Phase 2 Summative Evaluation of

ACTIVE PROLONGED ENGAGEMENT at the Exploratorium

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Note: This report replaces all previously dated versions.

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EXECUTIVE SUMMARY

Going APE! is a National Science Foundation-funded research/development project to investigate how to develop Exploratorium exhibits that elicit active prolonged engagement (APE) among casual museum visitors. As part of this research/development process, Selinda Research Associates, Inc. (SRA) conducted a summative evaluation to assess how and to what extent the exhibit units developed by the Exploratorium team were in fact APE exhibits. This report is the second of two distinct phases of the summative evaluation study. The first phase of the summative evaluation compared visitor engagement at three APE and three non-APE exhibits to more fully understand visitor active prolonged engagement.

The purpose of the second phase summative evaluation was to examine visitor engagement at nine of the APE exhibits (the three from the first phase in addition to six additional ones) to determine the extent to which and ways in which the Exploratorium achieved its goal of developing exhibits that facilitated active prolonged engagement. Phase 2 began in December 2003 with depth interviews and unobtrusive observations and will be concluded in February 2005 with a final tracking-and-timing study. This report will include a final addendum at a later date to include the results of the final tracking-and-timing study.

The overarching methodology used to design this study was naturalistic inquiry. A model of exhibit engagement (Perry, 1993) focusing on physical, intellectual, social, and emotional engagements was used as a conceptual framework for data collection and analysis. Data collection methods included unobtrusive observations of 86 visitors, 31 face-to-face interviews with related groups of casual museum visitors, and three telephone interviews with exhibit developers from the *Going APE!* team. Respondents were selected using purposive sampling methods. Data were analyzed through inductive constant comparison including debriefs of 34 casual visitor data sets, three exhibit developer interviews, group debriefs, and the development of case studies for the six new APE exhibits selected for this phase. Following is a brief summary of some of the important findings. Visitor engagements at each of the six exhibits are discussed individually, followed by general discussions about the ways in which and extent to which the APE exhibits did and did not facilitate active prolonged engagement. Readers are reminded that this executive summary highlights just a few of the primary findings, and are encouraged to read the remainder of the report to understand the results more completely.

Phase 2 Exhibit Case Study Findings

3-D Shapes. In general, we found *3-D Shapes* to have a relatively high overall capacity for emotional engagement by evoking previous experiences and personal connections. Physical and intellectual engagements, however, were somewhat lower than in other exhibits we observed. While we saw some joint social engagements between a parent and child, the higher-level APE engagements occurred among adults who used exhibit elements alone or with another adult.

Floating Objects. In general, physical engagements were somewhat briefer at this exhibit compared to some others in the study. This appeared to be due to the single-station design and vulnerability of the experience to interference by other visitors. Yet we also found some high levels of social engagement focusing on the exhibit phenomena. Visitors described the

phenomenon as surprising and intriguing, and this appeared to cue exploration activities among adults and children alike. While questions tended to be implicit and unarticulated, intellectual engagement often involved identification of variables, prediction in the form of humorous bets among visitors, and experiments to test implicit hypotheses.

Gravity Powered Calculator. While most of the engagements we observed involved connections to the concept of square root and use of the exhibit elements to calculate square root, several adults made connections to the underlying principles of physics, and two used it the exhibit in a surprisingly exploratory manner. Physically, the exhibit allowed the joint social engagement of adults and children, but the content of the exhibit appeared to cue adults to direct the children's engagement.

Heat Camera. *Heat Camera* appeared to have the highest overall capacity to elicit and stimulate APE engagements. We found that the intriguing phenomena provided intellectual entry points to a wide range of visitors and leveled the social playing field. Overall, the time of engagement was the longest among Phase 2 exhibits, and the range of activities was the highest. While the activity was vulnerable to crowded conditions, visitors did not interfere with each other's activities. Emotional engagement was closely tied to visitors' focus on their own bodies and the intriguing and manipulatable nature of the phenomenon.

Pulley Table. Here we found that the nature of the phenomenon appeared to elicit connections to previous experiences and expertise, making some visitors less willing to begin engagement, and cuing adults to guide their children's exploration. Among the cases we observed, we found some adult visitors choosing not to engage because the phenomenon was too familiar. Children choosing exhibits for their visiting group seemed to decide quickly not to use the exhibit. Observations at this exhibit may have been affected by its placement in a primary traffic path.

Visible Vibrations. The capacity for APE engagement at this exhibit appeared to be influenced by the physical interface and time required to see changes in the phenomenon. While time of engagement was relatively long, this appeared to be connected to the challenge and frustration in trying to "get the exhibit to work."

Extent of APE Engagement

Each of the nine exhibits in the study stimulated and facilitated what we categorized as medium and higher levels of APE engagement. Finding cases to observe of high levels of APE engagement was challenging for some exhibits (*Gravity Powered Calculator*, *Pulley Table*, and *Visible Vibrations*). In addition, only two of the nine cases of high APE engagement that we observed involved multigenerational groups, that is, adults with children. Adult groups and visitors using exhibits alone appeared more likely to move into APE physical and intellectual types of engagement than did groups with adults and children. But each of the exhibits that we studied stimulated and facilitated some higher levels of APE engagement among some visitors. We found high-level APE engagement among multigenerational groups at two exhibits, *Heat Camera* and *Gravity Powered Calculator* (Case 14 and 26).

Ways in which APE Engagements Were Stimulated and Facilitated

We identified several ways in which exhibits appeared to stimulate and facilitate APE engagement. None of these "ways," however, provides a simple solution to the challenging work of exhibit design. The strategies worked in concert with each other; some worked better for visitors and/or worked better with the specific phenomenon than others did. At exhibits with what we termed "high capacity for APE engagement," many of the following factors were involved:

1. Providing exhibit phenomena open to exploration.
2. Involving visitors in the process of scientific inquiry.
3. Evoking immediate physical engagement by visitors of all ages.
4. Providing labels with hints to launch exploration.
5. Providing access to engagement at multiple levels of previous knowledge, allowing both adults and children ownership of their own intellectual experience.
6. Rewarding novel ideas and behavior.
7. Enabling participation free from physical inference from other visitors.
8. Allowing members of a group to use the exhibit together.
9. Preventing interference with engagement by providing multiple stations.
10. Providing tasks requiring optimal time range for APE engagement in the context of a museum visit.
11. Providing resources for extended engagement.

INTRODUCTION

Going APE! is a National Science Foundation-funded research/development project to investigate how to develop Exploratorium exhibits that elicit active prolonged engagement (APE) among casual museum visitors. The project has two major aspects: to conduct systematic and disciplined research into the construct of active prolonged engagement in museum settings and to develop 30 permanent APE exhibit units. As part of this research/development process, Selinda Research Associates, Inc. (SRA) is conducting a summative evaluation to assess how and to what extent the exhibit units developed by the Exploratorium team are in fact APE exhibits. This report is the second of two distinct phases of the summative evaluation study. The first phase, which began in May 2003 and concluded in December 2003, focused on these overarching research questions: How do visitors engage differently at a good APE exhibit compared with a good non-APE exhibit? Secondarily, what are the design characteristics that seem to lead to these differences?

Findings from the first phase (Tisdal & Perry, 2004) were used to inform (a) the second phase of the study, and (b) the design of APE exhibits still under development.

The overarching research question for Phase 2 was:

> *In what ways and to what extent did the nine selected exhibits stimulate and facilitate APE engagements among visitors?*

Phase 2 began in December 2003 with depth interviews and unobtrusive observations. It will be concluded in February 2005 with a final tracking-and-timing study. Because the majority of data was collected and analyzed by June 2004, the body of this report will not include the tracking-and-timing mini-study. Those findings will be reported in an addendum written in early 2005. All findings from the second phase of the summative evaluation will be incorporated into the final publication being developed for this project by the Exploratorium.

Place of Study in the Field

The APE project is part of continuing explorations into ways to design exhibits that combine "access to phenomena with opportunities for deeper cognitive experience" (Exploratorium/*Going APE!*, p. 5). Like the *Investigate!* project at the Museum of Science in Boston and *Experiment Benches* at the Science Museum of Minnesota, the goal is to shift visitor engagement from the outcomes of the experiences to the experiences themselves (Ansbacher, 1998, 1999). Since the 1970s, science museums have become expert in providing hands-on access to phenomena that can, through strong initial engagement created by carefully crafted labels, produce simple understandings of scientific phenomena. But providing opportunities for deeper engagement with the phenomena, thereby enabling visitors to guide and construct their own knowledge, has been more difficult. The APE project addresses this challenge.

Theoretical Underpinnings

Assumptions Underlying the Project

The assumptions underlying the design of APE exhibits are based on constructivist learning theory.

> *Constructivism, as developed by Piaget and his colleagues . . . emphasizes the need for cognitive-conflict to drive learning (Gallagher & Reid, 1983; Hewson & A'Beckett Hewson, 1984). Such conflict lies in the surprise and paradox in many Exploratorium exhibits. Designing APE exhibits means providing visitors with tools to explore the conflict through experimentation, play, observation, and contemplation.* (*Going APE!* Exhibit Development Team, 2000, p. 6)

A central assumption of this project is that both APE and non-APE exhibits can provide good visitor experiences; these experiences, however, are different in nature. Good non-APE exhibits may be planned-discovery experiences that "support visitors' expectations that exhibits will tell them what to do and how to interpret their experience. APE exhibits will not meet these expectations. (*Going APE!* Exhibit Development Team, 2000, p. 8). The goal of APE exhibits is to provide visitors with opportunities to engage in their own scientific investigations, to question, wonder, and hypothesize.

Types of Engagement

An important aspect in the design of both phases of this study was the desire to view visitor engagement from four specific perspectives: physical, intellectual, social, and emotional (Perry, 1993; *Going APE!* Exhibit Development Team, 2002a). By constantly moving among these perspectives, inquirers could more deeply understand the nature of the engagement. The framework also provided a flexible construction that allowed emerging issues and themes to be connected holistically to initial questions and assumptions.

Physical engagement is defined as the different ways in which visitors physically interact with an exhibit. Physical engagement includes the amount of time they spend, the labels they read, where they sit or stand, and what buttons they push. It also includes the sequence of activities in which they participate. By analyzing physical engagement, we can understand whether an interaction was primarily guided by the exhibit design or if visitors engaged in self-directed exploration.

Intellectual engagement is defined as the various ways in which visitors engaged with their minds. Intellectual engagement is often referred to as "minds-on" to contrast it with hands-on. It includes the connections visitors make to existing knowledge during their interaction, the conceptual understandings, and the questions they have. An area of intellectual engagement that emerged during Phase 1 of this study was visitors' level of awareness of the type of learning experiences they encountered at both APE and non-APE exhibits and whether this affected their decision to use the exhibit, particularly with younger children.

Social engagement is defined as the many ways in which visitors influence other visitors' experiences at exhibits. It includes conversations that might guide what an individual does or

understands during the interaction. Social engagement also includes directions, observation, guidance, assistance, cooperation, and competition among visitors using an exhibit at the same time, as well as deliberate teaching/learning behaviors, such as a parent asking a child a question to get the youngster engaged in the exhibit, or one person explaining something to another visitor. Another factor is the impact of other members of a social group on the respondent, whether they are present or in another part of the museum at the time of the engagement.

Emotional engagement involves both the nature and intensity of the affect exhibited by visitors during the engagement and immediately after. The nature of the emotional engagement may be positive (fun, awe, pleasure, enjoyment, caring) or negative (embarrassment, confusion, disdain, humiliation). Affect seems to indicate preference, that is, it tells us which things individuals value more than others (Izard, Kagan, & Zjonic, 1984). The intensity of the emotion tells us about the level of this preference. During an interaction at an exhibit, the subject of this emotion might be an element of the exhibit itself, other visitors, or the environment of the interaction, e.g., temperature, level of crowding, noise level.

Findings from Phase 1

Findings from Phase 1 of the evaluation were helpful in focusing the design and protocol for Phase 2. By comparing visitor engagement at APE and non-APE exhibits, we were able to more clearly identify features of APE engagement among visitors and improve our methods for studying different forms of APE engagement. In Phase 1, we found differences (and a few similarities) in engagement patterns between APE and non-APE exhibits related to the four types of engagement. We also found differences about how visitors chose to begin and end engagement at these types of exhibits. Following is a bulleted list outlining some of the major findings from Phase 1. It does not represent all the findings but specifically those of interest to this second phase of the study.

Physical

- Tracking and timing data indicated that the average holding time (length of engagement) at APE exhibits was generally longer than at non-APE exhibits. We found that the average time spent at APE exhibits was 132 seconds compared with 51 seconds at non-APE exhibits. These findings were significant at the $p<.001$ level.
- APE exhibits prompted extended engagements more frequently than non-APE exhibits.
- Although APE exhibits were more effective at prompting more extended engagements, this occurred only in a few cases.
- Most engagements at non-APE exhibits followed the consistent guided-discovery sequence of "do, observe, and read" as described in the original proposal for this project, but at APE exhibits, visitor engagements varied in both pattern and sequence.
- Shorter physical engagements at APE exhibits were associated with (a) younger children, (b) social interruptions, and (c) unsuccessful initial attempts to interact with the exhibit.

Intellectual

- The intellectual engagement at non-APE exhibits focused on (a) knowledge about surprising phenomena and (b) making connections to prior knowledge about similar phenomena. The nature of intellectual engagement at APE exhibits varied by exhibit.

Emotional

- At each of the exhibits under study, there was evidence that an initial driving question, closely tied to the issue of motivation and satisfaction (e.g., Can I do this?), prompted continued intellectual and physical engagement. These driving questions tended to be different for APE and non-APE exhibits.

Social

- Child-focused social engagement was observed at both non-APE and APE exhibits. In both instances, adult visitors assisted children with (a) engaging with physical elements, (b) reading labels, (c) explaining things, (d) making decisions about whether to engage, and (e) deciding when to end engagement.
- At non-APE exhibits, social engagement was generally consistent and involved (a) pairs of visitors taking turns to use the exhibit together, or (b) individuals using the exhibit alone. Few large intact visiting groups were observed at non-APE exhibits. Nonparticipating members of these fragmented groups often encouraged engaged group members to finish interactions and move on.
- At some of the APE exhibits, multiple large intact social groups used the exhibits at the same time. This appeared to reduce social interruptions among members of the same visiting group.
- At APE exhibits, social engagement was more diverse overall and varied by specific exhibit.

Reasons for Engagement

- Choices about decisions not to engage were more clearly articulated by visitors at APE exhibits. This indicated that visitors recognized differences between APE and non-APE exhibits.
- Some visitors chose not to engage at APE exhibits because they judged them to be inappropriate for the younger children in their group.

Reasons for Ending Engagement

- At both APE and non-APE exhibits, the end of engagement was sometimes associated with social interruptions. Some social interruptions involved members of the same group prompting others to end engagement and move on. Other social interruptions involved members of other groups waiting to use the exhibit.
- At APE exhibits, social interruptions sometimes stopped an engagement before the individual was finished using the exhibit.
- Other reasons for ending engagement at APE exhibits included (a) unsuccessful outcomes, and (b) younger children using the exhibit in an age-appropriate way that conflicted with exhibit use by older visitors.

Limitations

This summative evaluation had several limitations. We made choices within these limits to maximize the quality of the data collected and the usefulness of the findings.

Both phases of this study focused on casual museum visitors. Respondents did not include school groups or other organized groups visiting the Exploratorium. This decision gave us a pool of

observations with enough detail and scope to reach stronger conclusions about APE engagement among casual museum visitors.

In addition, the majority of the study (depth interviews and unobtrusive observations) was conducted with only nine of the 30 total APE exhibits in the project. Efforts were made to select exhibits that maximized our understanding of APE engagement and its forms associated with exhibits of a wide range of conceptual and physical design. In addition, protocols and methods were designed to be similar enough to allow the Phase 1 APE exhibits to be included in the data analysis for Phase 2 of the study, thus increasing our pool of data for final analysis. After the *Going APE!* research/development project is completed and all 30 exhibits are on the floor, we will conduct a final tracking-and-timing study that includes data from all APE exhibits. The results from this mini-study will be included in an addendum to this report.

