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ABSTRACT

This paper examines how temporal and spatial observation variables can drastically alter a visitor's comprehension of the phenomena depicted by a museum exhibit. The focus is on a tornado exhibit at the Exploratorium, a museum of science and human perception in San Francisco (California). Videotaped recordings of 10 children interacting with the simulated tornado, field observations made at the museum, and an interview with a museum employee provide data. The 10 cases show how visitors can develop misperceptions about the exhibits and the phenomena they demonstrate. Some misconceptions were based on the faulty scripts of interactions with the exhibits. Some of the scripts were observed to be derived from observing other visitors and appropriating their ideas for interactions. Observations made by visitors are influenced by numerous factors, such as vantage point and time during which the observations are made. The visitors' backgrounds in science and their general understanding of the phenomena are also important influences on perceptual focus. Eleven figures present case data. Appendix 1 classifies the visitors, Appendix 2 presents the theoretical background, and Appendix 3 contains nine sample screens from the exhibit. (Contains 23 references.) (SLD)

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The Relationship between Changes in Perceptual Focus and Understanding

ED 370 971

Introduction

The Exploratorium is a museum of science and human perception located in San Francisco. The museum primarily consists of a large number of exhibits built to demonstrate physical and biological phenomena. The exhibits require a visitor's active participation. A "To Do and Notice" sig at each exhibit explains how to interact with the exhibit and describes the demonstrated phenomenon. A multitude of children and adults visit the museum daily.

A guide to childrens' museums summarizes the history and philosophy of the Exploratorium in the following passage:

> In the late 1960's ... the concept of a completely hands-on science and technology center was just taking root. The late Frank Oppenheimer, then a university professor of physics, developed what he called a 'library of experiments' to illustrate for his students what he was talking about in class. In 1969, he opened San Francisco's Exploratorium. Now with over 600 exhibits, the Exploratorium is a collection of props that lets visitors discover for themselves the properties of electricity, magnetism, gravity, temperature, weight, and myriad other natural laws that govern the matter of the world. ... *Oppenheimer's philosophy was that visitors should control and manipulate the elements of the exhibit and that staff or volunteer 'explainers' could help them understand what was happening.* Visitors then had first-hand observations that helped them organize their experience of scientific principles. Oppenheimer believed that the museum's role was to provide an environment for free-access learning. (J. Cleaver, 1992, page 10)

The Exploratorium is a place which fills the senses with sensations from all directions. Because there is a dynamic equilibrium between the visitor's perception and his or her understanding of the causality of events, this riot of sensations can make it difficult for a visitor to form a coherent, well-integrated causal net. By focusing on a particular aspect of an exhibit, the visitor can lose sight of (or, indeed, never notice) the true causal relationships demonstrated in the exhibit.

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When visitors leave an exhibit, they have a story to tell about their interaction with it. The story is a highly individualized account of the visitor's personal interaction with the exhibit. The story reflects the visitor's background, the initial conditions of the visit, his or her observations and interaction with the exhibit.

The temporal and spatial relationships between a visitor and an exhibits influence the visitor's perception. The interactions of a visitor with an exhibit are also partly dependent on the "script" that a visitor has for acceptable museum behavior. These scripts include attitudes like "hands-on" or "hands-off" toward exhibits. Changes in these variables can create dramatically different interactions between the visitor and the exhibits and can alter the causality of events perceived by the visitor and the stories that he or she tells of their experiences at the exhibits.

This paper examines how temporal and spatial observation variables can drastically alter a visitor's comprehension of the phenomenon depicted by the exhibit. Although the author believes that her conclusions can be generalized to many of the exhibits in the Exploratorium, this paper focuses on one exhibit and the stories that young visitors tell about it. That exhibit simulates a tornado and allows visitors to interact with a small funnel cloud formed from vapor. This paper analyzes videotaped recordings of children interacting with the Tornado Exhibit, field observations made at the exhibit, taped conversations with children who visited the exhibit, and an interview with an employee of the Exploratorium.

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Theoretical Background

Andrea diSessa describes the interplay between human perception and the causal net formed by an individual's prior knowledge and belief about physical phenomena as "coordination classes".

One can think of coordination classes in terms of the formulation: 'the more you know, the more you notice and the more you notice, the more you know.' DiSessa provides a rough definition of coordination classes in his 1991 paper, "Epistemological Micromodels: The Case of Coordination and Quantities":

> [C]oordination classes are systematic means of seeking out and combining sensory accesses so as to accumulate information that may be useful in taking actions appropriate to worldly states of affairs. The notion of coordination classes highlights the complex and active nature of perception as a central part of cognitive activity. (A. diSessa, 1991)

DiSessa's paper addressed the following question:

> Do changes in the perceptual focus, readout and encoding process influence the evolution of the causal net (and vice versa), and through what means is this influence exercised? (A. diSessa, 1991)

The relevant point for the visitors at the Exploratorium would be how their ability to notice different aspects of an exhibit, to name the various components of an exhibit, and to relate how the physical phenomena associated with those components influences the story of causality. Stated simply: what causes what to happen and why? How does perception influence the causal net and how does the causal net, in its turn, alter the perception of an individual. Or, in short, what people see is related to how they think things work. Figure 1 illustrates this relationship.

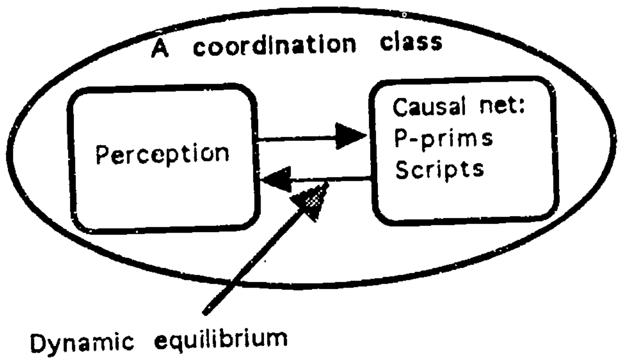

Figure 1. A coordination class.

DiSessa proposes that the relationship between perception and the causal net is in dynamic equilibrium—i.e. changes in one cause compensating changes in the other. As shown in Figure 1, the author proposes the causal net to be composed of "p-prims" and "scripts".

P-prims are phenomenological primitives defined by diSessa in the following way:

> P-prims are relatively minimal abstractions of simple common phenomena. Physics-naive students have a large collection of these in terms of which they see the world and to which they appeal as self-contained explanations for what they see. ... In becoming useful to experts, naive p-prims may need to be modified and abstracted to some extent. (A. diSessa, 1983)

P-prims have two attributes:

- Cuing Priority—how likely the idea (a p-prim) is to be profitable.
- Reliability Priority—how resistant the idea (a p-prim) is to change.

The cuing priority of p-prims seems to be closely tied to perception. At the Exploratorium, for example, by watching other visitors interacting at the Tornado Exhibit—walking around the vapor column in circles—a child might assume that it is necessary to move around in circles to generate a tornado. This situation could be described in terms of a child invoking a "Continuous Force" p-prim (A. diSessa, 1983)—a steady, constant effort needed to keep the tornado going. "Continuous Force" p-prim has a high cuing priority. This means that it comes to mind when a person perceives a steady effort. The situation described at the

Tornado Exhibit was responsible for cuing this p-prim. Priorities are context-dependent.

Another aspect of perception that cues a particular set of p-prims (figural p-prims or f-p-prims) is the recognition of figural patterns. People use figural patterns to judge, for example, the "plausibility of motions on the basis of the form or overall pattern of a trajectory." In his paper, "Toward an Epistemology of Physics," diSessa identifies a consistent problem that physics-naive individuals experience when describing dynamic situations. They tend to abstract and remember static configurations and form descriptions based on those perceptions. For example, they may remember a moon orbiting around a square planet in a square orbit even if the orbit they saw was actually an ellipse. DiSessa argues that this is due to the strong reliance that people place on visual cues. He writes:

> [The] impoverishment with respect to dynamic descriptions and gradient in confidence favoring statically describable phenomena should not be surprising in terms of the properties of our sensory system with its strong reliance on vision and spatial relations. Phenomenology consists, at first, of minimally abstract interpretations on a basis of strong vocabularies. If our touch sensitivity were as structured as vision (e.g. one could see forces as positions in force space), and, indeed, if we had remote touch sensing capabilities instead of being confined to where we can put our fingers, things would likely be different. Instead, we make use of whatever we can readily see that correlates with the structure of motion. Thus, for example, figural p-prims stand prominently to be abstracted, and these are only undermined and replaced very slowly by the weak force of evolving priorities. (A. diSessa, in press)

The concept of a script was introduced by Roger Schank of Northwestern University in the context of artificial intelligence research (R. Schank, 1992). A script is an archetypal story for a given situation about a set of expectations which include rules of behavior. The set of expectations form part of the causal net for the interpretation of events arising in that situation. For example, most individuals living in the United States have a "classroom script". This script includes modes of acceptable behavior in the classroom and a set of expectations of what might happen there. A person who has such a script could generate a story about a typical day in a classroom. This story would be based on the pattern of activities and events generalized out of multiple experiences of being in a classroom. Such a person would probably have a "lunchroom script" and a "school yard script". A subset of such individuals might also have a "visit to the principal's office script."

Most visitors who come to the Exploratorium have a "museum script". This script is composed of the experience of visiting other museums. If a visitor to the Exploratorium has never been to a hands-on museum, the script for behavior and expectations in such a place either does not exist and needs to be generated or is based upon the experiences in the "hands-off", archival mode museums. Such a person needs assistance in generating a new more liberal Exploratorium script. The assistance takes the form of reading introductory materials about the Exploratorium and observations of other visitors interacting with this museum. There are few children who engage in active research about places that they visit although the adults who accompany them may provide assistance. Most children base their scripts, and thus their behavior and interactions with the exhibits, on their observation of the behavior and interactions of other visitors. These observations are shaped by the conditions visitors experience at the museum (was the museum crowded or not crowded, how much of the previous interaction were they able to see, etc.) and by what visitors bring to the exhibit (their background knowledge of science, what they perceived to be important in the interaction and in the exhibit, etc.) It is important to note that while some visitors are aware of their scripts, others are not. Moreover, some visitors believe they act according to a particular script (e.g. read instructions before using the exhibits in the Exploratorium) when actually they were observed to do just the opposite (e.g. never read instructions). As seen in the data, such misperceptions about one's own scripts are common.

The Exploratorium contains many exhibits depicting physical phenomena. The phenomenon may be demonstrated by several exhibits utilizing different perspectives. When the perspective changes so does the visitor's perception. Do these different perceptions cue the same p-prims for the visitors? If they don't, what support does the visitor need to foster the genesis of a more mature understanding of the phenomenon demonstrated by the exhibits?

Since a particular exhibit makes only part of the phenomenon easily observable, the visitor's perception of the aspect of the phenomenon depicted by an exhibit selects the coordination class. The central question for understanding an exhibit's effect upon a visitor becomes, "What is observed?"

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The Tornado Exhibit

The Tornado Exhibit consists of a large cylindrical booth with a spinning column of vapor—the tornado. The visitor can control the fans located at the top and bottom of the exhibit's booth with a button located at the base of the booth. The fans are stopped by pushing the button. When the fans are turned off, the vapor coming in through the bottom of the booth is no longer sucked out through the top and the tornado formed by the vapor column dies. When the button is released, the fans restart and the vapor moves to the top of the booth and forms a tornado. This explanation is simplistic as there are also tubes that blow air at the bottom of the booth and help generate and maintain the circular motion of the vapor cloud. The shape of the exhibit also assists in the formation of the tornado: the cylindrical shape assists the circulation of the air inside the booth, and the back wall and the glass shield protect the vapor cloud from drafts. Vapor is constantly being generated at the bottom of the booth and flows into the exhibit through holes in the floor. If the holes are blocked or the vapor column is interrupted by placing an object in its path, the tornado dissipates. The fans are virtually unobservable—a visitor can not easily hear or see the fans.

