.
- Hein, G.E. 1998. *Learning in the Museum*. New York: Routledge.
- Hein, G. and M. Alexander 1998. *Museums: Places of Learning*. Washington, DC: American Association of Museums.
- McLean, K. 1993. *Planning for People in Museum Exhibitions*. Washington, DC: Association of Science-Technology Centers.
- Oppenheimer, F. 1968. A rationale for a science museum. *Curator* (November).
- Piaget, J. 1957. *Construction of Reality in the Child*. London: Routledge & Kegan.
- Richards, W. H., and M. Menninger, M. 2000. A discovery room for adults. In J. S. Hirsch & L. H. Silverman (Eds.), *Transforming practice: Selections from the Journal of Museum Education\_1992-1999* (pp. 301-311). Washington, DC: Museum Education Roundtable. (Also published in 1993, *Journal of Museum Education*, 19[1]: 6-11.)
- Roschelle, J. 1995. Learning in interactive environments: Prior knowledge and new experience. In J.H. Falk & L.D. Dierking (Eds.) *Public institutions for personal learning: Establishing a research agenda* (pp.37-51). Washington DC: American Association of Museums.

Sauber, K. (Ed.) 1994. *Experiment bench: A workbook for building experimental physics exhibits*. (Available from the Science Museum of Minnesota, 120 W. Kellogg Boulevard, St. Paul, MN 55102).

Schneider, B. and N. Cheslock. 2003. *Measuring Results: Gaining insight on behavior change strategies and evaluation methods from environmental education, museum, health and social marketing programs*. (Available from the Coevolution Institute, 423 Washington Street, San Francisco, CA 94111).

Stevenson, J. 1991. The long-term impact of interactive exhibits. *International Journal of Science Education*, 13(5): 521-531.