The majority of data was collected on weekends. To maximize the usefulness of the data, data collectors noted contextual factors such as levels of crowding and visitor mix during observations. Weekends at the Exploratorium tend to be more crowded than weekdays. We made sure that several data sets included observations early in the day during relatively uncrowded conditions. This allowed us to compare engagements that occurred under crowded and uncrowded conditions.

Finally, during both phases of the study, exhibits were placed fairly close to the Exploratorium entrance, including several in a special sound-abatement area designed to reduce extraneous noise from the museum. This decision allowed us to collect unobtrusive observations/depth-interview data and tracking-and-timing data in similar locations. Under this arrangement, however, exhibits in this study were among the first encountered by visitors on their visit to the Exploratorium. This may have limited some APE engagements, especially among first-time or infrequent visitors. We collected data about visit frequency and included it in the analysis to understand the impact of this limitation.

METHODS AND METHODOLOGIES

Methodology

Naturalistic Inquiry

This summative evaluation study used naturalistic methodology to frame the research. The goal of naturalistic inquiry is to provide a holistic understanding of the research question by collecting and analyzing data from a variety of perspectives and sources. Phenomena are studied in the natural context in which they occur. Rather than looking for an "average" experience, naturalistic inquiry aims to describe a range of visitor experiences and understandings with exhibits. This approach to understanding how visitors engage at APE exhibits is especially appropriate because museum visitors come to the experience with a variety of previous experiences, agendas, attitudes, expectations, and knowledge. They also visit in a variety of social configurations and influence each other's experiences through social interactions, social roles, and differing agendas.

Another characteristic of naturalistic inquiry is that the overall design of the study emerges in response to themes and patterns in the data. This study began with the collaborative development of a topical framework (Appendix A) to guide the research. As additional questions and themes emerged, they were explored during an iterative process of data collection and analysis.

Methods

An important characteristic of naturalist inquiry is the variety of data collected from a variety of sources. Although often focusing on qualitative methods, naturalistic inquiry is primarily concerned with understanding the phenomena under investigation as completely as possible. In this study, this required the use of both qualitative (i.e. observation and interview) and quantitative (i.e. tracking-and-timing) data collection strategies. Observation and interview methods will be described in detail below. Track-and-timing strategies will be described in detail in an addendum to this report scheduled for February 2005.

In naturalistic inquiry, data collection and analysis are iterative processes. For this study, we analyzed data using a modified inductive constant comparison approach (Lincoln & Guba, 1985), whereby each set of data is compared with previous data sets to direct the focus of subsequent data collection. Data analysis methods are described in more detail below.

Design of the Study

This study was a summative evaluation of a research/development project. As with most summative evaluations, the primary purpose was to investigate how and to what extent the project achieved its original goals, that is, developing and producing exhibits that elicited active prolonged engagement among visitors. Deborah Perry designed the study collaboratively with the client, and Deborah Perry and Carey Tisdal designed the protocols.

As described above, the evaluation was divided into two phases. The first phase (Tisdal & Perry, 2004) focused on identifying and defining the differences in visitor experiences between selected

APE and non-APE exhibits. The second phase, reported in this document, focused on the ultimate effectiveness of the APE exhibits at achieving active prolonged engagements as collaboratively defined by the exhibit development team.

Selection of Exhibits

Three APE and three non-APE exhibits were selected for the first-phase study. The specific exhibits were chosen by consensus of the Exploratorium team members as best examples of good non-APE and APE exhibits. The APE exhibits chosen were *Circuit Workbench*, *Downhill Race*, and *Watch Water Freeze*. *(Going APE!* Exhibit Development Team, 2003a*)*. The non-APE exhibits selected were *Bubble Suspension*, *Touch the Spring*, and *Water Standing on Air*. Descriptions of Phase 1 exhibits are included in Appendix B.

For the second phase of the study, the *Going APE!* exhibit development team chose APE exhibits based on two primary criteria. First, the exhibits were selected to represent the team-identified types of APE behavior: observation, construction, exploration, and investigation. This focus on scientific process skills is further discussed in the Findings and Discussion section. Second, the team selected complete or nearly complete exhibits, with no major changes expected after the timeframe of data collection. This ruled out several APE exhibits in progress. Descriptions of Phase 2 exhibits are included in Appendix B.

Table 1: Exhibits by Type in both Phases of the Evaluation Study

Exhibit Type	Exhibit Name	Phase of Evaluation
Construction	*Circuit Workbench*	1
	Pulley Table	2
	3-D Shapes	2
Exploration / Investigation	*Downhill Race*	1
	Floating Objects	2
	Gravity Powered Calculator	2
	Heat Camera	2
	Visible Vibrations	2
Observation	*Watch Water Freeze*	1

In both phases of the summative evaluation, exhibits were placed near the entrance to the Exploratorium, making them among the first that people saw as they began their visit. APE exhibits were interspersed with other exhibits to allow visitors to assess and select engagements as part of their normal visit agenda and to allow for unobtrusive observation. During the last two days of data collection, walls were placed around *3-D Shapes*, which may have changed some of the observed approaches to and engagements with the exhibit. This was, however, not cited as a factor in data collector debriefs.

Selection of Respondents

The focus of this study was on the experience of the casual museum visitor. School groups were not included. All respondents were purposively selected (Miles & Huberman, 1984). In purposive sampling, the goal is to select respondents based on specific characteristics that will provide additional evidence to answer the questions of the study. These characteristics may be demographic, such age, gender, and social group. In this study, however, it was also important to compare and contrast different types of visitor engagement at various APE exhibits.

As the study progressed, some respondents were selected because they exhibited very low or particularly high levels of APE engagement.

In addition to observing and talking directly with museum visitors, we also interviewed three exhibit developers who were also purposively selected.

Casual Museum Visitors

Eighty-six casual museum visitors were observed/interviewed in 34 data sets. A data set was defined as a unique data collection session involving an individual or group engagement at an exhibit. At least one member of a group using an exhibit was interviewed in 31 of the 34 cases. Members of the three other groups refused our requests for interviews citing a lack of time and the need to focus attention on children in their groups. We found that adults were more willing to be interviewed than children, often agreeing to talk to data collectors while children used another exhibit. All visitor respondent data was collected on the floor of the museum.

Since social interaction was one focus of the study, case data was mixed. That is, some observation/interviews focused on individuals whether alone or in a group, and some focused on engagement of the entire group at the exhibit. Data collectors described in their debriefings the makeup of the social group and why a group or an individual was selected for observation. See Appendix D for descriptions of observation/interview respondent social groups.

Data collected about engagements at APE exhibits in Phase 1 of the study were also available for analysis. This data was collected using similar methods and protocols and expanded our base of APE exhibit data for inductive constant comparison.

Exhibit Developers

In naturalistic inquiry, multiple perspectives are an important part of understanding phenomena. To provide additional perspectives about the effectiveness of the exhibits at facilitating APE engagements we interviewed three exhibit developers. These individuals were selected based on their diverse perspectives about the design strategies used to stimulate and facilitate APE engagements among visitors, and because they had been core participants in the development of APE exhibit characteristics. They were interviewed on May 24 and 26, 2004, by telephone.

Data Collection Methods

Data Collectors

Observations of and face-to-face depth interviews with casual museum visitors were conducted on site at the Exploratorium from February 21 to March 13, 2004, by Carey Tisdal of SRA and five on-call data collectors from the Exploratorium. The range of perspectives provided by

multiple data collectors, both in the collecting and debriefing processes, is an important element of naturalistic inquiry. Numbers of data sets gathered by individual data collectors are presented in the Data Source Table in Appendix E. Carey Tisdal conducted training in naturalistic methodology and the use of specific protocols for this study on Friday, February 20, 2004. She and Mary Kidwell, Adam Klinger, Darissa Phipps, and Jackie Wong collected data. Jackie Wong supervised data collection and led three of the four group debriefing sessions. Carey Tisdal also conducted the telephone depth-interviews with *Going APE!* exhibit developers.

Unobtrusive Observations

Unobtrusive observation is a technique that allows visitors' behaviors and conversations to be documented with as little interference as possible from the evaluator (Lincoln & Guba, 1985). In some instances data collectors are hidden from the respondents behind a two-way mirror, or they use a video camera. For logistical reasons and because it was important to overhear as much of the conversations as possible, in this study data collectors chose places on the exhibit floor where they would not be noticed by visitors. Signs were placed in the area to inform visitors that observations were taking place so they could avoid the area if they did not wish to participate.

Depth Interviews

Unlike highly structured interviews that restrict visitor response, depth interviews are more like a conversation about the experience between the data collector and the respondent (Lincoln & Guba, 1985). This allows respondents to share their own perspectives about the nature and the meaning of the interaction. In this study, each depth interview was guided by a protocol containing several common questions. These questions served to initiate the conversation with visitors and ensured that some common themes were always explored. When appropriate, data collectors also followed up on points of interest in the conversation and added questions that emerged from previous data sets as well as the preceding observation. With the permission of the respondents, data collectors tape-recorded the interviews. Most tape-recorded interviews were later transcribed to facilitate data analysis.

Face-to-face depth interviews enabled researchers to explore in more detail observed visitor engagement and particularly to capture the visitors' background information and perceptions of their own experience. After each observation, respondent groups were approached and asked to participate in an interview. Of the total 34 visiting groups observed, 31 agreed to be interviewed. The protocol for face-to-face interviews with casual museum visitors is included in Appendix F.

Telephone depth interviews with three exhibit developers allowed us to better understand the conceptual frameworks, exhibit design features, and developers' assumptions about visitor experiences. The protocol for these interviews is included in Appendix G.

Tracking-and-Timing

During the first phase of the summative evaluation limited tracking-and-timing data on the three APE and three non-APE exhibits was collected, analyzed, and reported. In December of 2004, after all of the APE exhibits are completed and on the floor, the Exploratorium staff will collect additional time-at-exhibit data using standard tracking-and-timing procedures (Serrell, 1998). Analysis of all tracking-and-timing data will be completed by SRA using standard statistical analyses and presented as an addendum to this report.

Data Analysis Methods

As described above, data collection and analysis were iterative processes whereby each set of data was compared with previous data sets to direct the focus of subsequent data collection (Lincoln & Guba, 1985).

At the conclusion of each observation/interview with casual museum visitors, data collectors wrote detailed data summaries, or debriefs. The debriefing process for this phase of the study asked data collectors to assess the level of APE engagement for each of the four types of engagement and then the overall level of APE engagement for that particular data set. The purpose of this assessment was twofold: (a) to encourage the collection and identification of very specific evidence about each of the four types of engagement, and (b) to provide for multiple perspectives about the nature and extent of APE engagement. To maximize inter-rater reliability and consistent interpretation of these scales, data collectors were asked to do joint observations and interviews with another data collector for the first data set of each day. The individual debriefing protocol is included in Appendix F.

Groups of data collectors met at the end of each day for further analysis and reflection. Debriefs for individual data sets and group debriefs were included in the final data analysis. At this step, written debriefs and transcripts of interviews were coded to identify evidence relevant to answering the questions in the topical framework. We also explored themes and issues that emerged during data collection. The initial protocols for these observations, interviews, and debriefs are presented in Appendix F. In accordance with the standards for naturalistic methodology, these protocols were adapted to enable the data collector to follow interesting leads and to ensure adequate probing.

Debriefs were also written following telephone interviews with exhibit developers. These debriefs, along with interview transcriptions, were used to expand concepts and findings from visitor data sets to answer the questions of the study.

When data collection was complete, we developed case studies for each of the six exhibits in Phase 2. In Phase 1, we found that visitor engagement at specific APE exhibits showed different patterns of physical, intellectual, social, and emotional engagement. The development of exhibit-based case studies allowed us to identify the extent and nature of different types of visitor APE engagement among the range of exhibits. Case studies from Phase 1 exhibits were compared and contrasted with patterns in Phase 2, expanding our understanding of APE engagement in general.

FINDINGS AND DISCUSSION

Focus on Scientific Process Skills

One area that became clearer in this phase of the study was the intent of the exhibit development team to cue visitor engagement focused on scientific process skills. For this phase of the study, the *Going APE!* exhibit development team chose APE exhibits based on four team-identified types of APE behavior: observation, construction, exploration, and investigation. We learned in interviews with exhibit developers that these categories emerged during the development of exhibits as the various approaches to the concept of APE were created. In general, the type defined the nature of intended visitor activities.

> *The main thing is that we're looking for certain kinds of behavior, so we're not so content driven . . . We know that some things are kind of conducive to games and challenges and races, things that get people engaged. (Case 35, exhibit developer)*

The typology also reflected another important attribute of APE engagements, "a focus on scientific process skills" (*Going APE!* Exhibit Development Team, 2003a). While the construction category was more closely related to the application (in contrast to development or discovery) of scientific knowledge, these categories themselves are an indication of exhibit intent. This clarification of exhibit intent was important in our classification of exhibits at various levels of APE engagement. It led us to classify visitor engagements that involved transmission of existing scientific knowledge as lower levels of APE engagement than those characterized as exploration or discovery activities.

Overview of Exhibit Findings

Each of the nine exhibits in the study stimulated and facilitated what we judged as medium and higher levels of APE engagement for some visitors. Finding cases to observe of high levels of APE engagement, however, was challenging for some exhibits (*Gravity Powered Calculator*, *Pulley Table*, and *Visible Vibrations*). In addition, only two of the nine cases of high APE engagement we observed involved multigenerational groups, that is, adults with children. Adult groups and visitors using exhibits alone appeared more likely to move into APE physical and intellectual types of engagement than did groups with adults and children. But each of the exhibits we studied stimulated and facilitated some higher levels of APE engagement among some visitors. We observed high-level APE engagement among multigenerational groups at two exhibits, *Heat Camera* and *Gravity Powered Calculator* (Cases 14 and 26).

We also saw interesting relationships among the four types of engagement that helped us better understand APE overall. In individual and group debriefings, data collectors discussed these relationships. Several of the characteristics of APE engagement that we were looking for were focused on social activities (Appendix C):

- *Visitors will ask each other a range of interesting questions.*
- *Visitor conversation will indicate play, observation, investigation, and contemplation.*
- *Visitor conversation will include discussions of multiple viewpoints, constructions, and understandings.*

- *There will be a range of types of social interaction including silence, teaching-learning, and showcasing.*
- *Visitors will challenge each other to engage with the exhibit in unique and interesting ways.*

But as we discussed cases, we all found ourselves reluctant to characterize engagements with high levels of physical, intellectual, and emotional engagement as anything but high APE experiences, even when social engagement was low. In two cases, each involving a female using an exhibit alone (Cases 31 and 33), both the range and level of physical engagement and the questions each posed trying to explore indicated that these were clearly APE engagements. We refined our understanding of APE engagement to include these solitary experiences.

We want to stress that we also found cases where social engagement appeared to support and extend APE engagement. These included dating couples who engaged in friendly competition (e.g., Case 23 at *3-D Shapes* and Case 32 at *Floating Objects*) and adults and children who asked each other interesting questions and called each other's attention to aspects of exhibits. We also saw adults supporting each other's exploration (Case 28 at *Heat Camera*) and adults who helped children formulate questions to explore (Case 18 at *Pulley Table*). We concluded that while social engagement supported higher level APE engagement in some cases we observed, it was not a necessary element.