The Tornado Exhibit was chosen as an ideal observation location for several reasons. Being a large exhibit, it allows the observer to be less conspicuous and to not interfere with visitors interactions. The large size also gives room for many visitors to interact with or watch the exhibit at the same time. The Tornado Exhibit is located next to a wall and there is a convenient place for a video camera. There is also a bench next to the exhibit where audio interviews could be conducted. These conditions made the Tornado Exhibit an ideal candidate for this study.

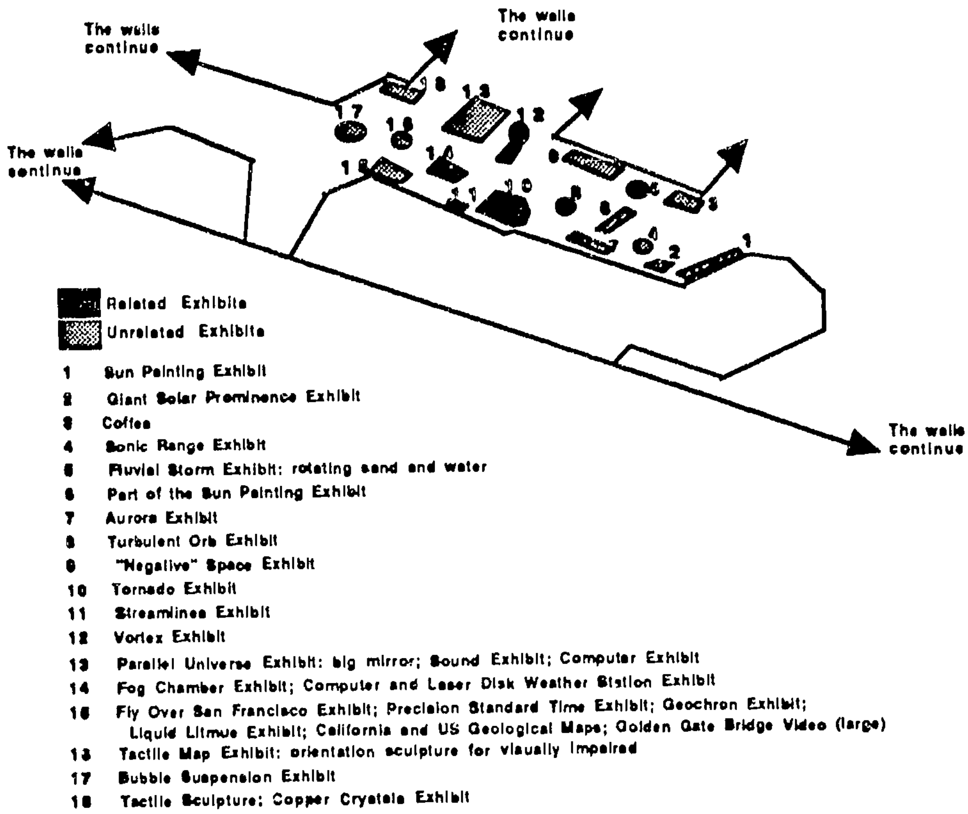

Figure 2. Location and layout of the exhibits.

The Tornado Exhibit is located near other exhibits which are thematically related to it. The Fluvial Storm Exhibit, the Vortex Exhibit, and the Turbulent Orb Exhibit all demonstrate vortices in action. The computer station shows a weather pattern, an orbital map, and a video clip of an actual hurricane. The exhibits in Figure 2 are not drawn to scale. The locations of the exhibits are only approximate.

Having the exhibits thematically arranged on the museum's floor should allow visitors to experience the same concepts over and over again and in different contexts.

There are also many more exhibits not thematically related to the Tornado Exhibit that are placed in the same area of the Exploratorium. These exhibits are shown in Figure 2.

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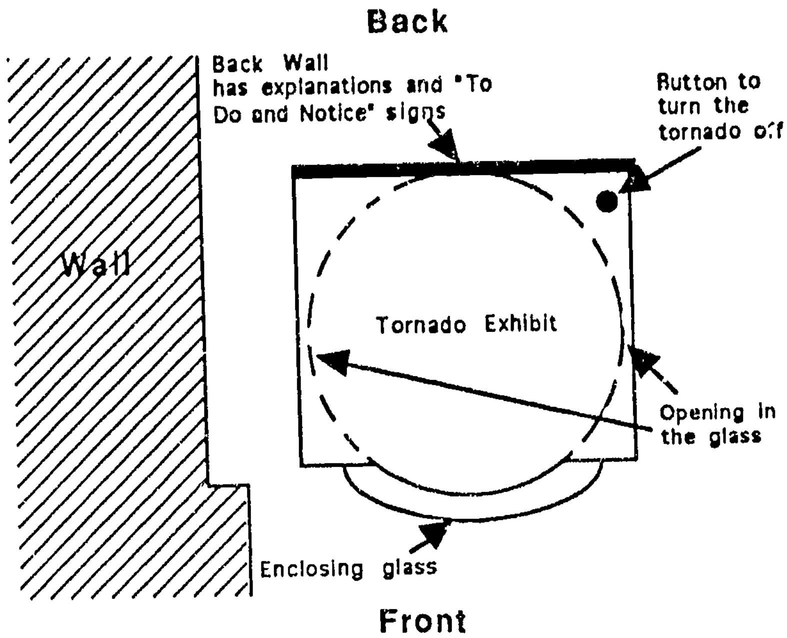

Figure 3. Diagram of the physical characteristics and the location of the Tornado Exhibit. Shown is the Tornado Exhibit's location next to the wall. The back of the exhibit is a black opaque panel. The front is a transparent glass shield. The sides of the exhibit are open.

The "To Do and Notice" sign is posted on the back of the exhibit. This is unfortunate because a visitor, waiting for a turn at the exhibit, has to maintain his or her position as close as possible to the opening in the glass shield. The closeness to this opening partly determines whose turn is next at the exhibit. If a visitor wanders away to read the instructions, the visitor may lose his or her place in line and may miss observing other visitors' interactions with the exhibit.

In the following sections, the Tornado Exhibit is described in terms of "observation zones". What museum visitors see partly depends on which observation zone they occupy while making observations and partly upon the timing of their observations.

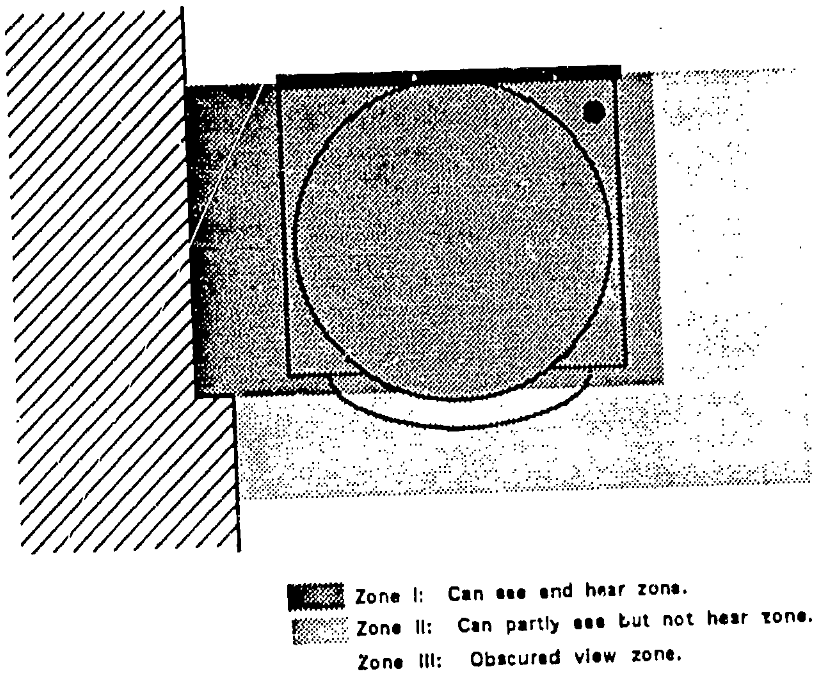

Figure 4. Diagram of different observation zones for the Tornado Exhibit.

- When in Zone I, the visitor is inside or just outside of the Tornado Exhibit. In this position, the visitor is either already in control of the exhibit or is in position to hear and see everything that is going on at the exhibit. Being in Zone I also implies that the visitor is in line to take his or her turn at the exhibit.

- When in Zone II (and depending on the amount of people in Zone I), the visitor can usually see most of what is going on at the Tornado Exhibit. The background noise level at the Exploratorium, the glass shield, and the distance from the exhibit make it very difficult to hear the exclamations and conversations of the visitors in Zone I. What can be heard also depends on the number of people in Zone I and Zone II.

- When in Zone III, the Tornado Exhibit is obscured from view by other exhibits or by people in Zones I, II, and III. Even when the museum is not crowded, it is hard to see the interaction of visitors at the Tornado Exhibit from Zone III. It is impossible to hear those visitors controlling the exhibit converse. (Note: some interactions are audible, such as when the visitors scream in unison at the exhibits.)

- When the visitor is outside of Zone III, the Tornado Exhibit is not visible.

These observation zones are not unique to the Tornado Exhibit. Each exhibit at the Exploratorium could be characterized in a similar way. The observation zones vary between the different exhibits depending on the exhibit's location, its physical characteristics, and on the type of interaction the visitors has with the exhibit.

For example, the Kaleidoscope Exhibit consists of three large mirrors joined together to form a room. Visitors are expected to climb inside and observe the infinite number of their reflections off its mirrored walls. This exhibit, due to its physical characteristics, does not have a Zone II. In order to see or hear other people interact at this exhibit, the visitor has to be located inside the exhibit with those people. Standing outside the exhibit, the observer sees only the bottom part of other visitors' legs and does not hear their conversations, thus the exhibit has a limited Zone III. Since the room is very small, turns at the exhibit are regulated—a visitor who wants to experience this exhibit has to wait his or her turn outside of the exhibit. A visitor benefits, however, from even limited observations of other visitors interacting with this exhibit. It is not obvious that one is to duck under the walls to get inside, so seeing another do so reinforces the actions needed to interact with this exhibit.

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Initial Conditions of the Visit

Figure 6 shows the various initial conditions possible when a visitor takes control of an exhibit. Prior to the time when the visitor actually gets to take control of the exhibit, the visitor may have some prior experience with the exhibit—an exhibit script. This script is developed from either a general hands-off museum script, from a general hands-on museum script, from the Exploratorium script formed by research about this museum, from the Exploratorium script formed by a previous visit to this museum (this may or may not include a script for a particular exhibit), or from other visitors' scripts observed while waiting for a turn to use the exhibit.

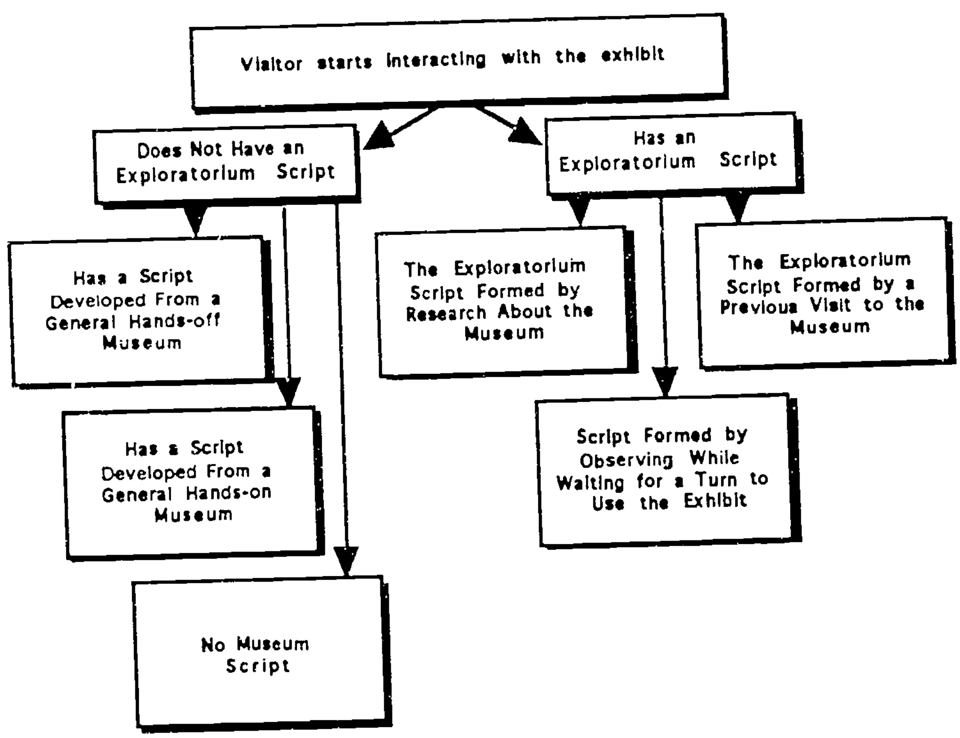

Figure 5. Visitor initial conditions.

Only in the case when a visitor has never seen the exhibit and has had no observations of others using the exhibit prior to taking control of it, would a visitor not have prior experience with the exhibit. A special case not considered here would be a knowledgeable visitor with an intimate familiarity of the phenomenon being demonstrated.

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If a visitor is returning to the Exploratorium and has had some experience with the exhibit, either by using it or by observing others, the visitor brings that memory to the exhibit. That memory can either be full or partial and it will affect the visitor's current interaction with the exhibit.

A first-time visitor who has to wait prior to taking a turn at the exhibit will make observations which will influence his or her subsequent interactions with the exhibit. These observations will be dictated, to a large extent, by which spatial zone the visitor occupies while making his or her observations. If the exhibit is not crowded, they will be able to observe from Zone I, while if the exhibit is more crowded, they may be forced to observe from Zones II or III.

A typical Zone I observation might be as follows. The Exploratorium is not crowded. When the visitor approaches the exhibit, a few people are at the exhibit but nothing is obscured from the visitor's view or hearing. The visitor waits to take a turn at the exhibit. When the visitor finally interacts with the exhibit, he or she has observed other people interacting with the exhibit. These observations affect the way the visitor is going to act at the exhibit. Even if the visitor sees and hears the previous interaction, he or she could still be missing information if the visitor did not start observing from the beginning of the other visitors' interaction.

A typical Zone II observation may be as follows. The Exploratorium is crowded. When the visitor approaches the exhibit, a lot of people are there. The visitor's view is partly obscured and he or she cannot hear what the people who have control of the exhibit are saying. The visitor thus gets incomplete information about the previous interaction. These observations will still affect the way the visitor will act at the exhibit during his or her turn.

A visitor's observations while waiting to control an exhibit also needs to be analyzed in terms of the time overlaps between the visitor's observation of a previous turn and his or her own turn at the exhibit. Was the visitor able to fully observe a previous interaction through the full duration of the experiment? In the case of the Tornado Exhibit, the experiment would be the interaction of the visitor with the exhibit through a full cycle of activity during which the tornado was active, then dissipated, and then active once more.

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Taking Turns

Most of the Exploratorium's exhibits are manipulated with a control that only a single individual at a time can operate. This means that only one individual, or an associated group of individuals, can manipulate an exhibit at a time. Other visitors interested in the same exhibit can observe and wait their turn at the controls. Waiting and taking turns at the exhibits is an unwritten law that is followed by almost all the visitors to the museum. When at the controls, the visitor takes charge of the exhibit and directs the actions of the other visitors by, for example, asking other visitors to move out of the way or restricting the control of the buttons at the exhibit.

The length of one's turn is partly determined by the number of visitors gathered at a particular exhibit—the larger the number, the shorter the interaction per individual or group. This control of the duration of a turn is exercised mainly by the adult visitors. The adult visitors direct the young visitors to stop and let others interact with the exhibit. The guardians sometimes have other objectives for the young visitors (e.g. seeing the whole museum, writing a report, teaching good manners, etc.) which help to determine the duration of their turns.

The turn-taking sequence can be represented graphically by the overlapping time lines of different visitors' interaction time and by the time line of the tornado itself. Figure 6 shows such representation.

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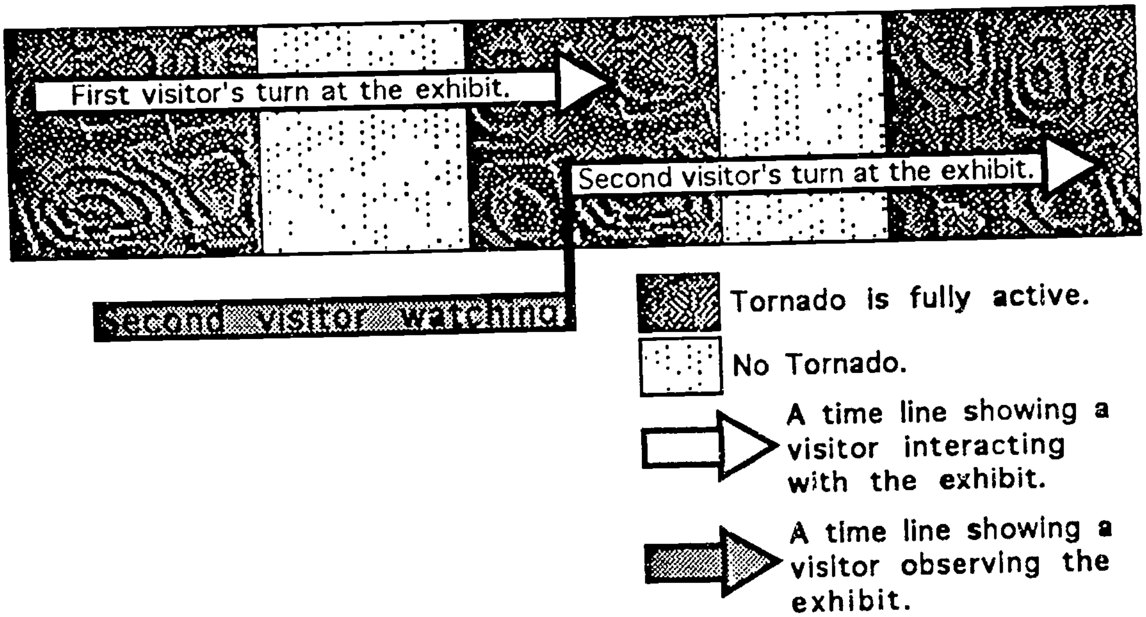

Figure 6. Sample time line.

In Figure 6, the second visitor observed the Tornado Exhibit through a full cycle of the tornado's activity. The diagram also shows the overlap in the time of the second visitors' observations and the first visitor's interaction at the exhibit. The second visitor, in this case, does not observe the entire interaction of the first visitor but is still influenced by the observation. The second visitor's script for interacting with the Tornado Exhibit would be partly based upon his or her observations—the scripts of the visitors to the Exploratorium are shared through observation.

Ann Brown et al. (in press) call this partial exchange of information "mutual appropriation":

> [L]earners of all ages and levels of expertise and interests seed the environment with ideas and knowledge that is appropriated by different learners at different rates, according to their needs and to the current state of the zones of proximal development in which they are engaged. (A. Brown et al., in press)

The "zone of proximal development" (ZPD) is a term developed by Vigotsky. It refers to the distance between the actual level of development (what an individual could do alone), and the level of potential development (what an individual could do with guidance). In this view, visitors to the Exploratorium

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appropriate only those ideas that fall within their ZPD. Thus a physics-naive visitor might perceive other visitor's circular movement around the vapor column in the Tornado Exhibit as an important interaction, while an individual knowledgeable in physics might not.

Exhibits and various objects within exhibits may also provide valuable suggestions on appropriate use to the visitors. For example, a button on the exhibit suggests a certain type of behavior to the user of that exhibit—push the button. A chair, which is part of an exhibit, invites the user to sit. This implies that an interface to an exhibit is extremely important. The more the exhibit could reveal about itself through its appearance, the easier it is for the perspective user.

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Collected Data

The study focused on young visitors to the museum (see Appendix 1). These visitors were observed interacting with the Tornado Exhibit and neighboring exhibits. Field notes and video tapes of the interactions were collected. Some of the visitors were interviewed after their experience with the Tornado Exhibit.

Below are ten cases describing experiences of certain young visitors to the Tornado Exhibit using the concepts of the observation zones, observation times, causal nets, and misperceptions.

Case #1: Zone II and Partial Observation Time

Two boys, Craig and William, ages 11 and 12, started their observations of the Tornado Exhibit from Zone II. Zone I was occupied by a group of children. At the time of the boys' observation, the children were walking in circles around the tornado and the tornado was fully developed. When the children finally left the Tornado Exhibit, the tornado had dissipated leaving only a loose floating vapor. Craig and William started their experimentation at the exhibit by pushing down the button that stops the tornado. Due to the stopping of the fan by the button and the disruptions created by the previous kids and by Craig and William, the tornado took a long time to regenerate. When the tornado started up again, Craig and William were walking in circles around the tornado.

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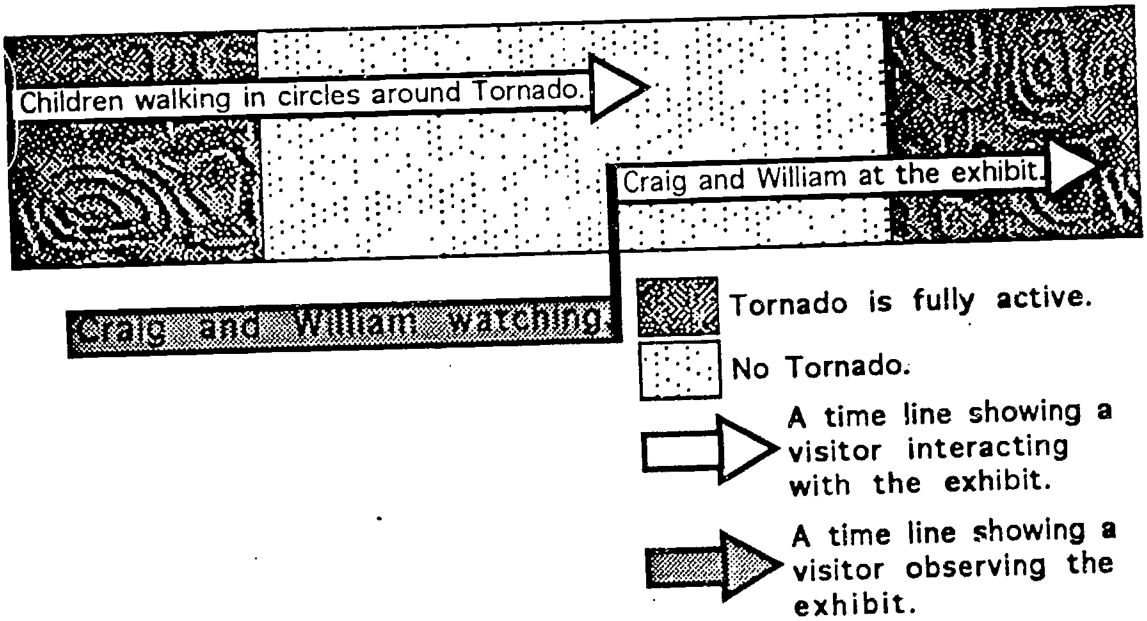

Figure 7. Time line of observations for Case #1.