One essential element we identified was the extent to which the visitor (or visitors in the case of groups) was using the exhibit to explore the phenomenon to reach new understandings and conclusions. That is, were the visitors in the case involved in active questioning and acquisition of new understandings based on their own observations and evidence? This characteristic of an engagement seemed essential given the central questions posed in the proposal: "How do we build exhibits that are tools for exploration rather than authoritative demonstrations? What design features enhance visitors' own questioning?" (*Going APE!* Exhibit Development Team, 2002, p. 4)

In some instances, we interviewed adults who perceived the exhibit experience to be an "authoritative demonstration" of some specific scientific content that they themselves knew and that they wanted their children to learn. One father described how he used *Pulley Table* to explain and demonstrate to his son:

> *Well, mostly I was explaining to my son what it was doing. Showing him that – for instance, there was one pulley that powered and the difference in putting the string on the smaller wheel as compared to the larger wheel, what it does to the other wheels . . . . Another boy walked up as well, and so I showed them the faster you turn it, the faster it plays, depending on the size of the pulley you use will also determine the power. (Case 24, male, early 40s)*

In this case, the father appeared to take the role of a teacher in what is sometimes called direct instruction. Direct instruction involves a teacher or expert stating and demonstrating principle or concept. In contrast, exploration involves asking a question and looking for the answer based on evidence. In a teacher-led exploration, the person in the teaching role can help the learner ask a

good question, but there is a difference between telling the information and asking someone to evaluate information and draw a conclusion. We found several cases where adults moved into the role of a direct instructor (e.g., Cases 8, 12, 24).

When adults perceived that the exhibit content was too advanced for the children, they appeared to move into a teaching-managing role (Cases 8, 12, 20). A father who used *Gravity Powered Calculator* with his two children explains how he managed the engagement.

> *And with the kids it really was just trying to get them to focus on the purpose of the exhibit, which was beyond my 8-year old son and my daughter over there. And getting them to get the B-B or whatever you want to call it – the ball bearing on a number where we could get a whole number result. So we hit the bar because when it just went down and landed, when you get down there and try to look down – it landed on 4.3 or whatever – that was too much for both of them, actually. To have to roll down, hit the bar, go up (inaudible). I even had my daughter – I asked her – I said, "Okay, the square root of 25 – square root is what number times what number equals 25." "Five." "Okay, so hit the five." Positive, good feedback – it worked. (Case 8, male, late 40s)*

As we will describe in the case studies, when adults were managing children's experiences, we saw highly social engagements. The children appeared to learn some new information or skill, and in some cases the children's own exploration was supported. Most of these engagements, however, did not involve any individual exploration or new conclusions by the adult involved. We want to stress that parts of these engagements were very good experiences, valued by both parents and children, and several were fairly label-independent. But aspects of the engagements, as we will describe, involved parents limiting children's use of exhibits to what they perceived as the "right way," in some cases precluding uses of the exhibit that were productive for other visitors in exploring phenomenon.

Yet we also observed cases at two exhibits, *Heat Camera* and *Floating Objects*, where the intriguing phenomenon appeared to cause doubt in the adults' minds about what was going on and launched them into their own process of exploration. The children in these cases moved into direct engagement with the exhibit without adult guidance or direction, and the adults and children explored together as co-learners, each having ownership of his or her intellectual experience and reaching some new conclusions about the phenomenon. From these observations, we judged the experiences to be higher levels of intellectual engagement because (1) both adults and children had intellectual ownership of their own experiences and (2) there was evidence of learning by both the adults and children.

We refer to this co-learning characteristic as the exhibit's ability to "level the social playing field." Exhibits such as *Heat Camera* and *Floating Objects* appeared to facilitate engagements where everyone in a group, despite existing levels knowledge, appeared to explore the phenomenon actively and, in the end, understand the phenomenon more deeply. At other exhibits, the level of content appeared to tip the social playing field, putting adults in charge of experience. In these engagements, the adults became the authority, much like label-directed experiences in which the museum becomes the authoritative source of science.

Interesting relationships also arose between physical and intellectual engagement. As we suspected from Phase 1 of the study, many of the lower-level APE engagements that we observed involved assessments of the exhibits and decisions not engage further (Cases 21, 25, 11, 13, 22, 29, and 27). These engagements were relatively short and involved few physical activities. Visitors gave a wide variety of reasons for deciding, after a brief assessment, not to commit to further engagement. Medium and high levels of APE engagement were more difficult to judge based on time alone. For example, we found a high APE engagement in Case 32 in only 3.2 minutes at *Floating Objects*, but only medium levels of APE engagement in longer engagements such as Case 12 (8.5 minutes) at *Gravity Powered Calculator* and Case 19 (*3-D Shapes*, 8.0 minutes).

Table 2: Cases Sorted by Holding Time in Decimal Minutes by Levels of Engagement

Case #	Exhibit	Exhibit Use Group	Total Time (decimal minutes)	Level of APE
33	Visible Vibrations	teenage girl alone	11.0	**High**
26	Heat Camera	two fathers and two sons and grandfather of one child	9.5	**High**
12	Gravity Powered Calculator	father and daughter	8.5	**Medium**
28	Heat Camera	grandmother, parents, and two sons	8.3	**Medium**
19	3-D Shapes	mother and son with other members of larger group	8.0	**Medium**
18	Pulley Table	family--but father used alone and mother used with child	6.5	**High**
30	Heat Camera	mom and two adult daughters	6.0	**High**
17	Visible Vibrations	mother, father, daughter, and son.	6.0	**Low-Medium**
23	3-D Shapes	adult dating couple	5.7	**High**
14	Gravity Powered Calculator	father and son	5.7	**High**
20	Visible Vibrations	father and daughter	5.2	**Low-Medium**
24	Pulley Table	father and son	5.0	**Medium**
4	Heat Camera	mother, father, and daughter--son less engaged, nearby	4.8	**Medium**
9	Heat Camera	man alone	4.3	**Low**
7	Visible Vibrations	woman alone	4.0	**Low-Medium**
31	Gravity Powered Calculator	woman alone	3.9	**High**
32	Floating Objects	dating couple	3.2	**High**
8	Gravity Powered Calculator	father, daughter, and son	2.6	**Medium**
3	Gravity Powered Calculator	man alone	2.3	**Low**

Case #	Exhibit	Exhibit Use Group	Total Time (decimal minutes)	Level of APE
34	Visible Vibrations	woman, daughter, and man (father or grandfather)	2.3	**Low-Medium**
6	Floating Objects	two brothers	2.0	**Medium**
1	3-D Shapes	mother and daughter	1.8	**Low**
5	3-D Shapes	woman alone	1.7	**Medium**
2	Pulley Table	man alone	1.6	**Low**
16	Floating Objects	four adult friends, male and female	1.5	**Low**
15	Floating Objects	father and son	1.1	**Low**
21	Pulley Table	grandmother with grandson	1.0	**Low**
25	Pulley Table	husband and wife	1.0	**Low**
11	Gravity- Powered Calculator	man alone and child from another visiting group	0.8	**Low**
13	3-D Shapes	father, son, and son's friend	0.8	**Low**
10	Heat Camera	man alone	0.8	**Low**
22	Pulley Table	grandfather with granddaughter	0.6	**Low**
29	3-D Shapes	three young adult friends, male and female	0.3	**Low**
27	Pulley Table	mother and two daughters	0.2	**Low**

Emotional engagement varied in response as well as intensity. *Heat Camera* and *Floating Objects* elicited surprise and humor at the medium and high levels of APE engagement. At *3-D Shapes*, several visitors took pleasure in creating shapes that expressed personal connections to occupation or family identity. Similarly, *Pulley Table* appeared to evoke connections to jobs and family stories. Several visitors to *Gravity Powered Calculator* expressed delight in the clever design seemed surprised that something as abstract as square root or the potential energy in gravity could be displayed physically before their eyes. *Visible Vibrations* appeared to challenge visitors, but in some cases it also provoked doubts about the visitor's capability or frustration with the exhibit.

Structure of Exhibit Case Studies

To present our findings more thoroughly, we include case studies from each of the six Phase 2 exhibits. We introduce each case study with a brief summary of findings related to that specific exhibit along with connections to other exhibits in both Phase 1 and 2 of the study. Exhibit descriptions and pictures are provided in Appendix B. Descriptions of each data set are in Appendix D, the data source table.

To classify cases as low, medium and high levels of APE engagement, we began by noting data collector ratings. Generally the classifications are consistent with their ratings, e.g., 1-2 ratings

are low, 3-4 ratings are medium, and 5 ratings are high levels of APE engagement. In cases involving *Visible Vibrations*, engagements rated as low and medium levels appeared to have very similar characteristics. At this exhibit, we could not make a distinction between low and medium levels of APE engagement, and apparently, this was difficult for data collectors, too.

Neither the frequency of cases by levels nor the lengths of engagement at specific exhibits should be interpreted as characteristic of a "generalizable" sample. These are purposively sampled observations, the goal of which is to obtain a full range of levels and times so that we might understand the nature of engagement at each exhibit and answer the overarching question of the study.

3-D Shapes

Findings

- **Range of Visitors**. At *3-D Shapes*, a wide range of ages and group types chose to interact with the exhibit, but we found full APE engagement only in the case of an adult male/female couple.
- **Physical Engagement**: Engagement times ranged from 19 seconds to 8.0 minutes. Some of the visitors we observed completed objects, but no visitor completed more than one, nor did anyone choose to engage at more than one station. Some visitors attempted objects related to labels, but most adapted these ideas or formulated their own designs based on personal connections and experiences.
- **Intellectual Engagement**. Only one couple made explicit connection to the underlying content. Other respondents' intellectual engagement was more limited. Some understood that they were involved in the process of construction, but they did not specifically identify the content or patterns among the shapes.
- **Social Engagement**: Several respondents constructed their own objects alone even when using the exhibit with someone else, but children appeared to require some parental assistance to persist in the task. In the sole high APE engagement, we saw a friendly competition about the idea for an object.
- **Emotional Engagement**: Satisfaction was related to completing objects. Another source of satisfaction appeared to be construction of a shape with a personal connection to occupation or family identity.
- **Capacity for APE Engagement:** In general we found *3-D Shapes* to have a relatively high overall capacity for emotional engagement. Like *Circuit Workbench*, this construction exhibit appeared to elicit connections to existing knowledge and previous experience. Physical and intellectual engagements were somewhat lower than that observed at other exhibits. While we observed some joint social engagements between a parent and child, the higher-level APE engagements (label-independent activities) were among adults who used exhibit elements alone or independently.

Cases and Levels of Engagement

Table 3: 3-D Shapes Cases and Groups

CASE #	Exhibit	Residence	# of Respondents by Case	Exhibit Use Group	Total Time (decimal min)	Physical Engagement Rating	Intellectual Engagement Rating	Social Engagement Rating	Emotional Engagement Rating	APE Engagement Rating	Level of APE Rating
1	*3-D Shapes*	Unknown	2	mother and daughter	1.8	1	1	1	0	1	**Low**
13	*3-D Shapes*	East Bay	3	father, son, and son's friend	0.8	1	1	2	1	1	**Low**
29	*3-D Shapes*	Sacramento and Fresno, CA	3	three young adult friends, male and female	0.3	0	1	1	0	0	**Low**
5	*3-D Shapes*	Redding, CA	1	adult female alone	1.7	3	3	2	3	3	**Medium**
19	*3-D Shapes*	unknown	5	mother and son primary	8.0	3	3	5	4	4	**Medium**
23	*3-D Shapes*	Belmont and San Jose, CA	2	adult dating couple	5.7	3	4	5	5	4	**High**

Physical Engagement

Among cases with lower levels of engagement, lengths of stay ranged from 19 seconds to 1 minute and 45 seconds. In the shortest engagement (Case 29), three adults had been observed beforehand at *Tippy Table,* involved in a long active engagement. They approached *3-D Shapes*, read a few of the labels, did not sit down, and moved quickly to the gift shop. In another case of

low-level APE engagement (Case 13), a father, his teenage son and the son's friend approached the table together, and the boys started picking up shapes. The father quickly moved on, and the boys followed. Finally, in the case of a mother and young daughter (Case 19), the child approached the table first and began to put together shapes. Her mother joined her about halfway through the engagement. Neither completed an object or looked at the label, and they operated independently of each other. The child left first and the mother followed.

In the cases with a medium level of APE engagement, the lengths of stay were 1 minute and 40 seconds (Case 5) and 8.0 minutes (Case 19). An adult female with a friend nearby, walked up to the exhibit, remained standing, and picked up a chain of connected squares put together by a previous visitor. She separated the pieces and pulled up a label showing a house with a domed roof. The woman built a pyramid and a square and placed the pyramid on top of the square, then raised her hands, palms up, in what appeared to be a gesture of satisfaction with her object (Case 5).

In the longer case, (Case 19, 8.0 minutes) a mother and her son, who appeared to be about 8 years old, approached the exhibit together. After the boy examined a soccer ball left by a previous visitor, the mother pulled up the label of the soccer ball. The mother pointed at the pieces, and both the mother and the child began to lay pieces on the table. As the building continued, the mother held the ball and the boy added pieces. At about 4.5 minutes into the engagement, the boy moved to another station while the mother continued to assemble the soccer ball. Other members of their group arrived at the exhibit. At about 5.5 minutes into the engagement, the boy returned to his mother and the soccer ball. Another boy of similar age joined the mother and son. He was a member of the larger visiting group. (We later learned that this was a large birthday party.) At about 8 minutes into the engagement, the three finished the ball. The son held the ball over his head and said, "It's a masterpiece." The son left and moved to a nearby exhibit. The mother stayed at *3-D Shapes* and talked to two other parents (who, we learned, were part of the larger group) for another 7 or 8 minutes after the shape was completed.

In the instance (Case 23) of a higher level of APE engagement, a dating couple, who later labeled themselves as an "artist" (the woman, an art student) and a "scientist" (the man, a former physicist and currently a teacher) used the exhibit for about 5.7 minutes. This couple approached the exhibit, with the man leading, and circled around the table looking at the pieces. About three-quarters of the way around the table, the man lifted the label reading, "Build a home." He sat down and started sorting pieces, and the woman sat at the station to his left. They both started building shapes. They talked to each other and used pieces from each other's stations in friendly competition over triangles. The man built his shape entirely of triangles. He held up his shape and showed it to the woman, appearing to explain what it was. The woman held up her shape and was heard to say, "My tank destroys your shape!" They then quickly left the exhibit.

Range of Activities and Independence from Labels

In the cases of low APE engagement, the range of activity at the exhibit was limited to touch and handling pieces on the table surface, and none of the individuals lifted a label. In one instance of medium level APE engagement, the woman looked at the label, and while it appeared to influence her idea of what to do, she judged the complexity too great to follow. Her house did not follow the pattern in the label.

Well, it said, "Build a house," so I was picturing my home. So, when I picked it up, it was a dome-shaped home. So, I put it back. (Case 2, female massage therapist, late 30s, using exhibit alone)

In the other case of medium level APE engagement, the mother looked carefully at the label and used it to guide the joint building of the ball with her son. Finally, in the case of the scientist and the artist, both looked at a label, but we learned in the interview that neither chose to follow the instructions, but rather built something on their own. The woman indicated she consciously avoided the ideas suggested in the label.

Appropriateness of Activities
Even among minimal levels of APE engagement, most visitor activities were appropriate to the construction nature of the exhibit.

Because my daughter has attention span – and I'm just following her. . .. We were just kind of sticking things together – like shapes together. (Case 1, mother with 5-year-old daughter)

Further Exploration
None of the individuals we observed put together more than one shape. Most of the individuals participated at only one station. It appears that individuals were satisfied with building one shape, and most left quickly after finishing. In some cases, visitors specifically pointed to their overall visit agenda, seeing as many things as they could at the Exploratorium that day, as a reason for moving on after building only one shape:

No, we're just on a short time frame today. So, I kind of want to catch it all and then come back and really spend time another day. I heard the lady in the line in front of me that said – she goes, "Which section do you want to go to today, because we don't have time to do it all?" And I'm going, "Okay, well, then I guess we're not going to see it all." . . . . I would have stayed there longer if I had time. (Case 2, female massage therapist, late 30s, using exhibit alone)

Multiple Entry Points
Visitors began engagement in several ways. The scientist and the artist began by walking around the entire table and examining what other people had made. They avoided stations where previous visitors' work was complete:

It affected where I sat at the table. I didn't want to take apart their stuff. So like if everything had been built, I might have been less inclined to go over there. (Case 23, female, art student)

Other people began by taking the shapes built by previous visitors apart, and some sorted pieces. Only one visitor looked at the label before touching pieces lying on the table. This was the scientist in Case 23.