<u>Partial Interview Data (q = question, c = Craig):</u>

q	Do you know how the exhibit works?

c	I think so. A bunch of steam comes out from the..., uh, from the bottom and there is a fan up on... is there a fan on top? I don't remember. I think you walk around in circles and you get the steam going to the top which sort of sucks it in. And it goes like a tornado.

q	So, if you walk... If you don't walk around in circles the tornado does not work?

c	I think so. No.

q	So you really have to...

c	(interrupting) Yeah.

q	... to walk around it to get the air moving? How does that work?

c	Um... hmm...

q	How does it help for you to walk around in circles? Around the tornado.

c	So that the tornados... the steam starts going in a circular motion so that it could start going up.

q	How does it do that? Does it look at you going around in a circle and think it's a great idea?

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c	No. It's just... if you just sit, uh... sort of... and since it's by the movement it's... we make so like a breeze and we walk in it so it gets the tornado going around in circles.

q	You created wind?

c	Yeah... cause...

q	Circular wind?

c	Yeah.

Summary for Case #1:

Case:	Observation Zone:	Observation Time:	Causal Net		Misperception:
			p-prim(s):	script(s):	
1	The exhibit was observed from Zone II.	• The exhibit was observed by the visitor through an incomplete cycle of activity of the Tornado Exhibit. • Only part of interaction of prior visitors to the exhibit was observed by the visitor.	• Continous Force	**Observed:** • Imitating other visitors—walking in circles around the Tornado, climbing inside the exhibit • Not reading the instructions	**Stated During the Interview:** •The need to walk in circles around the Tornado to make it work • Reading explanations before trying out the exhibits • Not imitating other people

In the table above, the category of Misperception consists of a list of discrepancies between the comments and self evaluations of the subject stated during the interview and the field observations of that subject during the subject's visit to the Exploratorium.

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Case #2: Zone I and Partial Observation Time

Edward is 10 years old and came to the Exploratorium with his school. He started his observations of the Tornado Exhibit with four other boys. His other classmates were at the Tornado Exhibit for some time. When Edward got there, they were walking in circles around the tornado. Edward and his group also got inside the Tornado Exhibit and started to walk in circles.

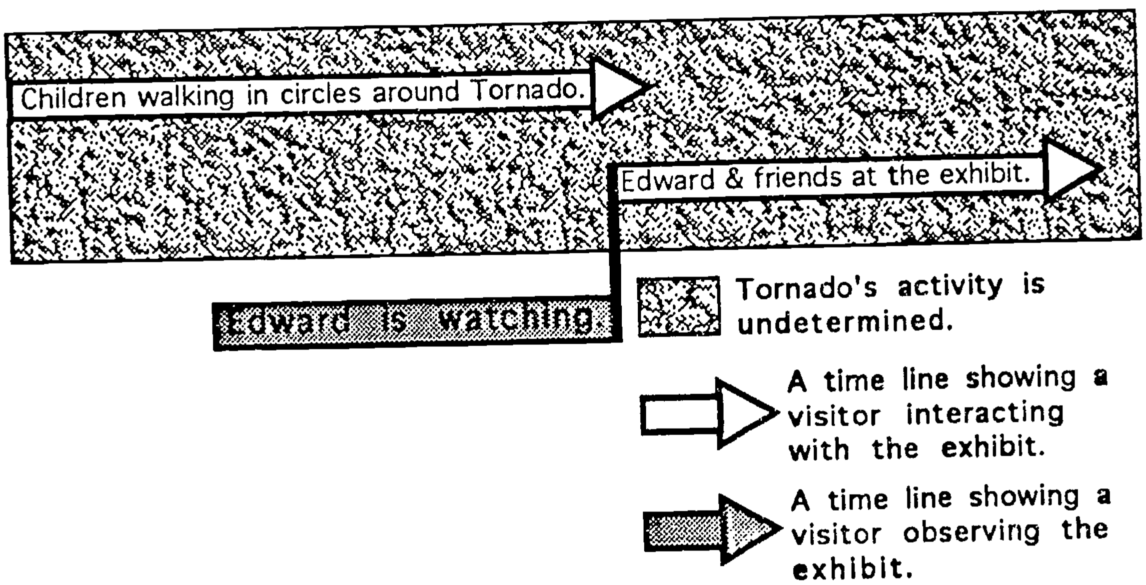

Figure 8. Time line of observations for Case #2.

<u>Partial Interview Data (q = question, e = Edward):</u>

q Describe the Tornado Exhibit.

e Well... in center... at the bottom of the center, there is silver circle with holes in it where the white smoke comes out of it and... whenever the kid walks around it, the wind turns into a tornado.

Edward goes on to explain the existence of the button that stops the tornado. The tornado is started up again by the movement of the people walking around the vapor in circles. The bodies of these people push the air around in circles creating circular wind.

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q How does pushing the air help form a tornado?

e Uh... try to get it [the air] going in one way and not all over the place.

...

q How does it work?

e Well, I try to make it so that the kids walked around inside it. The air that they are pushing would make the tornado start.

q Can the tornado form on its own?

e No.

q You need to walk around it?

e Yeah.

Summary for Case #2:

Case:	Observation Zone:	Observation Time:	Causal Net		Misperception:
			p-prim(s):	script(s):	
2	The exhibit was observed from Zone I.	• The exhibit was observed concurrently with other users.	• Continous Force	**Observed:** • Imitating other visitors—walking in circles around the Tornado, climbing inside the exhibit • Not reading the instructions	**Stated During the Interview:** • The need to walk in circles around the Tornado to make it work • Pushing the air with the body

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Case #3: Previous Observation Time

A boy and three girls from the same class visit the Tornado Exhibit. They were approximately 13 years old. The boy had visited the Exploratorium previously. The Tornado Exhibit was empty when the group approached. The boy stepped into the exhibit and declared that he saw other people climb inside the exhibit previously. He explained that this was the way to act at this exhibit. After his declaration, the girls also climbed inside the exhibit.

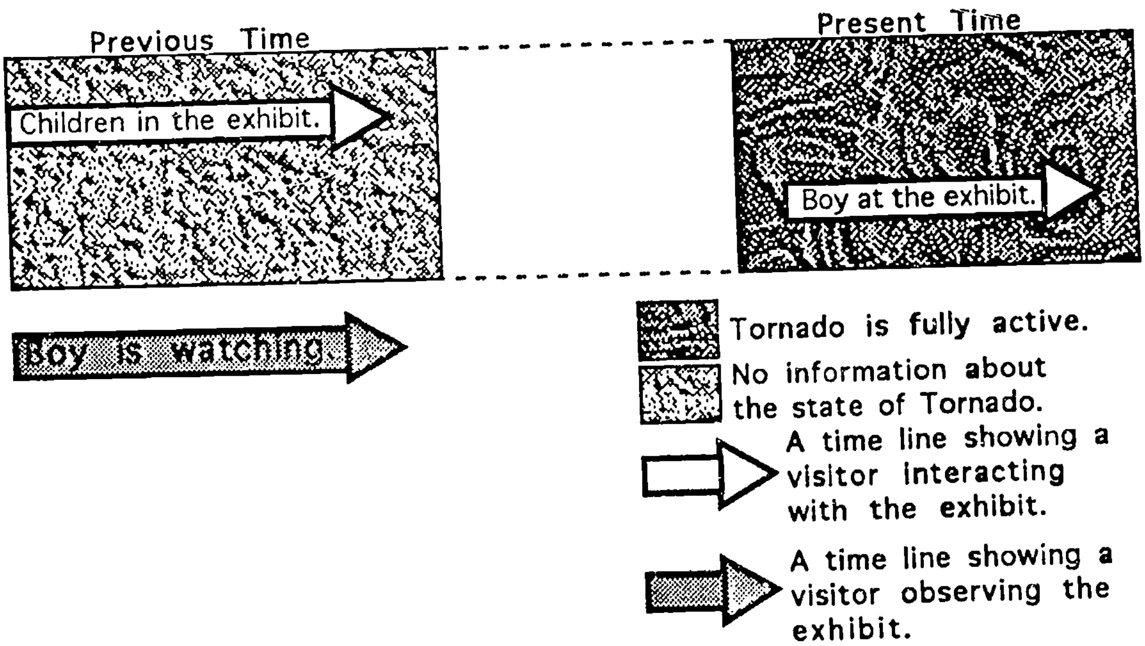

Figure 9. Time line of observations for Case #3.

Summary for Case #3:

Case:	Observation Zone:	Observation Time:	Causal Net		Misperception:
			p-prim(s):	script(s):	
3	Zone of observation is unknown.	• Past observations. • The type of observation is unknown.	• not observed	Observed: • Climbing inside the exhibit and share this script with others • Not reading the instructions	• not observed

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Case #4: Zone III and Total Observation Time

A group of young girls, roughly 5 years of age, came with a teacher to the Tornado Exhibit when it was empty. They played at the exhibit for a long time. They waved their hands through the tornado, they blew on it, and stretched to put their bodies and arms inside it. At no point during this interaction did the girls climb inside the exhibit. Their feet stayed on the floor.

After a period of time, the teacher motioned for the girls to leave the exhibit. They did so reluctantly. When they left, a group of older children arrived at the Tornado Exhibit. The older children climbed inside the exhibit and stood around. When the group of older children left, the girls, who had been watching the older children from some distance away, ran back to the Tornado Exhibit and jumped inside.

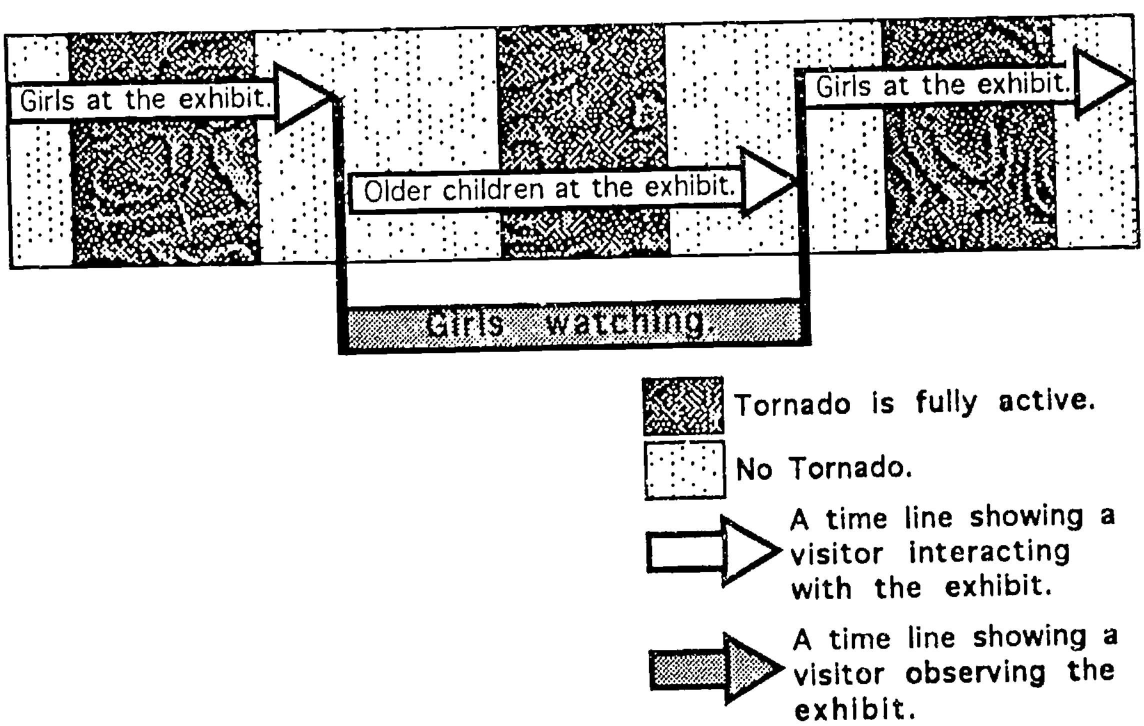

Figure 10. Time line of observations for Case #4.