Intellectual Engagement

Among visitors who made only cursory use of the exhibit, there was little intellectual engagement beyond identifying the nature of the experience offered, the time it would take, and deciding not to engage further. One group cited the considerable time they had spent at a previous exhibit.

> *I didn't really have enough time . . . we would probably have to have spent hours on it. It did seem like there were too many – you know, all the angles on the triangles and all the shapes. Unclear maybe what we were supposed to do real quickly. That one just seemed a little challenging for some reason. I had been trying to make all of the things on there [Tippy Table]. (Case 29)*

In another case the father sized up the exhibit as a guided-discovery exhibit on a topic that he was not interested in. Apparently the Velcro connectors on the pieces were the salient aspect of the exhibit for this father, and the two boys with him followed his lead.

> *Just seeing what it was that – the principal activity was (pause) . . . The reason I didn't spend a lot of time there was quite honestly I understand the physics of Velcro and that sort of thing. I'm more interested in some of the other experiments here. There are things I've never been exposed to. (Adult male, late 40s, visiting with son and son's friend)*

Visitor Questions and Intellectual Exploration

Among most groups we observed, there was little conversation. In Cases 1 and 29, the groups appeared to assess and move on (a decision not to engage) with no conversation. They appeared to read each other's expressions and followed individuals who left. In Case 5, the woman used the exhibit alone. In the cases of higher APE engagement, conversations between the mother and her young son and between the artist and scientist were about what they were building, what pieces they selected and how they put them in place.

There did appear to be two levels of implicit questions in visitor activities: (1) deciding what to build, and (2) deciding how to place pieces in the construction process. Of the four instances we observed where objects were completed, visitors drew primarily on previous experience and knowledge to decide what to make. The scientist clearly identified that he would build a form of carbon based on his knowledge as a physicist. The artist simply began building and used a process that was familiar to her. The scientist explained that he was constructing

> *The third kind of carbon, after diamond and graphite…Someone came up with a third idea for carbon – high-powered …So I built one of those…It's entirely made of triangles…You know, six triangles, and if you put them together, you get a hexagon. If you take five, you get a slightly curved pentagon. If you put enough of these together, you can get a ball made of triangles, which has 60 points. And if you formed carbon at a high pressure and heat, you can get a carbon that turns into this…Well, I think more than anything else, I was just trying to make sure I actually put the six triangles together rather than five. I knew exactly what I was trying to get. (Case 23, male, mid-20s, teacher, and former physics researcher)*

The artist, on the other hand, relied on a familiar process of creating an object and clearly resisted using the label to come up with her idea.

> *I was trying to make a unique shape, and then it just ended up sort of looking like a tank. So, I went with it. I didn't start out making a tank . . . I was just trying to come up with something that I didn't see, that wasn't a ball or anything else . . . .It wasn't something that was on the card, something just kind of different, and wherever it went from there I would elaborate on whatever I saw of it. (Case 23, female, mid-20s, art student, using exhibit with boyfriend)*

The woman using the exhibit alone explained that her decision to build a house was influenced by a personal connection to the idea of construction:

> *First, I was just trying to see what kind of pieces they were. And then I decided to try to build a little house . . . My grandfather was an architect . . . He designed Grauman's Chinese Theater. It's now Mann's Theater, but it used to be Grauman's. Actually, he was from San Francisco originally. (Case 2, female massage therapist, late 30s)*

While we were not able to interview the mother and son building a soccer ball (Case 19), the mother looked at the label more than once and, at one point, for a long period. She appeared to be guiding the engagement of her son. The object was built according to the label directions, and the mother appeared to consult these several times, so while the total nature of this intellectual experience is unknown, it appeared to be guided by the label.

Conclusions and Conceptual Understanding

Both of the women, one a massage therapist and the other an art student the underlying content of the experience. The massage therapist used process language to describe her experience while the art student used mathematical terms.

> *Well, it's more difficult than I thought it was going to be -- finding the right shapes that actually fit. To make it fit – so that was a pretty big one…Just seeing all the shapes and possibilities of what you could do with it if I were sitting down, taking time to play. (Case 2, female massage therapist, late 30s)*
>
> *I actually don't understand the point of the exhibit myself. (Laughs) I thought it was demonstrating angles of things and how it fit together. So maybe obtuse and acute angles – I don't know. I don't know the point of the exhibit. What was it, Dear? (Case 23, female, mid-20s, art student)*

Neither of these visitors noticed the underlying consistency of patterns described in one of our interviews with an exhibit developer. Specifically, this deeper content topic is about the dihedral angle of planes and that patterns exist when you put three pentagons, hexagons, triangles, or squares together. During formative evaluation, decisions were made not to focus on this content topic, but rather to encourage visitors to construct objects with these materials (Interview 1, exhibit developer). Only the former physicist, although he "didn't learn anything new," identified this underlying content.

I think the [point of the exhibit would be the] difference between how two-dimensional and three-dimensional geometry (inaudible). You start with a bunch of two-dimensional shapes and then you build three-dimensional things from that. For example, the triangles together – the whole thing of having six triangles gives you a flat surface, whereas having five gives you a slightly curved one. (Case 23, male, mid-20s)

Nature of the Phenomena

Like *Circuit Workbench*, a construction exhibit in the Phase 1 study, visitors using *3-D Shapes* had experiences connected to previous experiences and knowledge. Unlike in *Circuit Workbench*, even visitors with lower levels of experience and scientific knowledge appear to be willing to engage in this task. As the artist (Case 23) explained, "you can play" at this exhibit. Play was a concept also mentioned by her boyfriend.

Social Engagement

In the three cases with medium and higher levels of APE engagement, we found three types of social engagement at *3-D Shapes*. The mother and son (Case 19) clearly worked in an adult-guided but cooperative manner. The mother read the label, held the soccer ball, made comments to guide her son's activity, and even waited for him to reengage when his moved away from this rather extended task. We later learned that the birthday party group, of which this mother and son were a part, had decided to meet back at this exhibit after splitting up previously. This clearly influenced the length of the engagement.

We learned in the interview that the massage therapist using the exhibit alone (Case 5) made connections to her own personal experiences, e.g. her grandfather's design of Grauman's Chinese Theater. But she did not make efforts to engage her friend, who was standing nearby in the exhibit, nor did she share these connections with her. She told us that using exhibits alone seemed safer to her and that she preferred using them this way.

I'm more likely to work by myself, I guess…Just not taking risks. (Case 2, female massage therapist, late 30s, using exhibit alone)

This woman downplayed her own scientific knowledge and exhibited a limited self-confidence in interacting with exhibits. In contrast, two very self-confident individuals, the artist and the scientist, told us they were engaging in "friendly competition" at the exhibit, fighting over triangles to use in building their objects. The woman, the artist, noted that the social motivations might have been the reason they decided to use the exhibit, "because there was a curiosity to see what the other person would make." (Case 23) Each seemed to make his or her personal connections, and they shared these only at the end of their individual experiences. While the artist deferred to her boyfriend on the science content, she clearly believed her object was superior to his. She noted that she would have thought his was "just a ball" if he had not explained that it was a form of carbon. She commented, "My art kicked your science's ass." Her date agreed that "she won and I lost." Both were quite aware that the nature of their experience was shaped by the motivation of learning about each other in a dating relationship.

Emotional Engagement

Sources of Satisfaction
For most of the respondents, one source of their satisfaction was connected to completing an object. When the boy and his mother finished the soccer ball, he held it up above his head and said, "It's a masterpiece" (Case 19). When the architect's granddaughter completed her house, although she was alone, she spread her hands on either side of the house and turned her palms up in a gesture of presenting her creation to the world (Case 5). The artist and the scientist were also proud of their objects and engaged in a mock argument about which was better. The artist appeared to "win" because her object was unique (not based in any way by the label) and recognizable (Case 23).

Connections to other people seemed to be another source of satisfaction. The woman building a house (Case 5) thought of her grandfather who was the architect of Grauman's Chinese Theater. While we were unable to interview the mother in Case 19, the nature of the engagement indicated her motivation and satisfaction were perhaps tied to the social experience and her child's pleasure. Clearly, a primary source of satisfaction for the artist and the scientist was expressing their own identities and learning about each other.

Level of Satisfaction
While all the individuals who completed objects showed satisfaction, none of those we interviewed rated this exhibit extremely high compared to other exhibits. The architect's granddaughter alluded to other exhibits that were more fun, citing *Touch the Spring* and exhibits with larger phenomena.

> *It was fun and stuff, but it . . . wasn't things about magnetic, or the ocean floor – things that were a little more – it was just different. It wasn't the science that I was looking for. It was interesting and I liked it, but . . . . (Case 5, female)*

> *The thing is, it's fun, but for me it's kind of small scale. So it's fun and it's entertaining and it's reasonably educational. But it's not something spectacularly new or inspirational at the same time. It's kind of a good standard exhibit. (Case 23, male)*

Floating Objects

Findings

- **Range of Visitors**: *Floating Objects* appeared to attract a wide range of ages and group types to engage at the exhibit.
- **Physical Engagement**. Even those with higher overall levels of APE engagement spent a relatively short amount of time at the exhibit compared to cases we observed at other exhibits in the study. The range of exhibit elements that people used seemed to correspond to how crowded the exhibit was at the time they used it. One respondent specifically cited problems with interference by other visitors, and we observed several other instances of this. We identified only one case in which exploratory activities moved beyond those suggested by the label.

- **Intellectual Engagement**: Almost all the people we interviewed appeared to identify variables in terms of object characteristics and to compare variables, (i.e., to experiment to test relationships between variables), but none told us specifically that they were involved in this process. Several respondents indicated that they made predictions.
- **Social Engagement**. Several visitors engaged in cooperative behavior, and we found two cases of friendly competition, in which visitors "bet" each other about whether or not something would work, i.e., they made competing predictions. We did not see the adults moving into teaching-demonstrating roles to the extent we did in cases at other exhibits. Like *Heat Camera*, *Floating Objects* appeared to level the social playing field between children and adults and between males and females.
- **Emotional Engagement**. Satisfaction appeared to be connected to taking delight in and manipulating a counterintuitive nature of the phenomena. It was also connected to achieving results, i.e. floating objects. Adults told us about their pleasure in observing children's excitement.
- **Capacity for APE Engagement**: In general we found relatively short physical engagements at this exhibit compared to others in the study. This appeared due to the single-station design and vulnerability of the experience to interference by other visitors. Yet we also found some high levels of social engagement, and the surprising phenomena appeared to level the social playing field among visitors of various expertise. While questions tended to be implicit and unarticulated, intellectual engagement often involved identification and testing of variables.

Cases and Levels of Engagement

Table 4: Floating Objects Cases and Groups

CASE #	Exhibit	Residence	# of Respondents by Case	Exhibit Use Group	Total Time (decimal min)	Physical Engagement Rating	Intellectual Engagement Rating	Social Engagement Rating	Emotional Engagement t Rating	APE Engagement Rating	Level of APE Engagement
15	Floating Objects	San Leadro, CA, and Mexico	2	father and son	1.1	2	2	3	4	2	**Low**
16	Floating Objects	unknown	4	four adult friends, male and female	1.5	2	1	1	2	1	**Low**
6	Floating Objects	Lake Tahoe, NV	2	brothers, 18 and 13	2.0	4	4	4	4	4	**Medium**
32	Floating Objects	Chico, CA	2	dating couple	3.2	5	5	5	5	5	**High**

Physical Engagement

Time of Activities

The range of times was fairly restricted with the shortest engagement we observed at 1.1 minutes and the longest at 3.2 minutes. The two lower-level APE engagements were 2.0 minutes and 1.5 minutes. The medium level of engagement was about 2.0 minutes, and the high APE engagement was about 3.2 minutes. Crowding appeared to be a factor in people leaving the exhibit quickly.

Range of Activities and Independence from Labels

In both of the lower APE cases, the range of activities was limited, and all the activities were suggested in the label. In Case 16, a woman in her mid-20s approached *Floating Objects* and tried unsuccessfully to float a golf ball. Her male friend, also in his mid-20s, joined her and picked up another object from the floor. Another pair approached the exhibit at this point and

began using the other nozzle. The first woman adjusted the airflow to the nozzle and then tried the golf ball again. It fell off again. Her friend picked up an apple from the exhibit floor as she walked away. The man tried "flinging" a basketball over the nozzle two or three times and it fell. Finally, he placed the ball over the nozzle and then began spinning it with his hands. He watched it for a few seconds and left.

In the other lower APE case (15), a father and son walked up to the exhibit and each stood in front of one of the two airflow nozzles. The pair talked and laughed throughout the engagement. The teenage son floated a basketball and then a beach ball. His father reached over and floated a second beach ball in the airflow nozzle in front of his son. The father tried to float a third ball, and they all fell. The father and son turned and left at the same time.

In Case 6, a medium level of APE engagement, two brothers, one about 13 and the other about 18, approached the exhibit as it was already being used by a woman and a boy. The boy in this group was very active and was grabbing balls during the brothers' engagement. The younger brother maneuvered to a nozzle and placed a football in the air stream. His older, taller brother stood just behind him, and did not physically engage at the exhibit. Next, the younger brother floated a beach ball and then tried heavier balls that fell right way.

In Case 32, which we judged had a higher level of APE engagement; a man in his late 20s approached the exhibit when no one else was there. He held his hands over the airflow of each of the two nozzles and then floated a football on the combined airflow. The man left the exhibit and came back with a woman in her late 20s, who we later learned was his girlfriend. Both sat while using the exhibit. He grabbed both nozzles and tilted them towards each other, floating the football in the two streams in the center. Slowly, he moved both nozzles to his left, moving the football slowly towards the left. The man also floated objects over both air streams independently and then tried to move one into the other air stream. The woman read the label and then reached over and floated one beach ball on the left nozzle, leaving it in the upright position. She picked up the other beach ball and held it over the one already floating. It fell. She moved the nozzle slowly to the right with the floating beach ball above, apparently trying to move it from one stream to the other without it falling. Then she grabbed the whiffle ball and floated it, saying to her friend, "Let's get two to float at once." She floated the pair and tried to float a beach ball but it fell. Then she tried to float two beach balls and succeeded. A crowd started gathering, and the man walked away. The woman stayed and attempted to float two beach balls. After three attempts, she succeeded and then left.

Appropriateness of Activities

All the visitors we observed clearly understood what they could do at the exhibit and floated one or more balls. In three of the four cases, however, visitors only floated objects above one nozzle and stayed fairly close to label-suggested activities.

Further Exploration
Only in Case 32 did we observe visitors clearly moving beyond the label-suggested activities. The man used the nozzle like a pair of arms to move objects from one stream to another, in one instance on top of an object already afloat. The woman read the label before using the exhibit and followed suggestions to try activities. Both visitors repeated iterations several times.

Multiple Entry Points
Most visitors began by observing other people at the exhibit floating balls and then walked up and floated a ball themselves. Only in one case (32) did a visitor begin engagement by playing with the nozzles first. He held his hands over the airflow and then moved them to combine the air streams. This occurred when the Exploratorium was not crowded and no one was at the exhibit when he approached.

Intellectual Engagement
All the visitors we interviewed expressed surprise at how a small amount of airflow could hold objects in the air.

> *I was just . . . intrigued by the way that the air was holding the balls up and how high the football – that it was way up there. (Case 15, male, teen)*

Visitor Questions
Even in shorter engagements with activities suggested by the label, we found evidence that guests identified more than one variable. Three of the four groups recounted specific predictions they had made. A Spanish-speaking father explained that during the rather short engagement with his son, they had several questions and made predictions. In this case, however, the salient variable of the exhibit was the airflow, and neither he nor his son focused extensively on other variables such as weight or surface area.

> *We were wondering if the air could support two balls at the same time or a different kind of ball . . . Also, we wanted to see if it was possible if at that air speed it was possible to support three at the same time, which it wasn't. Not enough air speed and the second thing is the other two balls are disrupting the airflow to such an extent that it will not – there won't be any airflow for the third one to stay up there. (Case 15, male, flight instructor)*

We found evidence of further exploration of several variables in other cases, and visitors took the opportunity to play and explore.

> *I basically just fooled around with different objects, seeing the different weights and stuff, you know. Seeing how high a ball would go or how low a ball would go, seeing how high it would shoot up and how long it would stay in the air. (Case 6, male, 13)*

I just tried the pineapple and the football. And it just amazed me how they could keep it up. Even at an angle, it didn't shoot it away and drop away. It just floated there…At first, I just did the one. And then I was kind of messing with it and pushing it over to that side and it was still floating right over here, so I started playing with both of them. (Case 32, male, late 20s)

Conclusions and Conceptual Understanding
Most visitors' conceptual understanding was articulated as surprise at a counterintuitive phenomenon, that is, objects floating on a stream of air.

Well, the air is capable to move everything if it's fast enough. It can move. It can spin something. (Case 15, male, teen)

Oh, yeah. I was like, oh, I didn't know that. I didn't know it could stay up for so long. I thought eventually it would just die down and the weight would overcome the air pressure and stuff. But it just kept on floating. Like the football kept on doing misties and stuff. It was pretty cool. (Case 6, male, age 13)

It's compressed air – almost like a little pocket that you can just set things into. And try to tie it in with – not necessarily metaphors, but examples. Like imagine you putting golf ball in your pocket, how it holds there. Like a pocket of air. (Case 6, male, age 18)

Even visitors who appeared to have the highest overall levels of APE engagement at this exhibit were not entirely articulate in summarizing how they understood the science concepts underlying the exhibit. When asked to explain the exhibit to third-graders, the couple from Chico provided rather limited explanations.

I think I would just kind of draw the lines showing how the air spins around the thing that…. (Case 32, female, late 20s)

And how there's a center of balance to everything. Because that football, no matter how much it weighed, it stayed dead center with the center of balance. (Case 32, male, late 20s)

Metacognition
While most visitors identified variables and actually performed some experiments, none of them conceived of their experience this way. Some indicated they played, messed around, and wondered, but the intriguing nature of the experience did not appear to connect to "doing science" among most of the visitors.

Social Engagement
One of the themes of social engagement at this exhibit was competition between two visitors about differing predictions. The father and son from Mexico had hamburgers bet on whether or not the football would float. The father indicated that "neither of us was sure" but the father made a competing prediction to make the engagement fun. The couple from Chico also made competing predictions.

I was telling him that when I was trying to put the two balls on top of one another, he was like, "No, no, you can't do that." . . . And I said, "No, the picture right there says you can put two in. But you've got to put the ball on top. So, he was joking around with me that you couldn't do that. And I said, "They wouldn't have the picture here if you couldn't do that." (Case 32, female, late 20s)

In two cases (15 and 32), people in the same visiting group worked together. The woman from Chico suggested, "Let's see if we can float two." The Mexican father and son worked together to float two balls and then to try to float three. In the case of the adult friends (Case 16), however, they used the exhibit sequentially and did not work together or talk. Finally, in the case of the two brothers (6), the younger brother physically engaged in the exhibit while the older brother looked on. Both cases of less social interaction occurred when the museum was busy and the area was crowded.

There was additional evidence at this exhibit that crowding and a single complete station shortened engagements. On visitor explained why she left the exhibit,

And then when the kids came up there, they just – you know how kids are. They're not as – the other one is like "Ah!" More direct, I guess, or maybe violent, for lack of a better word. And I was trying to get two balls on top of each other and they were trying to do their thing with the other one and it was kind of interfering with what I was trying to do. (Case 32, female, late 20s)

Emotional Engagement

Source of Satisfaction

The primary source of satisfaction in this exhibit appeared to be participating in a counterintuitive experience. As cited in the quotes above, people enjoyed playing with the apparatus and generally smiled and laughed as they were using it. As one visitor explained simply,

I guess the people have fun. I believe that was it for me. (Case 6, male, 13)

But other visitors appeared to be somewhat frustrated by the design of an exhibit that did not protect their experiences from interference. Children especially were observed to become quite rambunctious and interfere with other's experience.

It's a really good exhibit. It's interesting. . . . [But] I think they could make it bigger and maybe have – if you wanted to put more people in there, maybe you could have a wall so it was like two exhibits so four people can be blasting each other – you know, kids. (Case 32, female, late 20s)

Another visitor noted the pleasure he took in watching children get excited about science.

I was talking to the mother of the other boy that was there and just kind of – not necessarily small talk, but talking about the objects and how you could see how he was really excited when he was playing with it. And we had some jokes going on about (inaudible) when he had the football up in the air, and he got a little excited about the whole thing. It was cool to see him light up over something that – you know, science isn't normally fun for those kids. So I thought that was kind of cool, that we were having a good time over there. (Case 6, male, 18)

Gravity Powered Calculator

Findings

- **Range of Visitors**. While this exhibit attracted a diverse set of visitor types, we observed higher APE engagements in the case of a female with a higher level of previous knowledge. A father with a younger child was able to manage the son's engagement and have a higher-level APE experience himself.
- **Physical Activities**. The exhibit appeared to stimulate extended engagement by suggesting initial activities that helped some visitors notice relationships among variables and patterns among numbers.
- **Intellectual Engagement**. Intellectual engagement at lower levels was focused on using the exhibit to demonstrate and calculate square root. In cases of higher-level APE engagements, one visitor was using the exhibit to predict where hypothetical ski jumpers would land, and another was exploring the pattern of distances among numbers and their square roots. These visitors used resources, such as the digital calculator, and the exhibit apparatus to answer self-initiated questions.
- **Social Engagement**. The level of the content appeared to stimulate adult males to take a directive role with children. In some cases, this limited the exploratory activities by children and blocked high-level APE engagement by parents. This pattern was also identified at other exhibits in the study, *Pulley Table*, *Visible Vibrations*, and *Circuit Workbench*.
- **Emotional Engagement**. In the higher-level APE engagements, the exhibit provided visitors with an intriguing mental challenge that they found satisfying.
- **Capacity for APE Engagement:** While most of the engagements we observed involved connections to the concept of square root and using the exhibit elements to calculate, several adults made connections to the underlying principles of physics, and two used it in a surprisingly exploratory manner. Physically, the exhibit allowed both the joint social engagement of adults and children; the content, however, appeared to motivate parents to manage and direct engagement.

Cases and Levels of Engagement

Table 5: Gravity Powered Calculator Cases and Groups

CASE #	Exhibit	Residence	# of Respondents by Case	Exhibit Use Group	Total Time (sec)	Total Time (decimal min)	Physical Engagement Rating	Intellectual Engagement Rating	Social Engagement Rating	Emotional Engagement Rating	APE Engagement Rating	Level of APE Engagement
3	*Gravity Powered Calculator*	Wichita, KS	1	male alone	138	2.3	2	3	0	3	2	**Low**
11	*Gravity Powered Calculator*	San Francisco	2	male alone and child from another visiting group	50	0.8	2	2	2	2	2	**Low**
8	*Gravity Powered Calculator*	San Francisco	3	father, daughter, and son	157	2.6	3	4	4	3	3	**Medium**
12	*Gravity Powered Calculator*	unknown	2	father and daughter	510	8.5	2	2	2	2	2	**Medium**
14	*Gravity Powered Calculator*	unknown	2	father and son	339	5.7	4	3	1	4	3	**High**
31	*Gravity-Powered Calculator*	Montreal, Quebec	1	adult female alone	235	3.9	3	4	3	4	4	**High**

Physical Engagement

Time of Activities
Lengths of engagement at this exhibit ranged from 50 seconds to 8.5 minutes. Interestingly, the case with the longest engagement was one we classified as medium APE engagement.

Range of Activities and Independence from Labels
One of the things we learned from analyzing data from this exhibit was that higher APE and lower APE engagements may at times look similar in terms of physical engagement. At *Gravity Powered Calculator*, similar-appearing engagements had very different intentions. To illustrate, we have briefly summarized the visitor explanations of what they were doing from interviews at the end of each of these physical descriptions.

Both lower level APE engagements were characterized by limited label-directed activities. In lower-level APE cases (3 and 11), both men, using the exhibit alone, walked up, looked at the exhibit apparatus and then read the label before touching the exhibit. The older man (Case 3) took one ball, placed it on the ramp and released the lever. The Hispanic man, in his mid-30s, placed a marble on the ramp but did not hit a bar. He then looked back to the label and then placed another marble at a lower position, released the lever, and hit a metal bar. After a brief conversation with a child from another visiting group, he left. In interviews, both of these visitors indicated that their primary intent was focused on using the exhibit to calculate a square root.

We classified Case 8 as a medium level of APE engagement. In this case, the physical activities were more extensive, but all were label-directed. The father approached the exhibit first and then watched and talked to another man using the exhibit. He read the label. He knelt down at the tray, looked closely at it, and then stood up and talked to the man again. As the other visitor left, a boy (about 8) and girl (about 11) walked up. The children put individual balls on the ramp and released the levers but did not hit the bars. The father looked at the tray again, and the girl placed a ball and hit the bar. The girl began to put several marbles on the ramp, and her father stopped her, indicating this was an incorrect way to use the exhibit. She positioned the marbles one at a time. The group continued to talk to each other throughout the engagement. The children placed marbles again, making the "dinging" sound as a marble hit the bars, and then quickly left. The father in this case explained in the interview that he was trying to get his children to place marbles so that they would get feedback when there was a "ding." He wanted the children to observe the proportionality in the distance, i.e., that the higher up the ramp the marbles were placed the farther they would go.

In Case 12, which we also classified as an overall medium level of APE engagement, more numerous and varied activities took place at the exhibit, but they were all label-directed. This discrepancy led to our exploration of differing perspectives about this exhibit. A man in his late 40s approached the exhibit and watched another visiting group. As they left, he stepped up to the exhibit and read both labels. He picked up balls, placed them on the ramp, and hit the metal bars for a "ding" three times. A girl, about 8, and a boy, about 10, joined the man. The boy left quickly, but the daughter stayed and continued the interaction with her father. With her father talking to her, the girl placed one ball on the ramp, released it, and hit the bar. She repeated this at another whole number. The man sat down on the stool, and the girl placed six balls and hit six

bars. She then repeated this activity using five balls. While talking, the girl placed one ball on the ramp but didn't hit a bar. They placed six balls on the ramp, and hit five bars. They laughed and left together. While the father thought about "potential kinetic energy" while using this exhibit, "We used it in a way to learn about square roots." The father judged the physics concept was beyond his daughter.

We classified Case 14 as an overall high level of APE engagement. This engagement involved a father (a chiropractor visiting San Francisco for a convention) who used the exhibit with his 4-year-old son. Both were able to use the exhibit at the same time, and the father engaged in several activities not suggested by the label. The father approached first, but immediately involved the boy in the engagement, and the pair tried a couple of repetitions, with the boy placing the bar. They hit a bar on the second attempt. After getting his son a stool to stand on, the pair placed multiple balls on the ramp for several repetitions, some hitting bars, and some not. The man looked at both labels for a considerable length of time. The adult used the digital calculator several times, and we learned in the interview that he was calculating where the balls would land. The pair continued to place multiple balls and observe where they landed; some hit bars and some did not. We learned in the interview, that this father was thinking about ski jumping during the engagement. His placement of the balls, in the same iterations where his 4-year-old son was placing balls, was intentional. The man told us that he was observing the relationships between where balls left the ramp and where they landed, seeing if he could predict where the ski jumper would land based on where he left the ski slope.

The other case that we classified as a high level of APE engagement was a woman in her 30s, who we later learned was a physician. While there was a great deal of activity in this woman's engagement, exactly what she was doing is difficult to interpret from the observation of her activities. She approached the exhibit with her rollerblades in her hand at a time when the museum was quiet and relatively empty. First she touched the red handle but did not move it, and she appeared to be looking at the label on the front of the exhibit. She picked up one ball, placed it somewhere midway on the ramp, and missed the bar. She then picked up ball and put it on 16, released the lever, and the ball hit the bar. She paused, looked at the label on left side of the exhibit, and then picked up another ball, placed it on 10, and missed. She placed another ball on the higher end, and again the ball did not hit the bar. She paused again, and appeared to be thinking. She released another ball and missed again. She released three more balls, one at a time, missing the bar each time. She later explained that she was placing them on prime numbers. She backed up slightly from the exhibit, picked up a ball from the tray, and put it on position 9. This ball hit a bar. She put a ball on position 4 and this ball hits a bar. She paused again, looking thoughtful, and released another ball that hit a bar. She walked away from the exhibit for a second, returned to the exhibit and placed her finger sequentially in positions on the ramp, starting from the bottom, and tapped on each spot: 1, 2, 3, 4, etc. She moved slightly to the right and appeared to be reading the explanation on the pink label. She moved away abruptly. In the interview, she explained that she was exploring the relationship between the distances between the numbers on the ramp and where the balls landed in the tray. She noticed that there was a nonlinear relationship, and she was trying to understand the nature of that relationship by entering numbers with whole square roots and then seeing what would happen with prime numbers.

Appropriateness of Activities
All the visitors we observed placed at least one marble on the ramp, and most of them went through several iterations of this activity. Two fathers corrected children in the exhibit use. One of these corrections was about placing multiple balls on the ramp. In the interview, the father suddenly realized that this would work and exclaimed, "Oh, bad Dad!"

Further Exploration
The two cases of high APE engagement showed activities beyond the label suggestions. In Case 14, the father was predicting where a hypothetical ski jumper would land by watching the balls. In Case 31, the Canadian doctor repeated several variations of ball placement that missed the bars. These iterations of the activity could have been interpreted as unsuccessful attempts without the visitor's explanation of how her physical and intellectual engagements were related, that is, through understanding the nonlinear relationship of the numbers on the ramp and those in the tray.

Multiple Entry Points
Visitors began engagement by either observing another visitor or by reading the label. Both appear to have been means of assessing what the exhibit was about and how to use it. The label on the front of the exhibit was used most often near the beginning of the exhibit. This set of observations appear to indicate that this is an exhibit that adults approach first, and five of the six engagements were initiated by adult males opening a question about whether or not more males than females are attracted to this exhibit. Tracking-and-timing data may provide a clearer answer to this pattern of use.

Intellectual Engagement
In the two cases of overall low APE engagement, the two men were primarily focused on getting the exhibit to work and the ability of the apparatus to calculate square root.

> *I didn't know that the thing could be measured by speed and by distance; it would tell me the square root of a number. That's a little bit strange. (Case 3, male, 60s)*

> *I was just trying to figure out what it was, what it did. I try to look for stuff that kind of uses your mind a little bit. And it was kind of neat, too…The way it always hits the brass – when the brass bar goes across. It's kind of interesting. (Case 11, male, mid-30s)*

In the two cases we classified at a medium level of APE engagement, both fathers had based their engagement with the exhibit around ideas they believed their daughters, ages 8 and 11, could understand. Both interpreted the exhibit as a way of demonstrating physics principles, and they worked with their children with these assumptions.

> *I thought it was a…test by the people who were here [Exploratorium staff], that they thought of something like that to demonstrate the increase in potential energy – more than the square root calculator. . . . (Case 8, male, late 40s)*

We used it as a way to learn about square roots. But only at a very basic level because she's 8. And we had a lot of fun sort of seeing the predicted outcome actually happen. When the balls hit the bars, right? – we arranged it so that the five balls hit the five bars all at once…I even had my daughter – I asked her – I said, "Okay, the square root of 25 – square root is what number times what number equals 25." "Five." "Okay, so hit the five." Positive, good feedback – it worked. (Case 12, male, 40s)

In the two cases we classified as high APE engagements, visitors were exploring the relationships, and trying to answer questions, by using the exhibit apparatus. Both clearly perceived of their experience as a process of exploration rather than as a demonstration of a principle. The father with the 4-year-old son liked it because his son could "develop his fine motor skills" by placing the marbles while he engaged on another level.