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Summary for Case #4:

Case:	Observation Zone:	Observation Time:	Causal Net		Misperception:
			p-prim(s):	script(s):	
4	The exhibit was observed from Zone III.	• The exhibit was observed by the visitors through a full cycle of activity. • Full interaction of other visitors at the exhibit was witnessed.	• not observed	**Observed:** • Imitating other visitors— climbing inside the exhibit, standing inside • Not reading the instructions	• not observed

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Case #5: No Previous Observations

Lisa, Alicia, and Becky, three girls from fifth grade, came to the Exploratorium with their class. They are a team and have an assignment to do as part of the trip to the museum. The girls were observed at the Tornado Exhibit and interviewed after their experience at that exhibit. At the exhibit they did not read the explanations and moved through the exhibit very quickly. The girls were also observed to walk through the vapor cloud thus disrupting the tornado.

Summary for Case #5:

Case:	Observation Zone:	Observation Time:	Causal Net		Misperception:
			p-prim(s):	script(s):	
5	No prior observations.	No prior observations.	• Circular motion	**Observed:** • Climbing inside the exhibit • Not reading the instructions	**Stated During the Interview:** • Reading explanations before trying out the exhibits • Grouping all the exhibits which include circular motion into one category of exhibits—Circular Motion Exhibits. The Tornado Exhibit and exhibits demonstrating conservation of angular momentum belong to the same category

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Case #6: Multiple Observations

Jessy is 10 years old and he is in the 5th grade. He came to the Exploratorium with his class. His mother was a teacher's assistant for this trip. Jessy travelled through the Exploratorium with a group of five other boys. The boys were assigned to be together by the teacher and were under the supervision of Jessy's mom. During the interview, Jessy had difficulty describing how the exhibit looked. But when the function of different parts of the exhibit came up during the interview, he remembered many more details. The context of remembering different interactions experienced at the exhibit brought up memories of the construction of the exhibit—descriptions of the individual functions triggered the memory of different components of the exhibit and how they work.

Summary for Case #6:

Case:	Observation Zone:	Observation Time:	Causal Net		Misperception:
			p-prim(s):	script(s):	
6	The exhibit was observed from Zones I and II.	• The exhibit was observed through several interactions of prior visitors.	• not observed	**Stated During the Interview:** • "I like to figure it out on my own. I explain it to myself." • "I have never asked the explainer. I never have any questions."	**Stated During the Interview:** • "I never have any questions."

Case #7: Zone I and Multiple Observations

A small girl, age 4, played at the Tornado Exhibit. She came to the Exploratorium with both her parents and a grandmother. She was visiting from out of town. This girl really liked the Tornado Exhibit. She came back to it several times and spent a long time standing inside. She did not want to leave the exhibit. Her parents said that she likes the Wizard of Oz story very much and that she pretends to be Dorothy. The little girl tried to get other little children to come inside the Tornado exhibit. She was telling them that it was fun and not scary. She said that it did not hurt. But the other children were scared of coming inside even when their parents encouraged them. One little boy insisted that the "smoke" was hot even after he touched it. His mother felt the "smoke" too and tried to show and tell him it was OK and not hot. But the child still insisted that it was.

Summary for Case #7:

Case:	Observation Zone:	Observation Time:	Causal Net		Misperception:
			p-prim(s):	script(s):	
7	The exhibit was observed from Zone I.	• The exhibit was observed through a full interaction of another visitor of similar age.	• The concept of smoke is the same as the concept of hot	Observed: • Avoid danger—don't touch hot things	Stated at the Exhibit: • Smoke = hot

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Case #8: Multiple Observations

Sarah is 11 years old and she is in the 5th grade. She came to the Exploratorium with her class. Her mother was a teacher's assistant for this trip. Sarah travelled through the Exploratorium with two other girls. The interview was done at a bench on the museum floor. From this position the Vortex Exhibit was clearly seen and the Tornado Exhibit could almost be seen. Sarah stopped at the Tornado Exhibit several times with her friends. They did not spend more than a few seconds playing with it at a time.

Summary for Case #8:

Case:	Observation Zone:	Observation Time:	Causal Net: p-prim(s):	Causal Net: script(s):	Misperception:
8	The exhibit was observed from Zone I.	• The exhibit was observed through several interactions of prior visitors.	• Something forces the circular motion	**Stated During the Interview:** • Putting a hand inside the exhibit • Blowing into the exhibit • Usually not reading the instructions • Figuring out the exhibit alone • Not asking questions **Observed:** • Short interaction time • Not reading the instructions	• not observed

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Case #9: Zone I and Multiple Observations

Genevieve is 7 years old. This is her first time at the Exploratorium. She came with her mother and, at the time of the interview, only had seen the first portion of the museum. Genevieve's father is a science teacher. Her family lives in Seattle. She was videotaped during her interaction with the Tornado Exhibit. She was one of the few girls that spent a considerable amount of time at this exhibit.

Summary for Case #9:

Case:	Observation Zone:	Observation Time:	Causal Net		Misperception:
			p-prim(s):	script(s):	
9	The exhibit was observed from Zone I.	• The exhibit was observed by the visitor through several cycles of activity.	• Tornados are made up of circular and upward motions of air.	**Stated During the Interview:** • Keeping the tornado inactive • Clapping hands inside the vapor clumn • Removing the hands to activate the tornado	• not observed

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Case #10: No Observations of Other Visitors

Veda is 7 years old. He was accompanied by his guardian and a friend. The friend is a 5 year old girl. The guardian is male and is about 30 years of age. He is very involved with the kids as they go from exhibit to exhibit. The interview with Veda was done when they had only visited the Tornado Exhibit and a few exhibits around it. Their interaction with the Tornado Exhibit was videotaped. They went to the Tornado exhibit twice. The first time they did not know that you could get inside the exhibit. After the interview, they were told that it was okay to get inside and touch everything. Veda and his friends went back to the Tornado Exhibit and climbed inside. The second interaction is also on videotape.

Summary for Case #10:

Case:	Observation Zone:	Observation Time:	Causal Net		Misperception:
			p-prim(s):	script(s):	
10	The exhibit was observed from Zone I.	• The exhibit was empty during the time of visitor's observations. • The tornado was active during the observation period.	• not observed	**Stated During the Interview:** • Being able to get inside and walk through an exhibit is important **Observed:** • Needing permission to climb into the exhibit • Not reading instructions	**Observed:** • Not getting inside the exhibit

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Short Summary:

The ten short cases discussed in this paper show how visitors to the museum could develop misperceptions about the exhibits and the phenomena the exhibits demonstrate. Some of the misperceptions are based on the faulty scripts of interactions with the exhibits. Some of the scripts were observed to be derived from observing other visitors in the museum and appropriating their ideas for interactions with the exhibits. As mentioned previously, the observations of the visitors are influenced by numerous factors such as the vantage point of the observation and the slice of time during which the observations are made. The scripts are also observed to be based on previous experiences of the visitors to the Exploratorium and other museums. The visitors' background in sciences and general understanding of the phenomena shown in the exhibits is another important factor influencing the perceptual focus of the visitors.

Misperceptions

The stories that the visitors told about their experiences at the Tornado Exhibit were based on the events and objects they perceived as important and relevant to their interactions. The scripts and p-prims which were generated or invoked both before and during their interactions seem to directly affect the visitors' observations and influence their perceptions of events.

In Cases 1 and 2, the stories young visitors told about the Tornado Exhibit were very similar: to form the tornado requires that visitors move the air in a circle with their bodies by walking around inside of the exhibit. Presumably, had these visitors had a chance to see the formation of the tornado from the beginning with no one near the exhibit, they would have drawn other conclusions. However, such misperceptions about the exhibits are probably common. Visitors have a limited time to observe and interact with each exhibit.

Another source of misperceptions are the scripts the visitors have. The scripts affect the interactions that visitors have with the exhibits by making, for example, certain modes of behavior unavailable. The cases listed above show that some visitors are reluctant to climb inside the Tornado Exhibit. Other visitors provided for them a script that involved getting inside the exhibit.

Some visitors worry about the way they look in the exhibit. During an interview with one of the Exploratorium's librarians and former explainer the following comment was made:

> (A)dults if they are asked tc do something really dopey by an exhibits' graphics, will either not do it or they'll pay real close attention to what other people around them are doing in the hopes that no one's attention is on them. (Exploratorium's Librarian, 1993)

In part the reluctance to climb inside and other rough handling of the exhibits comes from fear of breaking the exhibits or assuming that such behavior is unacceptable in a museum. The parents of the young visitors were observed to stop their charges when their behavior did not fit the parents' script of interaction. The parents, in turn, get their scripts from other museums and from

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research. One source of research is a book by Joanne Cleaver, "Doing Children's Museums", which provides a list of childrens' museums and some guidelines. When describing "hands-on" museums she writes:

> As you are undoubtedly already aware, children can be hard on things. Though participation exhibits are specifically and ruggedly designed for excessive use and abuse, they still break and wear out. ... Hands-on exhibits also require many more explainers (to guide visitors through the exhibits), as well as more staff and custodians. In short, they are expensive to build, maintain, and staff. ... The moral is: Please don't allow your kids to be rough on hands-on exhibits. (J. Cleaver, 1992, page 33)

People who work at the Exploratorium also acknowledge the generation of "hands-on" museum script as a problem:

> If you have a museum that's set up as a sort of a cemetery for artifacts and they have gone to die and now we are just going to honor them by going to look at them, then it makes sense that you wouldn't do a whole lot of touching. 'Cause things would wear down. When you have an active museum, like the Exploratorium, then you have to acknowledge to them because... In the language of active museum it still is sort of odd, sort of uncertain to the general public. ... But we just have to introduce the possibilities of the active museum to the public. It means that you have to constantly remind them 'this is a hands-on museum, which means, you know, put your hands on the exhibits.' ... (Exploratorium's Librarian, 1993)

The same person continues to comment about script generation:

> (T)here are all sorts of other social behaviors that are learned at school that are hard to drop when they (children) get here. ... In an initial visit I think formulating the script on your own really can't happen on your own unless... Kids frequently will walk past an exhibit that has no one at it. And not knowing what to do with it will... If they see a button they'll push it and continue to walk past it. Unless, of course, if upon that pushing of the button something changes drastically. So that it could be caught in the peripheral vision and if all of a sudden this big glass tube lights up because there is some goofy orange gas in there, the kids would come back to it. ... But a lot of exhibits they do take, you know, more ornate preparation. If, um... you need to let all the gas out of this tube and then turn on the power all the way up and then hit this valve in order to get it to light up, they might not always get it. But if they walk around and come back to this exhibit and watch

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someone else interacting with it, that shortens their script up. Because then their script does not say, you know, do X and then do Y and then do Z. It's just imitate somebody else. I think that there are times that the exhibits could be, uhm, rearranged or redesigned so that there is a better, quicker access... it's more intuitive. (Exploratorium's Librarian, 1993)

Other misperceptions could arise from only a partial understanding of the physical principal illustrated, an incomplete understanding of the construction of the exhibit, and limited time which prevents the performance of all relevant activities and observations. The unwillingness of visitors to read the explanations and the "To Do and Notice" cards also aggravates the problem of misperceptions.

> (K)ids generally don't read these things [explanations] unless an adult drags them over and says 'read this'. (Exploratorium's Librarian, 1993)

The basic principles of the construction of an exhibit are given in its accompanying explanation cards together with the major physical principles illustrated by the exhibit. But even for individuals who read the "To Do and Notice" cards, there is still a problem. The language chosen for these explanations is difficult not only for children and for visitors to whom English is not their first language, but for well-educated adults. Some passages require extensive backgrounds in a variety of scientific disciplines in order to be comprehensible.