It encouraged me to play with it – you know, put the balls in different spaces, take the calculator afterwards, determine before I let the marble go and see if it lands in a particular spot. (Case 14, male, mid-40s)

In his mind, this man connected the exhibit to ski jumping. He associated the exhibit with,

Watching the downhill skiers, trying to figure out where they might land when they're coming off the ramps. (Case 14, male, mid-40s)

The Canadian doctor, a native French speaker, assumed the basic physics principle was a given of the exhibit. Her question focused on the nature of the relative distance among the numbers on the ramp and the numbers in the tray.

Well, first I tried the number 16. I just went from 0, 10, 20, 30 to see how it would go…Well, of course, the higher it goes, the further it goes on, and the higher you start, the further it goes on the bucket – whatever – the tray. And then you realize it's not a linear relationship. So it's got to be something else…Well, it's not centimeter-by-centimeter. If you tried10, it won't be – if you tried10 and then20, when you tried the 20, it won't be 10 centimeters further away. That's what I mean . . . 30 – and then I went back and tried the numbers – how do you say that? The number that has a square root?…Like 4, 16— And I was looking for my boyfriend and I was actually trying – I wanted actually to try how you say that first number – primary number?…Prime number, yeah. (Case 31, female, 30s)

Conclusions and Conceptual Understanding

In the cases with the lowest level of APE engagement, this exhibit functioned as a novel way to calculate square root. Both men used the exhibit to do this and left quickly. Among the mid-level APE engagements, however, both fathers clearly recognized and were familiar with the physics principles involved. They used the exhibit as an opportunity to demonstrate the principles to their children, but did not, according to interviews, enlarge their own conceptions of the relationships.

We did not get extensive interview data with children. The parents we interviewed assumed the 8- to 11-year-olds focused on the concept of square root. The little interview data we have

indicates that this may have been the case. Whether the children understood the relationship between the placement of the marble on the ramp and the distance the marble flew is unclear. One child told us:

> *Well, we did the square root . . . I learned more math. (Case 8, female, 8)*

The father with his 4-year-old son explained how the exhibit worked on more than one level for these two age groups.

> *It was like a little puzzle. It's much more interactive than just turning a dial and watching a little umbrella spin, even though that's cool to read and figure out how that works. It's just more hands-on, my son, for him, trying to teach him motor skills, putting the marble in the biggest one. (Case 14, male, 30s)*

Social Engagement

Data sets included three cases of the exhibit being used alone (two low APE and one high APE engagements.) Two men appeared to have split off from their larger visiting groups and were wandering on their own. Both explained that they left the exhibit to find or rejoin their larger visiting group.

The Canadian doctor engaged intensely alone but left the exhibit to find her boyfriend. The father and his 4-year-old son appeared to have parallel but individual experiences at the same exhibit.

The other two other cases the primary interaction was between fathers and their daughters. The two fathers, each with school-age children, moved into a teaching role (Cases 8 and 12), exemplified by assessing what their children could get from the exhibit and using the exhibit as a guided demonstration of these concepts. In one case, the father "corrected" a child when she tried to launch multiple marbles. One father explained what he perceived as the purpose of the exhibit and why he guided his children's experience.

> *And with the kids it really was just trying to get them to focus on the purpose of the exhibit, which was beyond my 8-year-old son and my daughter over there. (Case 8, male, 40s)*

Emotional Engagement

Both visitors with lower APE engagement had only minimal emotional engagement with the exhibit. Each found it mildly interesting, but one seemed to consider the exhibit too challenging.

> *I think that was pretty neat. It took a lot of mind work to figure all this out. And also, I saw the calculator on the side, so I'm assuming that it probably had something to do with mathematics and so forth. So, it took a lot to figure that one out. (Case 3, male, about 60)*

Among other cases, we found two primary sources of emotional satisfaction, using the exhibit "together," and having the opportunity to solve a challenging problem. Social interaction was a

primary source of satisfaction for some adults and most of the children. One child told us the reason she liked the exhibit was "I like doing it together" (Case 8, female, 8).

But other visitors appreciated the design of the exhibit. One cited the multiple dimensions of the exhibit.

> *It's a very clever exhibit . . . It's just really cool . . . A lot of dimensions to it and an awful lot of ways to know – a lot of things you can come away from knowing. That's really cool about that. I like that for me…You learn something and maybe there are some more things that – we could come back next year and learn other things. And we come back again the next year and learn other things. (Case 12, male, 50s)*

People involved in the two high APE engagements found satisfaction in the challenge of the exhibit. Each described the challenge as fun.

> *I like math and physics and just kind of challenging my head to see if I can come up with something…it was fun. It was like a little puzzle. It's much more interactive than just turning a dial and watching a little umbrella spin, even though that's cool to read and figure out how that works. (Case 14, male, 30s)*

> *I really, really enjoyed it. It's fun. I like things like that. It depends on your taste, but I like things like that…That I have to think -- that makes me think. How does it work? Or what's the – when there is a solution I can find, it's even better, and that pretty much does it. It's fun! (Case 31, female, 30s)*

However, one father, with a medium level of APE engagement, expressed some dissatisfaction with his experience and that of his children. He established his expertise by telling us that he had been in the Physics Department at Berkley. He was dissatisfied with what his children got out of it. While he had clearly guided his children's experience into calculation of square root and had "corrected" his daughter's attempt to launch multiple marbles, he wanted "more physics" in the experience to get people to calculate where the ball would land. This indicated to us that he perceived the exhibit to have one primary point and to be a demonstration of that point. He indicated he thought this would work only with teenagers and not with children as young as his own (Case 8, male late 40s).

Relationship between Physical and Intellectual Engagement

Based on these observations, this appears to be an exhibit where it is difficult to judge the intellectual engagement by the physical engagement alone. Mid-level and higher levels of APE engagement were difficult to assess without understanding the specific intellectual processes underlying the activities. We believe that this may have been the reason for the consensus among the team and some data collectors that this exhibit had limited capacity for APE engagement. We found two cases of extensive exploration at this exhibit. Like *Circuit Workbench* in the Phase 1 study, previous content knowledge appeared necessary to lead to the exploratory activities, and this was only when adults did not feel motivated to guide their children's experiences. In addition, this exhibit may also have been more attractive for males than for females; in four of the five cases we observed, men were the first to approach this exhibit. One man told us he was using the exhibit alone because the group of family and friends with whom he was visiting was

"just trying out the more touchy-feely type stuff" (Case 11, male, mid-30s). This is a question to explore in the tracking-and-timing study, where a random sample could provide additional information to answer questions about the overall level of exhibit attraction among males and females.

Heat Camera

Findings

- **Range of Visitors**: *Heat Camera* appeared to attract groups of both adults and adults and children to engage at the exhibit, and high levels of APE engagement were observed among both adult groups and a group with children.
- **Physical Engagement**. In the cases we observed, visitors had relatively long times of engagement (45 seconds to 9.5 minutes) compared to visitors we observed at other exhibits. In interviews, however, we found that people did leave to allow others to use the exhibit when the museum was crowded. Visitors showed a wide range of activities, including several instances of novel ideas that moved beyond the activities directly suggested in the label.
- **Intellectual Engagement**. While articulated intellectual activity may not have been as high as in other exhibits, we observed implicit experimentation to test variables, and a respondent in one case articulated a theory related to blood circulation. Visitors appeared to make personal connections to the phenomena, although the types of connections differed by visitor gender. Males appeared to associate the phenomenon with military night vision equipment, and females appeared to connect the phenomenon to medical imaging. There were some misperceptions among a few visitors that the images were X-rays.
- **Social Engagement**. While individuals appeared very involved in their own participation, there was a great deal of conversation and showcasing, that is, one visitor drawing other people's attention to some effect that he or she had created. Members of various visiting groups were able to participate without interfering with each other's engagement. This exhibit did not appear to elicit teaching-demonstration social roles among adults with children; the social playing field was level for people of various ages and entering knowledge.
- **Emotional Engagement**. Satisfaction was connected to delight in the unfamiliar images of visitors' own bodies, the effects achieved by manipulating the image, humor, and participation at the exhibit as a group.
- **Capacity for APE Engagement**: *Heat Camera* appeared to have the highest overall capacity to elicit and stimulate APE engagements. We found that the intriguing phenomena provided intellectual entry points to a wide range of visitors and leveled the social playing field. The lengths-of-engagement were relatively long compare to other exhibits, and the range of activities was the highest. While engagement was vulnerable to crowded conditions, visitors did not interfere with each other's activities. Emotional engagement was closely tied to visitors' focus on their own bodies and the intriguing and manipulatable nature of the phenomenon.

Cases and Range of APE Engagement

Table 6: Heat Camera Cases and Groups

CASE #	Exhibit	Residence	Exhibit Use Group	# of Respondents by Case	Total Time (decimal min)	Physical Engagement Rating	Intellectual Engagement Rating	Social Engagement Rating	Emotional Engagement Rating	APE Engagement Rating	Level of APE Engagement
9	*Heat Camera*	Utah	mother, father, two sons, and male family friend	2	4.3	3	2	3	4	2	**Low**
10	*Heat Camera*	probably local	male alone, 40s	1	0.8	2	4	1	2	2	**Low**
4	*Heat Camera*	El Sabronte, CA	mother, father, and daughter, and son nearby (less engaged)	4	4.8	3	4	4	4	3	**Medium**
28	*Heat Camera*	Calistoga, CA	grandmother, parents, and two sons	5	8.3	4	3	4	4	4	**Medium**
26	*Heat Camera*	San Francisco and visitors from Sacramento, CA	two fathers, two sons, and grandfather	5	9.5	5	4	5	5	5	**High**
30	*Heat Camera*	Redding, CA	mom and two adult daughters	3	6.0	5	5	5	5	5	**High**

Physical Engagement

Time of Activities

Overall, we noted some of the longest holding times of the study among the cases we observed at *Heat Camera.* But some shorter engagements had a higher level of APE engagement than the longer ones did. Lengths of engagement for the cases of low APE engagement (Cases 9 and 10) were 4.3 minutes and 45 seconds. Lengths-of-engagement for cases of medium APE engagement (Cases 4 and 28) were 4.6 minutes and 8.3 minutes. For high levels of APE engagement (Cases 26 and 30), lengths of engagement were 9.5 minutes and 6.0 minutes.

Range of Activities and Independence from Labels

In both cases of lower APE engagement, the physical activities we observed were limited to those suggested by the labels. Both engagements began with individuals noticing the screen and picking up the hair dryer. In one multigenerational group (Case 9), a 7-year-old boy approached first and was followed by his mother. The two men followed. All sat on the bench and used the tattoo activities; several licked their lips. The woman in the group talked to other members, and everyone laughed and smiled. The father in this group told us they left because they had used all the activities. The man alone (Case 10) used the hair dryer to warm up his hand and made more than one tattoo. He smiled as he used the activities. This man told us he was with a larger group and planned to go find them and bring them back to the exhibit.

Both groups with medium levels of engagement visited during crowded times at the museum. They made considerable use of cued activities and did not move far beyond the labels. Both groups told us that they had not seen the label until they were seated and had been attracted to the exhibit by the image on the screen. In Case 4, mother approached first and stood behind and to the left of the bench (facing the screen) among several other people crowded around the exhibit. Her husband joined her. They waved to the camera and talked but did not use any of the panels at the back of the exhibit. They appeared to be looking for a way to find a seat on the bench. The woman walked behind the bench and found a seat. Her husband stood next to her and their daughter joined them. The three talked and laughed, used the tattoos, and the woman rubbed her hands on the daughters face, as she later explained, “putting on make up." The family of five in Case 28 also used the exhibit in crowded conditions. The two boys sat during most of the engagement, but the adults sat and then moved around exhibit elements, with the mother interacting with the mirrors at the back of the bench. In addition to using most of the cued activities, the boys held their heads on the metal table. Comments were heard included “Look at this, Mom!” and “That’s hilarious!” as the individual created various effects.

Both high-level APE engagements involved physical activities not cued by the label and considerable laughter and conversation. Again, both groups told us that they did not see the label until they sat down, and they were attracted to the exhibit by the image on the screen. In Case 30, the mother and her two adult daughters opened their mouths, stuck out their tongues, and compared heat levels on various parts of their bodies. They also used the hair dryer on various body parts. One sister made “war paint” impressions on her face with her hands, and the other sister “put on blush” and turned her head as if putting on makeup in a mirror. We learned in the interview that one of the sisters was ill and had a fever. The group noticed her higher body temperature on the screen and used it as a point of comparison to the two other group members. This group told us that they would have stayed longer if other people had not been waiting.

Case 26 was the longest of all six *Heat Camera* engagements. This case also involved the most imaginative and extensive set of explorations beyond the label. In addition to using all the cued activities, one dad noticed the heat difference between the screen images of his coffee cup and the boys’ soda cans. The cup and cans were compared, and then used to change body temperature on various parts. First, the man used his coffee cup to put on “lipstick” by changing his lip temperature. Then the dad with the coffee used his warmed hand to make a handprint on

the other dad's bald head in the screen image. The bald-headed dad rolled his son's soda can back and forth across his head to "make hair." His friend extended this process by warming his hand, holding it against the star tattoo, and then holding his hand on his friend's bald head to create a star tattoo that showed on the screen. In addition there was a great deal of conversation among group members with the dads explaining to their sons what the effects would be if you held hot and cold things on your body and jokes and laugher about using the man's bald head in the heat transfer processes. The grandfather in this engagement stayed for the first 3 minutes of the engagement, then left and used other exhibits nearby.

All groups used the exhibit in appropriate ways, and two cases moved beyond the activities suggested by the label. All the groups appeared to enter the engagement the same way, by noticing the image on the screen, then approaching the bench, looking for a seat, and finally noticing the additional elements and the label. Several of the groups left when they saw other people were waiting. Crowding appeared to affect both the length and range of engagement at this exhibit.

Intellectual Engagement

In both cases of low APE engagement, we interviewed adult males. Both expected and wanted the exhibit to have more focused scientific content and point. In both interviews, the men talked about the relationship of play and learning and perceived the exhibit as inadequate because it did not provide information that was more direct. The man who used the exhibit alone clearly interpreted the exhibit to be a demonstration of an infrared camera (like ones used in airports), and he critiqued his experience and the exhibit on this basis.

> *I'm always surprised that there are other frequencies out there that you can't perceive that are obviously available to other animals or to cameras or other ways of picking up things that are going past you…I think it's just a reminder of how limited our sense impressions of the world are. It gives us a very small focus picture of the world. There is a lot of other stuff happening out there that you wouldn't know about unless you had a special camera or some kind of equipment. (Case 10, male, 40s)*

This man left the exhibit with several questions, but he wanted these questions to be addressed through direct presentation of information on labels, and he believed that such direct presentation was the way his son (using another exhibit nearby during the observation) learned.

I didn't see much of an explanation of radiation and different sort of energy signatures of the radiation or anything that technical. So, I don't know if they're trying to keep people from getting scared off by that or what. Because I know when my kid went over there, he didn't really pick up anything about – and probably noticed that he could see the heat. But I don't know how much of that he really got. I would have liked a little more explanation and sort of technical – like how much is the infrared seeing? Can you adjust it to different heat signatures? How sensitive is it to that? Can you adjust the sensitivity upwards or downwards? How much energy is it picking up? Things like that would be interesting to me. Can it detect a one-degree temperature difference from a football field away? What are the sensitivities of these machines? What is it looking at? How does it measure? Something a little bit about the technical aspects of how the machinery works to detect this. And then what kind of translation it's making to put it onto a screen? Can you tell the temperature of something at the surface by the intensity on the screen? Or is it a function of how far it is from the camera? If you held it in closer, would it show as a higher temperature? Something like that – because those are the questions that I had. How does the thing work? (Case 10, male, 40s)

The father in Case 9, who identified himself as a college-level science educator, said that he did not think the exhibit had a point and that he expected an exhibit to demonstrate a point to benefit children. This father told us that he believed that play was fine for adults, but children needed specific content.

I think it could be better . . . the exhibit doesn't really have a point. A lot of these things are demonstrating points, but the exhibit itself doesn't really say what the child is supposed to learn from it – unless I missed it…As an educator in science, I feel like [exhibits should] demonstrate something…For children, I would rather have something that's mildly educational at each exhibit…I'm happy to not have a point. I'm not going to change my career just because I learned something about heat. (Case 9, male, 30s)

While the man in Case 9 had many questions, they were not questions that could be directly explored in the exhibit. Both men appeared to have fairly high existing knowledge of infrared cameras and the measurement of heat. We only were able to talk briefly to the woman in Case 9, but her experience appeared rather different. The exhibit reminded her of "zombie movies." And she gave us some idea that she was testing some of her ideas by observation. She noted:

The hair dryer – I thought it would shoot out and you'd see the heat coming out. (Case 9, female, 30s)

In the cases of medium levels of APE engagement, Case 28 appeared to have had a lower intellectual level of engagement than Case 4. In the Case 4 interview, neither the mother nor fathers were very articulate about their questions. They said that they were exploring heat differences among various parts of their bodies. The woman said the exhibit reminded her of "an X-ray," another association with medical technology. The father clearly understood that the exhibit involved an infrared camera, and his facial expression revealed surprise when his wife and daughter talked about the exhibit and shared their connections and conceptions. Both the

wife and daughter recognized they were seeing their bodies in a different way, but connected it to X-ray technology.

> *Oh, I think it was great to see the skeleton and see your features in a different light, in a different color – I just thought . . . it was an engineering feat just to go up and sit down and you're not visibly, physically seeing the radiology. It's very streamlined. And to see this high technology these days and sit on a bench and look at the screen in front of you and (inaudible) the full body image…I just had a mammogram and chest X-rays. This machinery is much smaller . . . (Case 4, female, mid-30)*
>
> *I could see your innards. (Case 4, female, 10)*

In the two cases of high-level APE engagement, we found Case 26 to have a slightly higher level of intellectual engagement than did Case 30. In Case 26, "the guys" appeared to be testing the ability of the camera to pick up transferred heat, and they found humorous and creative ways to do this. In Case 30, the women provided some evidence of developing an underlying theory and testing it. Both cases showed high degrees of intellectual engagement in processes such as observation, prediction, and testing characteristic of the scientific process. In neither case, however, did individuals appear to have formulated the idea that they were involved in scientific process.

The adults in Case 26 connected the exhibit experience to infrared night equipment used in the military. One told us that he explained what they were seeing to the boys as "cameras that take pictures of heat." But both adult males made the military connection.

> *And I also think about in the Army, how they use those infrared cameras – you know, the heat-seeking cameras and the goggles. It's interesting because now you can see how it works. (Case 26, male, mid-30)*
>
> *I was just thinking about that Army thing that stuck in my head. Because when I was playing with it, I was like, oh yeah, that is like the night-vision goggles. (Case 26, male, mid-30s)*

In Case 30, the three women had several questions, made observations, and used exhibit elements to explore these questions.

One of the oddly fortuitous observations involved the sister who had a fever.

> *…She was like, "Why am I so white?" And then when we read what it says – the warmer you are, the whiter you are, and the colder, the darker, then it made sense why she was so white, because she's sick. And then my mom's nose being really black, that was kind of funny, because it's so cold . . . . . And her fingers [the other sister's] were dark. (Case 30, female, mid-30s)*

The group described several questions they had.

Why are my cheeks so black? Why do I look like a monkey? Why do you guys look okay? (Laughter) (Case 30, female, mid-30s)

One woman had developed and evidently tested a theory of the underlying reasons for what she observed.

I've never seen anything tested like that before. The most you ever hear is if you have a temperature . . . . You know, you think that your whole body is 98.6 when you're healthy. You don't think about the blood flowing to different parts. (Case 30, female, mid-30s)

Social Engagement

The social engagement at this exhibit was quite high overall among all cases except for the man using the exhibit alone in Case 10. Visitors in all cases involving groups touched and rubbed their own bodies and those of other group members. They also talked and laughed. Questions tended to be implicit, and most conversations involved calling other group members to watch or observe some element. In Case 26, one father did explain the camera to the boys.

Social interactions appeared lively and focused exploration of the phenomenon rather than children's use of the exhibit and learning of specific content. Even among groups where parents perceived that the exhibit "should" be demonstrating a particular scientific point, the exhibit appeared to prevent them from taking a dominating role, either physically or conversationally. No parent was observed in an exclusively teaching role as they were at *Gravity Powered Calculator* or at *Circuit Workbench* in Phase 1. That is, while adults explained and supported children at this exhibit, children appeared to initiate and sequence many of their own physical activities, and conversely, parents appeared to initiate and explore their own questions. In addition, group members with higher and lower levels of knowledge (e.g. the man with higher knowledge than the woman and the child in Case 4 and the fathers and the sons in Case 26) seemed to be able to engage on a socially level playing field. In addition, most likely because the nature of the interaction rewarded novel behavior (e.g. putting on makeup or transferring the tattoo to the man's bald head), we never heard parents correcting children at this exhibit. The social engagement appeared to be very egalitarian at *Heat Camera*.

Emotional Engagement

Emotional engagement at *Heat Camera* was high across all levels of APE engagement. There appeared to be several types of satisfaction at this exhibit. The most obvious one involved visitors' focus on their bodies.

Because it's different than the other ones where you have to visualize what you're seeing. You can see yourself in it. (Case 4, female, 10)

Like [his daughter] said, this is one of the exhibits that reflects on you. Other exhibits are mechanical and are broader. This one you're actually in the exhibit. You can see how the effects play on yourself. (Case 4, male, mid-30s)

I always think it's kind of fun to see where your heat is coming out of your body -- what parts are shaded. And it's a cold day, so I'm bundled up. (Case 10, male, 40s)

Some visitors found their images humorous.

And I looked like a clown because I had a dark nose and white – really white around here. (Case 30, female, mid-30s)

Among the groups, the other area of satisfaction appeared to be using the exhibit with family members or friends.

Because it seemed like we all got involved in it. Like in a group, it was easy to get everybody involved and messing around. Even my friend's father was playing with it. (Case 26, male, mid-30s)

Finally, another area appeared to be the rewards provided by the exhibit for novel and humorous activities. In interviews, visitors enjoyed telling us about something the thought was particularly clever or humorous that they had done at the exhibit.

I was trying to put makeup on her and rubbing her cheek. (Case 4, female, mid-30s)

And my friend is bald, so we were putting the cold things on his head to make it look like he had hair. (Case 26, male, mid-30s)

The only visitors who appeared to have less than satisfactory experiences were adult males who wanted the exhibit to have a focused, scientific point. This included the man alone in Case 10, and the science professor in Case 9. The father in Case 10 specifically stated that he liked to visit museums with his 13-year-old son. On this occasion, his son and his son's friend were off on their own using an exhibit nearby. This father seemed a little lonely on this visit, perhaps missing the younger child who enjoyed his teaching role.

He's got a little friend with him today, so I let him just kind of romp around a little bit. But I like to show him some of that kind of stuff. (Case 10, male, mid-30s)

Given the level social playing field facilitated by this exhibit, we suspect that the less-than-satisfactory emotional engagements appeared to among men with a higher level of scientific knowledge who enjoyed taking a teaching-demonstrating role with the children in their groups, that is, directing the children's experience. Unlike at other exhibits, such as *Gravity Powered Calculator* or even *3-D Shapes*, here the experience of even the youngest children appeared to be self-directed. For adults who are used to being in charge and displaying their knowledge, this exhibit may be little frustrating.

Pulley Table

Findings

- **Range of Visitors**. Among the cases we observed, the nature of this exhibit, both in content and physical arrangement, appeared to promote adult-child joint engagement. Adults perceived the exhibit to have a content level too simple to spark their interest.

Children looking at the exhibit without adult encouragement did not appear stimulated to further exploration, and one indicated he was expecting a guided discovery.

- **Intellectual Engagement**. Adult intellectual engagement was highly connected to guiding the experience of their children. The topic and content appeared to be highly connected to some adult males' identity and occupations. Children's experiences appeared connected to the sequence and ratios of the pulley connections.
- **Social Engagement**. Unlike *Heat Camera*, which leveled the social playing field, this exhibit appeared to promote interactions where adults guided the intellectual and physical engagement
- **Emotional Engagement**. Achieving results was one satisfaction at this exhibit. But adults appeared to take satisfaction in sharing their values for the content and teaching their children. Children similarly appeared to enjoy using the exhibit with adults and making objects on the table operate through the connection of the pulleys.
- **Capacity for APE Engagement**: Overall, at *Pulley Table*, we found a relatively lower level of capacity for APE engagement. Intellectually the nature of the phenomenon appeared to elicit connections to previous experience and expertise, making some visitors less willing to begin engagement and motivating adults to share their knowledge in directive ways. This perception appeared to influence the nature of the social engagement. In addition, children leading groups appeared to perceive the exhibit as a guided discovery, and they appeared to looking for large physical effects in selecting exhibits to use.

Cases and Range of APE Engagement

Table 7: Pulley Table Cases and Groups

CASE #	Exhibit	Residence	# of Respondents by Case	Exhibit Use Group	Total Time (decimal minutes)	Physical Engagement Rating	Intellectual Engagement Rating	Social Engagement Rating	Emotional Engagement Rating	APE Engagement Rating	Level of APE Engagement
2	*Pulley Table*	San Ramon, CA	1	male alone	1.6	1	1	1	1	1	**Low**
21	*Pulley Table*	AZ	2	grandmother with grandson	1.0	2	2	2	2	2	**Low**
22	*Pulley Table*	TX	2	grandfather with grand-daughter	0.6	1	1	2	3	1	**Low**
25	*Pulley Table*	unknown	2	husband and wife	> 1.0	1	1	2	2	1	**Low**
27	*Pulley Table*	unknown	3	mother and two daughters	0.2	0	1	0	1	0	**Low**
24	*Pulley Table*	unknown	3	father and son--mother observing nearby	5.0	3	3	2	3	3	**Medium**
18	*Pulley Table*	Bay Area	3	family – but father used primarily alone and mother used with child, almost 6	6.5	4	5	4	4	4	**High**

Physical Engagement

Time of Activities
Cases of low-level APE engagement ranged from 10 seconds to 1.6 minutes. The medium level of engagement was 5 minutes, and the high level of APE engagement was 6 minutes.

Range of Activities and Independence from Labels
All the low APE engagements involved minimal physical interaction with the exhibit and no conversations. In Case 27, a mother with two young daughters stopped and looked at the table briefly, but no one in the group touched the exhibit. In Cases 21 and 22, each grandparent followed the grandchild to the exhibit and watched as the child touched one or two items, then followed as the child left. The husband and wife (Case 25) briefly watched children at the exhibit before approaching, touched one or two items, read the label, and left.

During the medium-level APE engagement (Case 24), the father and son approached the exhibit together and used four different stations. The mother stood nearby but did not interact with any exhibit elements. First, the father and son moved bands to reconfigure the fan, and the mother commented, "That looks like something your father or grandfather would make." At one point, the father moved bands from a smaller to larger pulley to demonstrate and explain to his son the relationship between the size of the wheel and the speed of the fan. The boy walked to the umbrella table alone and turned the pulley with the crank on it to make the umbrella spin. The man moved to the motor table and said to his son, "Look at this," and the son joined him. The mother moved to a nearby exhibit and was followed by the father and son, but the father soon returned and worked at the music box station. The boy joined his father, and they connected pulleys until the music box played. The father walked away, and the boy continued to turn the crank but soon left, too.

In Case 18, which we classified as a high level of APE engagement, we saw a family use the exhibit both independently and together, show their completed tasks, and draw the child's attention to the cause-and-effect relationship between the pulleys and other exhibit elements. They asked the almost 6-year-old to make predictions. This family had a moderate amount of conversation in Chinese that appeared to be related to what they were doing at the exhibit. The mother scouted out the exhibit and called over the father and daughter over when other visitors left. The daughter reached first for a pulley, and the father moved to the other side of the table near the fan. The father worked independently through several iterations of connections until he made all the fans work at the same time. Meanwhile, mother and daughter used the motorized pulley apparatus together. When the father finally got all the fans turning at the same time, he called over his wife and daughter to show them. The daughter took over turning the pulley to make the fans spin. The mother reached in, disconnected one of the pulleys near the fan, and told her daughter to try turning the pulley. The fans did not spin this time. Mom then connected the pulley again, and indicated to the girl to try again. She did and the fans moved. The child continued turning the crank as her father moved to another exhibit. Wife and daughter soon followed him.

In all the observations, visitors used the exhibit elements in appropriate ways, and only the adults who left quickly were observed reading the labels. This exhibit appeared to be easy to use without instructions. Visitors in both the medium- and high-level cases selected and

accomplished tasks using the apparatus. The people we observed tended to walk up to the exhibit at the end near the fans, probably because this end of the exhibit faced them as they moved through the museum.

In cases 24 and 18, conversation included brief directions, generally from parent to child when they were working collaboratively, parents pointing out the effects to children, and showcasing the completed tasks. The mother in Case 24] connected the experience to family occupations.

Intellectual Engagement

In all the cases of low APE interaction, visitors appeared to be assessing the exhibit and deciding not to use it. In the case of the mother with two young daughters (Case 27), she explained that she was looking for her sister and her sister's children, and it was time to go home. She glanced at the exhibit and thought it was about building something, and thought it would take a long time to use. She wasn't especially attracted to the exhibit, and she was in a hurry.

In both cases with grandparents with grandchildren, the adults looked weary. Their tone and comments indicated they were a bit frustrated with their grandchildren. The grandmother (Case 21) was with the child on vacation, and they had already been to several San Francisco sites that day. Both seemed weary, and there appeared to be some tension between the two. She told us that she was letting the child choose the exhibit. The boy seemed to expect the exhibit to do something bigger or more obvious, and he thought that his brief interaction was all that the exhibit "could" do.

> *I thought it was going to be something – well, I thought it was going to be something else. But I knew it was going to be where you turn the pulleys and they do something. (Case 21, male, age 10)*

His grandmother realized there was more to the exhibit, and indicated some displeasure with the amount of motion, noise, and activity during a crowded time at the museum.

> *I was going to explain to him the different sizes and motion, but we didn't get to it. [There is] a lot of stimulation in the room . ... (Case 21, female, 60s)*

The grandfather explained that his son had died and he was raising his granddaughter. He told us that he was interested in the exhibit and in using it with his granddaughter, but she was not.

> *She wasn't into it. I was. She left. I've got to keep an eye on her. I looked at it for a little bit. And if she would stay still long enough, I would have explained it to her.…I do a lot of work in that area – mechanical and air-conditioning work and stuff. Do a lot of pulleys and belts.... I just wanted to show her how it worked and the differences in the ratios – in the pulley ratios. . . . If it doesn't splash or flow or something, she just goes on. And I was trying to look over my shoulder and watch her and do the exhibit, too. (Case 22, male, 60s)*

Adults alone appeared to find the content too simple. In Case 2, the man said that he already understood the concepts in the exhibit. He explained why he didn't stay longer.

I think it's interesting for kids…Not for adults. (Case 2, male, mid-30s)

We found similar assessments about the overall level of the content in the interview with the engineering professor and his wife (Case 25), who had bypassed the elements on the table that they were familiar with. They had both been intrigued by the umbrella because intuitively it didn't make sense. His wife continued:

> *Yeah, I was going to say that. Things that I know already, I just kind of fly by. That's pretty much how I – pulleys, I knew what was going on. I was enjoying the kids doing it. (Case 25, female, mid-30s)*

In Case 24, the medium level of APE engagement, the father we interviewed also indicated that he was very familiar with the content. His own intellectual engagement at the exhibit was focused on teaching and demonstrating concepts to his son.