The main factors influencing the perceptual focus of the visitors can be summarized as follows:

1. Prior beliefs and knowledge
   what p-prims and scripts are cued for the visitor by the exhibit?
2. Design of the exhibit
   what parts of the exhibit are transparent to the visitor? For example, the fans of the Tornado Exhibit cannot be directly observed, the large size of the Tornado Exhibit at close range hides its circular shape, nothing directly invites the visitor inside (like stairs), etc.

3. Observation Zones

   from which vantage point does the visitor make his or her observations?

4. Time of observations

   what changes does the exhibit undergo during the visitor's observations and what interaction of other visitors are observed?

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Sense Making in the Exploratorium

Joanne Cleaver, in her field guide to childrens' museums, defines the goal of such places:

> The basic goal of all children's museums, discovery rooms, nature centers, and science centers is to show us how slices-of-life in their exhibits relate to our own lives and the world at large. ... Ultimately, a museum's mission is to help us relate to the world around us. (J. Cleaver, 1992, page 11)

With such goals, the Exploratorium could be a wonderful tool for teaching science. Thousands of children visit this museum every month—some children come with their parents or guardians and some come on school trips. Among these children there exists a large number that, due to their circumstances, get to visit the Exploratorium very rarely or even only once. These are usually children who come from disadvantaged socioeconomic backgrounds or who live too far away. Many of these children use English as their second language. For them, the clarity and ease of use of the Exploratorium's exhibits are essential if this museum is to be used as such a tool.

The cases discussed earlier show how changes in the perceptual focus of young visitors and their backgrounds could affect their understanding of the phenomena demonstrated by the Exploratorium's exhibits. The science-motivated visitor needs to work harder to realize the full potential benefit of this museum. A visitor could greatly improve his or her understanding by asking questions about and generating explanations for the exhibits, and by forming connections between the different exhibits and between the phenomena demonstrated by the exhibits and the real world.

For some visitors, the interviews conducted for this study might have provided the only time they had to think and talk about their experiences at the exhibits. Kenneth A. Strike and George J. Posner write:

> Explaining, arguing, constructing metaphors, giving counter examples and the like express the social character of rationality. Views that assume that people are only being rational when they discover things for themselves (where discovering is somehow

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juxtaposed to being told about) strike us as so wrongheaded as to require some inquiry into why people should believe them.
(K. Strike et al., 1990)

Ann Brown and A. Palinscar also write:

> [Conceptual] change is more likely when one is required to explain, elaborate, or defend one's position to others, as well as to oneself; striving for an explanation often makes a learner integrate and elaborate knowledge in new ways. (A. Brown et al., 1989)

Constructing explanations for those exhibits, coming up with examples of similar exhibits and real world experiences, identifying physical phenomena illustrated by the exhibits, and generating questions about the exhibits, are difficult activities and they require a lot of support. Lave et al. state: "The activity of finding something problematic subsumes a good deal of knowledge about what would constitute a solution." When visitors have questions about an exhibit, they are not just accepting what they see and do at the exhibit as a given. The visitors that ask questions are actively engaged in making sense of the exhibits. Those visitors are learning not only how and what to do at a particular exhibit, they are learning how the exhibit works, what principles are illustrated by the exhibit, etc. Unfortunately, the visitors that were interviewed did not confess to having questions about the exhibits. Rather, it was just the opposite:

Question: Do you read the explanations to the exhibits?
Answer: I like to figure it out on my own. I explain it to myself.
Question: Do you ask the explainers for help?
Answer: I have never asked the explainer. I never have any questions.

and

Question: When you come to the exhibit, do you read the explanations?
Answer: Uh, sometimes. But...
...
Question: Do you ask anybody? If you don't know what to do?
Answer: Uh, no.

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and

Question: Do you have questions that you ask or do you understand all by yourself?

Answer: Uh, some questions. But not very many. 'Cause my dad is a science teacher.

While these examples should not be generalized to all of the Exploratorium's visitors, they do show that some visitors need more help and support. M. Scardamalia and Carl Bereiter stress the same point in their article "Higher levels of agency for children in knowledge building: a challenge for the design of new knowledge media" when they warn of "romanticizing the idea of the child as independent knowledge builder:"

> When successful learning from experimentation and analysis does occur, it generally depends on more rather than less intense involvement of the teacher than is required for didactic instruction. ... When teachers fail to provide direction, hands-on activities tend to degenerate into the kind that Roth (1988) found typical of process approaches to science instruction: An experiment in light and shadow degenerates into the children making shadow rabbits and an experiment in plant nutrition leads a student to report, 'I already knew that plants need light to grow and now I know it again.' (M. Scardamalia et al., 1991)

The Exploratorium's resources, like those of the classroom teacher, could also provide the support and direction for the visitors attending to its exhibits. This support could create fertile environments for question asking and sense making for the visitors to the Exploratorium. M. Scardamalia and Carl Bereiter also stress the importance of creating such environments. They write:

> Evidence shows that children can produce and recognize educationally productive questions and can adapt them to their knowledge needs. The challenge is to design environments in which students can use such questions to guide their building of knowledge, thus assuming a higher level of agency in learning. (M. Scardamalia et al., 1991)

An environment that would support the science-motivated visitor to the Exploratorium should also address the problems of misperceptions seen in the data and discussed previously. One possible way to achieve this environment is by providing an easy to use and highly interactive assistance system for the visitors. Such a system would support development of scripts for general behavior in the museum and for interacting with individual exhibits. This system should also be able to provide visitors additional information about the demonstrated phenomena and the visitor should be able to get as much or as little information as desired. It should assist the visitors in forming thematic connections between the exhibits. The system should be easy to use and be consistent throughout the museum and exhibits. The visitor should be able to use it at any time during his or her stay in the Exploratorium. And another important characteristic of the system should be its ability to communicate with visitors with limited ability to understand and read English.

The system with the characteristics described above could be a series of multimedia computer stations next to the exhibits—the Exploratorium Kiosks. The detailed software development rationals for such a system are given in Appendix 2. An example, the Exploratorium Kiosk for the Tornado Exhibit, is presented in Appendix 3. The mission of such Kiosks would not be to take anything away from the actual exhibits but to provide interested visitors with easy access to information.

Optimally, each exhibit in the Exploratorium would have its own Kiosk. A collection of all the Kiosk would form a database of the Exploratorium's exhibits. Such a database could be placed in the museum's library or at an entrance. The Kiosk database could be searched by staff and visitors to find a particular exhibit and its location or to find a set of exhibits with specific characteristics (e.g. exhibits demonstrating an electrical phenomena, exhibits with long interaction times, computer exhibits, etc.). Such a database would also be useful for teachers to plan their field trips to the Exploratorium.

The Exploratorium Kiosks would certainly not solve all the problems of misperceptions and sense making of the visitors, but it would provide an additional support system for the museum that is a creative learning environment for children and adults.

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Conclusion

The Tornado Exhibit at the Exploratorium is an ideal place to study the relationship between visitors' spatial and temporal observations of the exhibit and their subsequent interaction with and understanding of the physical principals being demonstrated.

By analyzing recordings of children interacting with the Tornado Exhibit and by conducting subsequent interviews with these same children, the author concludes that a visitor's experiences at the Exploratorium's exhibits are based in part on the visitor's prior knowledge of the exhibits. That prior knowledge comes from either earlier experiences with the exhibits or from observations of others utilizing the exhibits. In the observed cases, prior knowledge served as a vehicle to get permission for certain types of interactions and as a source of ideas for the types of interactions possible—i.e. formation of the causal net.

Turn-taking facilitated visitor understanding by giving the visitor an opportunity, while waiting in line, to observe others utilizing the exhibit. These observations often served as a jumping off point for the visitor's own interactions—the visitor appropriated the scripts for interaction by observing other children in the museum.

What a visitor takes away from the Exploratorium is the story they create about their experiences. The extent to which their story represents reality and the physical processes being demonstrated by particular exhibits are partially based upon their observations and interactions with the exhibits. If the Exploratorium is to serve as a teaching tool, the limitations of observation and interaction must be well understood and supporting materials must be developed to fill in the weaknesses of the setting. The "To Do and Notice" signs, while well intentioned, need to be supplemented with other materials that help the visitor learn. The Exploratorium Kiosk Stations is one possible solution.

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Appendix 1: Classification of Visitors to the Exploratorium and Data Collection

The Exploratorium is visited by a diverse range of people with different expectations of the museum and with different reasons for their visit. As shown in Figure 11, the visitors as social units were divided into 2 sets of five groups.

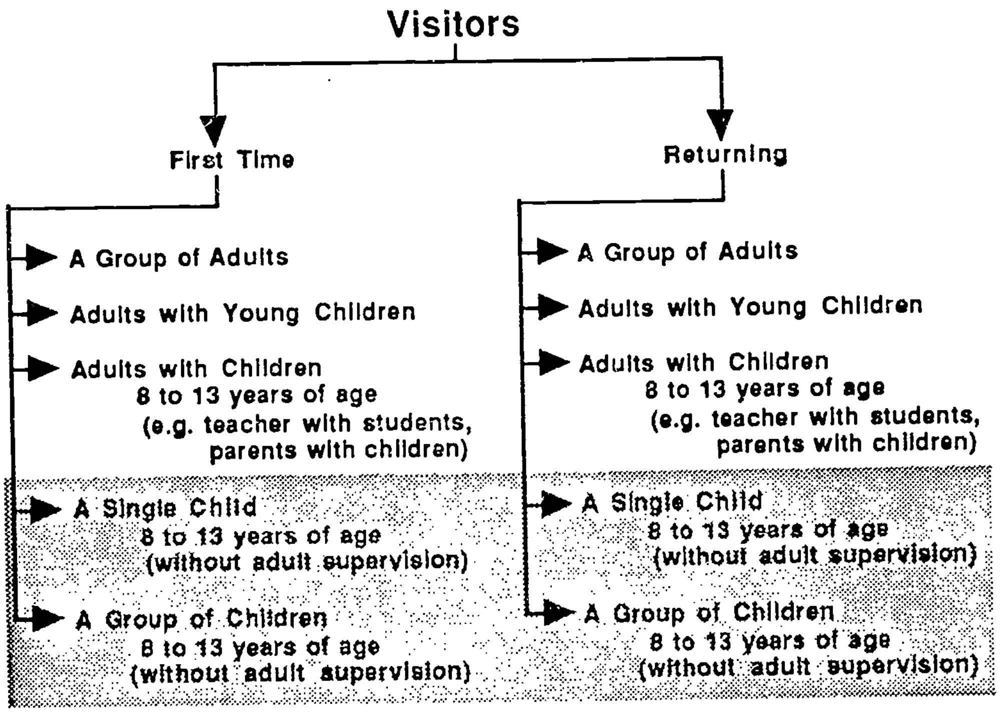

Figure 11. Visitors of the Exploratorium.

The shaded area in Figure 11 represents the subgroup of visitors that were observed and interviewed for this article. This subgroup of visitors was chosen because primarily they are elementary and junior high school students visiting the museum. From prior observations, school field trips to the Exploratorium usually leave students to explore the exhibits without adult support, but with adult chaperones. These students form their own personal stories about their experiences. These students are presumed to be physics-naive individuals. This study focused on observing the interactions of young, physics-naive children with the museum's exhibits.

Based on observations of visitors at the Tornado Exhibit, a set of post interaction interview questions was constructed.

1. What do you remember about the Tornado Exhibit?
2. What was the most interesting thing about the Tornado Exhibit?
3. Could you explain what was happening at the Tornado Exhibit?
4. Did you read and follow the explanations and directions given?

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5. Was the exhibit easy to understand?
6. What was hard?
7. Are there any similarities between the Tornado Exhibit and other exhibits?
8. Are there any similarities between the Tornado Exhibit and things in the real world?
9. Was something about tornados that you believed prior to visiting the museum changed?

These questions served as points of possible discussion and were used to start off the interviews. Answers were followed up with unstructured questions. The interviews were not used to collect any quantitative data but rather to gain a feel for the types of responses the young visitors might give. Some basic observations could still be made, however, and are presented in the Data Collection section of this paper.

Additional information was obtained by videotaping visitors interacting with the Tornado Exhibit before conducting the interviews. The stories that the visitors told about their experience at the Tornado Exhibit was compared with the visitors' actual interactions there as recorded on videotape.

An interview with the Exploratorium's librarian was conducted. An attempt was made to understand his theories of learning and his perception of museum's philosophy toward learning and instruction.

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Appendix 2: Theoretical Background of Software Design

One of the key constraints on the Exploratorium Kiosk software is that it is being designed for a novice user. The software consists of several different parts and covers a large spectrum of exhibits. It was important that the visitors using this software had a mental model of all of its functions. A mental model for this project meant a creation of a metaphor for each mode of use of the software.

Carrol and Thomas, in their paper "Metaphor and the Cognitive Representation of Computing Systems," describe the possible implications of metaphors on computer design:

> If people employ metaphors in learning about computing systems, the designers of those systems should anticipate and support likely metaphorical constructions to increase the ease of learning and using the system. In addition and as a complementary strategy, designers should provide guidance to new users who may otherwise select inappropriate or inefficacious metaphors. As this suggests, we believe that the topic of metaphor-based learning is crucial in software psychology and human factors. (J. Carroll & J. C. Thomas,1982)

A set of principles that had a large impact on the development of the Exploratorium Kiosk software was described by Smith et al., the team of designers who developed the Star user interface for Xerox. They believed that a well designed system should have the following features:

> Visibility: A well-designed system makes everything relevant to a task visible on the screen.
>
> Consistency: Consistency asserts that mechanisms should be used in the same way wherever they occur.
>
> Simplicity: Obviously a simple system is better than a complicated one if they have the same capabilities.
>
> (D. C. Smith et al.,1982)

Smith et al. also generated a list of operations that were considered easy or hard for the user. They state:

Our experience before and during the Star design has led us to the following classification:

Easy	Hard
concrete	abstract
visible	invisible
copying and modifying	creating from scratch
choosing from a list	filling in a blank
recognizing	generating
editing	programming
interactive	batch

(D. C. Smith et al.,1982)

The above principles are also named by Bewley et al. as the principles of interface design derived from cognitive psychology:

- There should be an explicit user's model of the system, and it should be familiar (drawing on objects and activities the user already works with) and consistent.

- Seeing something and pointing to it is easier for people than remembering a name and typing it.

- Commands should be uniform across domains, in cases where the domains have corresponding actions.

- The screen should faithfully show the state of the object the user is working on: "What you see is what you get."

(Bewley et al., 1983)

Yet another important component of the Exploratorium Kiosk software design was the need to make it simple and yet interesting to use from the start. DiSessa describes this principle of design in the following way:

> To succeed in enticing individuals and society at large to learn a complex and subtle device, that device must offer "continuous incremental advantage," motivation to take each step forward at each stage and each level: from day one, to expertise; from immediate gratification to the noble goals of intellectual advance of civilization. (A. diSessa, 1991)

Ingalls summarizes the main design principles used in the Exploratorium Kiosk software in his article on the "Design Principles Behind Smalltalk":

Personal Mastery: If a system is to serve the creative spirit, it must be entirely comprehensible to a single individual.

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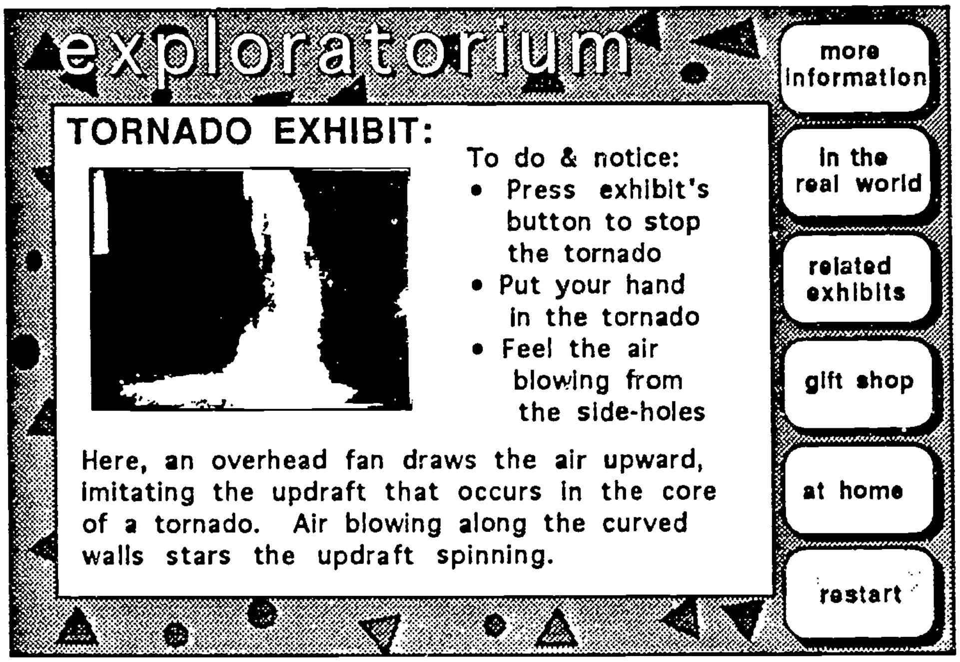
Good Design:	A system should be built with a minimum set of unchangeable parts; those parts should be as general as possible; and all parts of the system should be held in uniform framework.
Reactive Principle:	Every component accessible to the user should be able to present itself in a meaningful way for observation and manipulation. (D. H. Ingalls, 1981)

It is also important to note that some of the principles used in designing the Exploratorium Kiosk software were the result of two years of observations of the classrooms participating in the Fostering the Scientific Literacy ("FSL") project. The FSL project was created by Ann Brown and Joe Campione. They have developed alternative methods for teaching science in elementary and secondary school. Brown and Campione are working on a model called "A Community of Learners", where students working in small groups of four to five students develop educational materials that they use to teach the rest of the class the topics they have researched. The students use Macintosh personal computers for word-processing, graphics, and e-mail. The field observations of the students utilizing the computers to achieve their goals in the class as well as extensive observations of visitors in the Exploratorium served as a foundation for many decisions made on the design of the Exploratorium Kiosk software and on its function.

Appendix 3: Exploratorium Kiosk

Below are sample screens for the Exploratorium Kiosk—the Tornado Exhibit Station.



This is the first screen for the Tornado Exhibit Station. It contains basic descriptions of what could be done or noticed at this exhibit as well as shows a short video of the exhibit and children playing with it. The video consists of several interactions of children with the Tornado Exhibit and continuously loops through them. If a current visitor does not understand English very well and does not know what to do at the exhibit, the video would serve as a helpful hint.

A visitor using the Exploratorium Kiosk Station could choose to get further help by selecting other options available: "more information", "in the real world", "related exhibits", "gift shop", and "at home". If the Station is not in use, it would automatically return to the first screen showing the exhibit and children.

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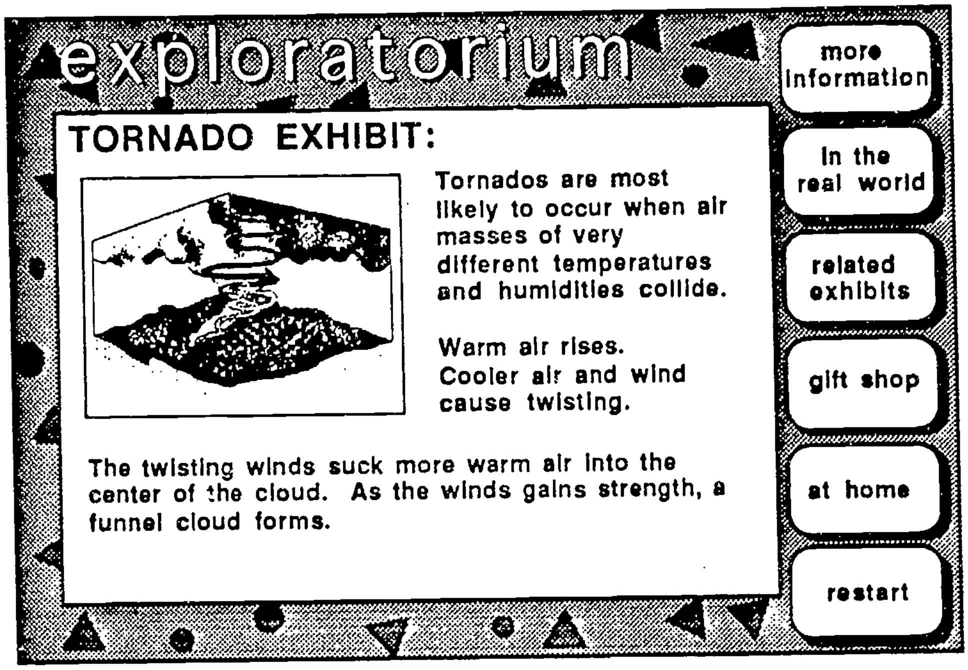
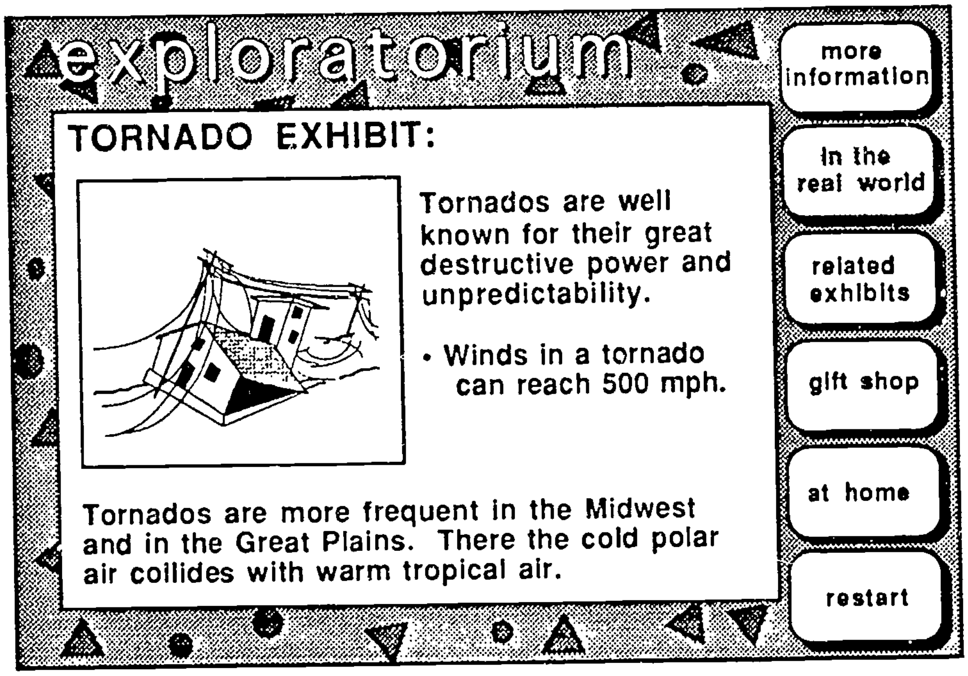


Above is a sample screen showing the "more information" option at the Tornado Exhibit Station.



The graphics for each option in the Exploratorium Kiosk Station could be diagrams, drawings, photographs, videos, etc. But while the graphics and the text change for every option, the format of the screen remains the same. This would minimize the confusion and the learning curve of the visitors using the Kiosks.

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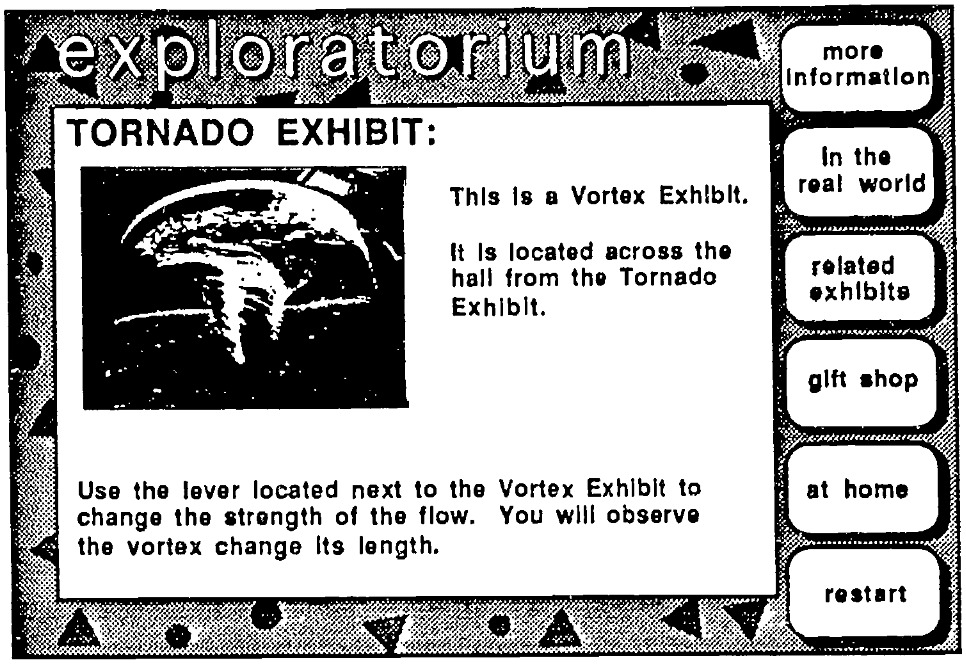
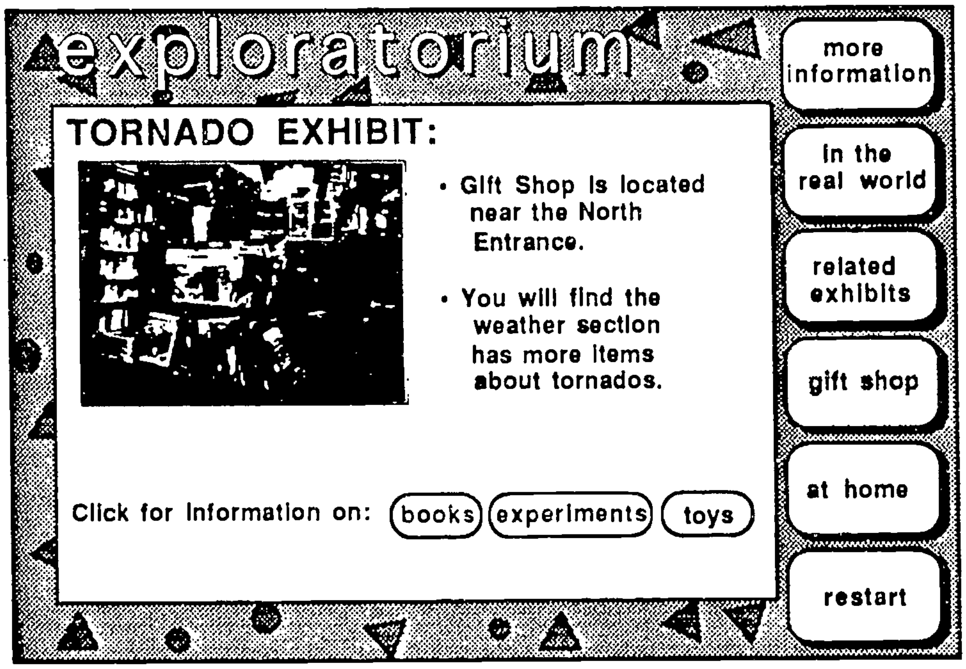


While the above screen shows only one related exhibit, the Vortex Exhibit, other exhibits that thematically relate to the Tornado Exhibit could be incorporated into the Kiosk. Below is an example of multiple screens for a single option.



The screen above shows a "gift shop" option of the Tornado Exhibit Station. The gift show offers several items that relate to the Tornado Exhibit: books, experiments, and toys. By touching those items on the screen the information about them would become available to the Kiosk user.

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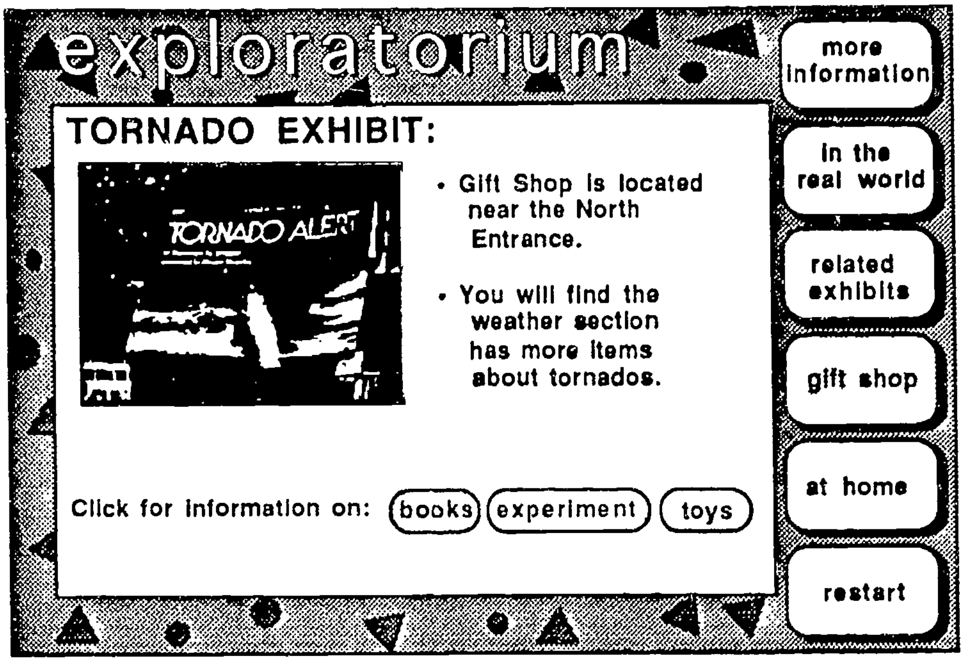
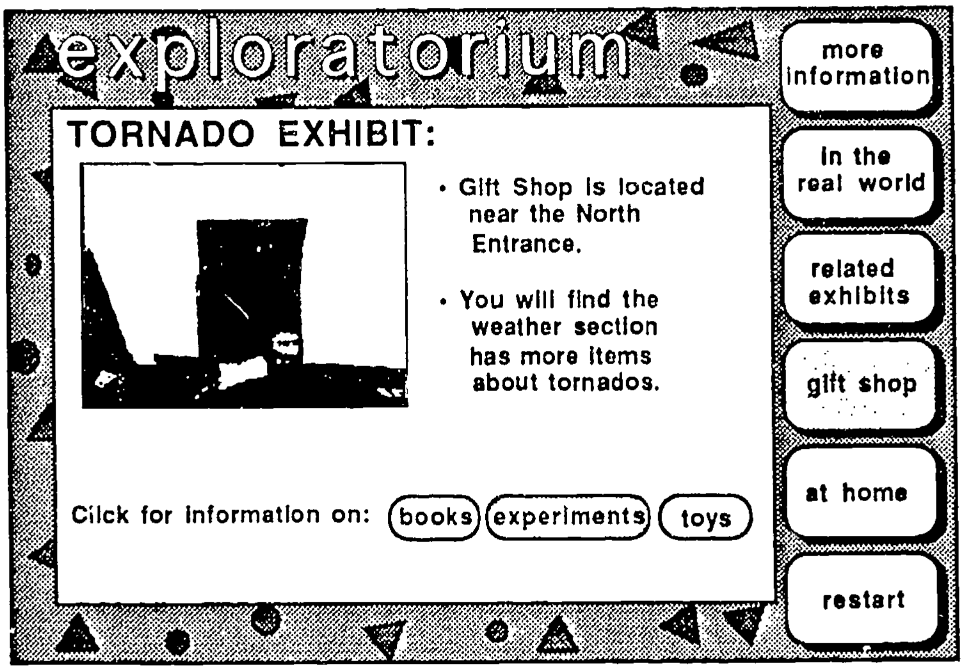


The screen shown above shows the "book-gift shop" option of the Tornado Exhibit Station. The textual information need not stay the same. Multiple books could be listed through a scroll bar text window . Upon the selection of a particular book, that book's summary and perhaps sample illustrations could be shown. The book's summary could include such items as the abstract, the price, the reading level, and the recommendations of the Exploratorium's staff. The "experiments-gift shop" and the "toys-gift shop" options would work the same as the "book-gift shop" option.



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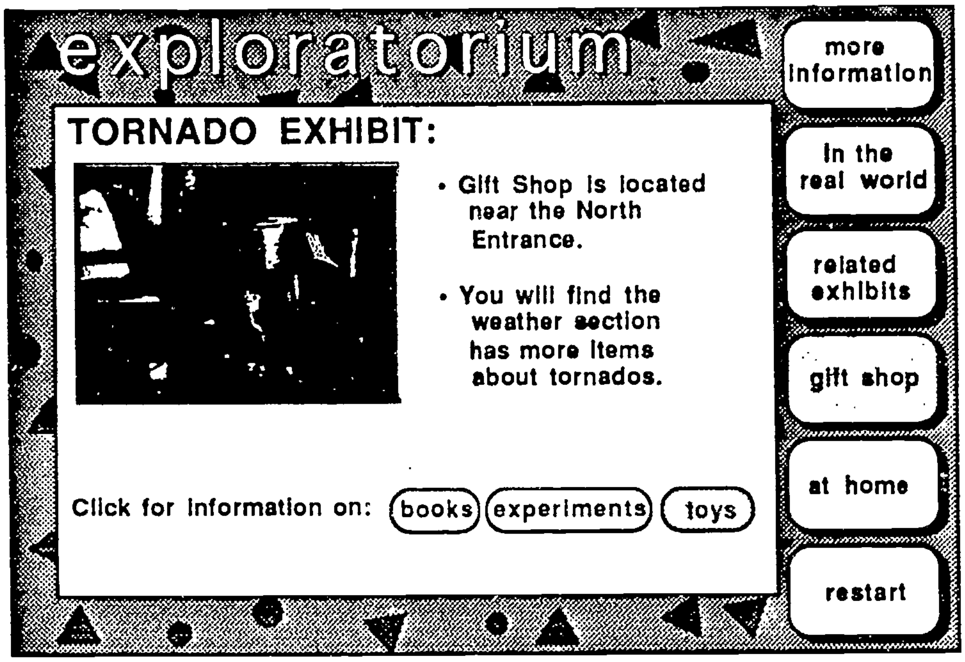

The last sample option of the Exploratorium Kiosk Tornado Exhibit Station is the "at home" option. This option would give the visitor further suggestions of what could be done outside the Exploratorium. It could include experiments that children could do at home and possible topics of discussion in the classroom. This screen also shows a way to interconnect several options. The "gift shop" option could be accessed through the button on the bottom of the "at home" screen or through the buttons on the side.