> *I was a physics major in college. I don't think there was anything that I didn't know. (Laughs)…I find it interesting to play with it a little bit, especially to show somebody like him [his son] …I was explaining the relationship of the size of the pulleys. I pretty much thought that's what the exhibit was trying to accomplish. (Case 24, male, mid-30s)*

Unfortunately, we were not able to get this boy's perspective. One thing we did observe: In the interview the father told us that they returned to the exhibit because his son asked him to explain how the music box worked. We observed that the father returned and called the son over to the exhibit. It may be that fathers initiate and maintain their teaching-demonstrating role through behaviors that they interpret as responding to children's questions.

In the Case 18, which we identified as a high level of APE engagement, we interviewed the mother from the group. Her husband had appeared absorbed in making all the fans work together during the engagement. When asked about her own engagement, she explained how she worked with her daughter. Clearly, her intellectual engagement was focused on her child's learning. At one point, however, she noted that she tended not to explain things to her daughter but rather she asked questions.

> *I asked her what if I took up one of the -- what do you call that? The ribbon? [The rubber bands on the exhibit] …What if I moved out this one after – whether she thought the pulley will move or not? And she said yes. I said, "Okay, just try." And she tried and it didn't move. So, I asked her why, and she said because it didn't touch the ribbon. (Case 18, female, mid-30s)*

Social Engagement

Among the low levels of APE engagement, we saw adult groups choosing not to use the exhibit because they were familiar with the content or decided the exhibit was for children. These two ideas were probably closely related in their minds.

The two grandparents we observed were following the leads of their grandchildren. Neither of the children chose to engagement very long at *Pulley Table*. The grandfather expressed some

regret about his granddaughter's choice because he was interested and wanted to explain the phenomena to her.

The social engagements in both the medium and high level of APE engagement involved parents managing learning situations. The father (Case 24) used words like explain and demonstrate in his interview to describe what he was doing with his son. He noted his high level of knowledge in the interview (i.e., "I was a physics major in college..."), and appeared to be directing and guiding his son's engagement.

In contrast, the mother in Case 18 asked her daughter questions and asked her to predict what would happen. We also noted that the father in this engagement, while quite involved in his own tasks, stayed nearby, and at one point called the mother and daughter over to see what he had done. He cued his daughter to use the pulley system he had made. The mother explained in her interview that this was no accident.

> *I know dads and some of my friends come here all the time. Fathers were the ones who were most interested in doing things themselves – doing experiments, whatever. . . . So this time I told my husband, I said, "Don't try to leave us behind you." . . . Like my daughter used to say, "Dad's lost again. Oh, we lost Dad. We lost Dad," because she couldn't find him. (Case 18, female, mid-30s)*

Emotional Engagement

One source of satisfaction at this exhibit appeared to be making something on the table move or operate by connecting the pulleys. In Case 18, the father called his wife and daughter over to see what he had done. The father and son in Case 24 worked intently to get the music box to work.

Another source of satisfaction at this exhibit was the parents' opportunity to use the exhibit with their children. Both the father in Case 24 and mother in Case 27 clearly indicated that their pleasure in this exhibit was tied to their interactions with their children. The mother in Case 27 made associations to this exhibit and another exhibit on pulleys at a children's museum that she had used with her daughter. When asked why she left, the mother in Case 27 returned to the topic of her daughter's learning.

> *I think my daughter left. Probably I would have spent a little bit more time there because I really wanted her to observe to see – just watch a little bit of how things work, in which direction it rotates – that matters, too. And how to get everything connected. (Case 27, female, mid-30s)*

When ask to rate the exhibit, this mother rated it very high, primarily because her husband was engaged and stayed with them at the exhibit the entire time. She recalled that she had told him that he should stay with them because their daughter was "old enough to understand things now."

For the father in Case 24, however, the experience may have had deeper associations. During the engagement, his wife mentioned that the exhibit looked like something his father would do. Passing along the appreciation for things valued in his family appeared meaningful to this father, whose own occupation was physics. He told us about this in the interview.

My father and my grandfather were engineers…my grandfather was an electrical engineer, but he liked to tinker with mechanics and so forth. So he would – in order to do something, he would use old ways of doing it, not that this is necessarily old. But he would use pulleys and electric motors and everything -- something very elaborate to get something done like that -- very crude, but simple and profound at the same time. He would do something like that. He would appreciate it. (Case 24, male, early 40s)

Visible Vibrations

Findings

- **Range of Visitors**. *Visible Vibrations* appeared to attract both adults and adults with children, but the only case of high-level APE engagement was a teenage girl currently taking physics in high school, who used the exhibit alone.
- **Physical Engagement**. Most respondents engaged in a considerable range of physical activities, but most of these were label-directed (and unsuccessful) attempts to form a pattern. Only a 17-year-old girl, using the exhibit alone, appeared to engage beyond the label through arranging the sand, using all the disks, and making frequent small adjustments to observe subtle differences in the phenomena. While the range of times at the exhibit was relatively long, only one observation included the successful formation of a pattern.
- **Intellectual Engagement**. Intellectually most of the observations were focused on "getting the exhibit to work." Only in one observation did the respondent fully explore the relationships among frequency levels and plate shapes; she also made rich personal connections to the phenomenon and left with several interesting questions.
- **Social Engagement**. We saw the exhibit used in several configurations, but the visitor alone was the most successful in using the exhibit. She and an adult woman both indicated a preference for using exhibits alone to allow exploration and prevent interference by other visitors. In groups, we observed male adults directing engagement of an adult female and of children.
- **Emotional Engagement**. Several visitors were somewhat frustrated by this exhibit, but one visitor, the case of a high-APE engagement, was satisfied by her experience. But even this visitor did not indicate a high degree of emotional engagement.
- **Capacity for APE Engagement**: The capacity for APE engagement at this exhibit appeared to be influenced by the physical interface and time required to see changes in the phenomenon. While time of engagement was relatively long, this appeared to be connected to the visitors' challenge and frustration in trying to "get the exhibit to work." Gender-based differences in perceptions of the cause were observed, as was the tendency of adult males to manage the experience of others.

Cases and Levels of APE Engagement

We observed five cases at *Visible Vibrations*, but it was difficult to classify four of the cases (7, 17, 20, and 34) into either low or medium levels of APE engagement because only two groups were able to get the shapes to form. Multiple repetitions of the phenomenon appeared to be attempts to achieve the goal rather than exploration of the phenomenon. One observation, Case

33, involving a 17-year-old Asian girl, was clearly a case of high APE engagement. For discussion, we will simply refer to the other cases in this study as low-medium cases of APE engagement.

Table 8: Visible Vibrations Cases and Groups

CASE #	Exhibit	Residence	# of Respondents by Case	Exhibit Use Group	Total Time (decimal minutes)	Physical Engagement Ratings	Intellectual Engagement Ratings	Social Engagement Ratings	Emotional Engagement Ratings	APE Engagement Ratings	Level of APE
7	*Visible Vibrations*	unknown	1	woman alone	4.0	3	3	1	4	3	**Low-Medium**
34	*Visible Vibrations*	unknown	3	woman, daughter, and man (father or grandfather)	2.3	1	0	2	4	2	**Low-Medium**
17	*Visible Vibrations*	unknown	4	mother, father, daughter, and son	6.0	2	1	2	1	2	**Low-Medium**
20	*Visible Vibrations*	unknown	2	father and daughter	5.2	3	2	3	3	3	**Low-Medium**
33	*Visible Vibrations*	tourist	1	teenage girl alone	11.0	5	5	0	4	5	**High**

Physical Engagement

Time of Activities
Overall, the times of engagement ranged from 2.3 to 11 minutes. Low-medium cases had lengths of engagement of 2.3 minutes (Case 34), 4.0 minutes (Case 7), 5.2 minutes (Case 20), and 6.0 minutes (Case 17). The high-level APE engagement was 11.0 minutes.

Range of Activities and Independence from Labels
One of the difficulties in categorizing the cases was the variable success of the groups in getting shapes to form. In one instance (Case 7), the group achieved a shape on the plate by turning the frequency knob and then immediately left the exhibit. Two cases (7 and 20) involved visitors changing plates, sprinkling sand, and turning the frequency dial multiple times. In interviews we learned that the reason for the iterations was not exploration but failure in both cases to get the shapes to form. In Case 17, each group member at some point changed a plate, but it was unclear from a brief conversation at the end of the interview whether any of the individuals had been able to form patterns.

Every group we observed looked at the label, often many times, and stressed that it was essential to read the label to use the exhibit. Several people mentioned that, in general, they like to try to figure out exhibits for themselves first, but at this exhibit, they had to read the label.

> *But I like to just try it, figure it out before I read the instructions because that's no fun. But I was kind of confused on that one [Visible Vibrations]. I mean, without the instructions, you don't really know what to do exactly. Like if you put too much sand on it, then it won't work. (Case 33, female, 17)*

Although she clearly followed the label instructions, the case of high APE engagement at this exhibit showed a wide range of activities and numerous instances of success in forming shapes. She used different shapes, tried spreading the sand, adjusted the knobs quickly and slowly, and made observations of the patterns themselves. She also noted how well the shapes formed at different frequency ranges. Her activities, while within the scope of those suggested in the label, involved considerable subtlety and use of the exhibit elements. Her observations were careful and extended; she noted small differences in patterns and the processes by which they were formed.

While all the activities we saw at this exhibit were appropriate, the exhibit did not appear to have multiple entry points. In all cases, visitors read the label shortly after approaching the exhibit. In interviews, they reported that they read the label to understand what the exhibit was about and how to use it.

Intellectual Engagement

Visitor Questions
The primary questions for most respondents were about how to use the exhibit correctly to achieve the outcome portrayed in the label.

I don't know – the machine – it looked from the beginning that when we started playing with the frequency, the vibration wouldn't go on. So I don't know, maybe something was wrong. I don't know. I couldn't feel it vibrating, though. Maybe I was doing it wrong. I don't know. (Case 20, male, 40s)

Some respondents expected to be able to see the vibrations on the plates, but some of these movements were so subtle that they were difficult to observe.

Actually, first thing in the mind was that – first I expect that I can see the vibration of the plates, that I can see it . . . . (Case 17, male, 40s)

Visitors appeared to identify several variables involved in the phenomena, but the difficulty appeared to involve (a) getting the sound within the range in which the patterns would form, and (b) understanding the time element involved in the formation of the pattern.

I worked with it for a couple minutes, and I could never get the patterns to emerge. I noticed when I set it down at certain frequencies; it jumps around a lot – like it goes real rapid. And at other frequencies, it's real stagnant. And I just had a hard time getting it to go in a pattern. But I could kind of see them start. But it was hard to find the right frequency and the right amount of salt and all that. So, I worked with it for a minute, and I thought it was kind of difficult. (Case 7, female, late 20s)

Conclusions and Conceptual Understanding

All the people we interviewed were able to articulate what they were intended to learn at the exhibit. But among the low-medium cases of APE engagement, the language indicated uncertainty.

I found out that very small vibrations can make some kind of regular shapes – I guess I found that. (Case 17, male, 40s)

I guess that vibrating plates have different shapes. I guess they're different sound patterns, the vibration patterns. (Case 20, male, 40s)

On woman, whose response also indicated metacognition related to her learning experience, clarified that she probably got her understanding from the label and not from using the exhibit elements.

I think I probably always knew that patterns emerge from vibrations. I think that was probably always in my head. But I think from reading the signs, I could tell the shape of the metal plate – there are other factors to the patterns that emerge. And I think that I probably picked up on that not from the exhibit – not from the actual exhibit, but from the pictures and the writing. (Case 7, female, late 20s)

In the high APE engagement, the young woman's conceptual understandings were stated in a way that indicated a good deal of metacognition, She was also more confident in her conclusions this seemed closely connected to the experience of "seeing" the patterns.

I never knew that sound can make patterns. I just thought they would be like – you can hear them. But I thought it would be more like those up and down -- like those graphic things on the computers. I didn't know you could actually see -- like you can make patterns. I just didn't know. . . . And I guess you have to see -- it's better to show them than to explain it. And also, different plates can create different patterns of things. I tried the square one and the circle one. And they all make different patterns. Like the circle, one makes a circle pattern around it. And the square one can make butterflies . . . . (Case 33, female, 17)

In addition, she was able to recall the questions she had at specific points in the engagement. After reading the title of the exhibit in the early part of the engagement, she had questions.

So, I was wondering -- like you know how there are graphic charts of the frequencies and everything. And Visible Vibrations -- I just wondered how visible -- what do you mean by Visible Vibrations? (Case 33, female, 17)

She was also able to recall the types of questions she asked herself during the hands-on part of the engagement.

Like how high does it have to be -- like why at a certain point -- like if you move a little bit over the vibration -- like the most part, then you don't get a pattern. Why is that? How come it gradually changes? It changes pretty drastically, like 100 DBs can create different things. Why does it do that? (Case 33, female, 17)

She left the exhibit with some interesting and thoughtful questions.

Well, maybe the sand matters, too, I guess. I mean, why don't you use flour? But it's just a random question. Well, maybe like high sounds make -- like certain high sounds work better for one shape and another sound works -- maybe higher sounds make the circle patterns -- like the circle . . . . (Case 33, female, 17)

Finally, among all the people we interviewed, this young woman was the only one who placed the phenomenon she was observing in contexts outside the exhibit experience. She told us about two contexts. The first related to school. The second related to an experience outside school.

Yeah, it's fun because we're learning physics in school. So I think we're going to learn about sound probably like the next two months. (Case 33, female, 17)

. . . like when you're at Sea World, you have the sound of dolphins, they like use the sounds -- like maybe the sound pattern can tell them something about the sound the animal makes? Like high-pitched or lower or maybe. If you can make a pattern off the sound, then you know the secret message. (Laughs) I mean, that would be a good way to transfer [secret messages]. (Case 33, female, 17)

Social Engagement

We saw several forms of social interactions. In both Cases 7 and 33, females used the exhibit alone. Both seemed to want to be alone at this exhibit to concentrate and observe. Each indicated that social engagement interfered with certain types of experiences they like.

I think whenever I go to an exhibit, I get sort of in my own world, and I tend to wander off. I like to be alone so I can think about it, so I can process what it is I'm seeing. (Case 7, female, late 20s)

I guess you don't have your mom and dad on your back all the time. And then I concentrate better and I can just take notes and learn things -- yeah, just have fun without them noticing me there. I'm a pretty independent person. (Case 33, female, 17)

In other cases, we observed adult males directing the engagements involving both adult females and children. In Case 34, the man took a directive role, telling the woman to "close [the box] if you want it to work," and saying to her to "lower the frequency and it will bounce off."

In Case 20, the man appeared to be driving the interaction, and in the interview he told us he was giving to directions to others in the group. He explained why, specifically, he directed his 8-year-old daughter's experience.

My daughter doesn't realize a lot of stuff that's happening. So, we have to explain it to her. (Case 20, male, 40s)

Similarly, in Case 17, the child approached the exhibit with her father and he read the label and then guided her initial activity. But the rest of the family appeared to use the exhibit in a tag team fashion with individuals, pairs, or three of them at the exhibit. The mother and daughter left at one point to use another exhibit, and then returned.

Emotional Engagement

A great of deal of the emotional engagement in *Visible Vibrations* resulted from visitors not being able to accomplish what they clearly perceived as the intended goal, i.e., to form patterns on the plates. In the case of the woman using the exhibit alone (Case 7), this emotional response took the form of doubting her own competence. She seemed to continue in a fairly long engagement (4.0 minutes) to prove to herself that she was not "stupid." She generalized her experience at this exhibit to "places" with hands-on exhibits.

In these places, I'm always like -- I know that I'm not going to be able to get this to work, and some little kid is going to walk up and just do it. And I'm going to feel so stupid. So, I like stayed there for a time to figure it out. And I'm looking up, seeing if little kids are walking up. (Case 7, female, late 20s)

One male respondent also indicated that he might not be using the exhibit correctly, but he did not generalize this to his level of competence in other situations.

I don't know -- the machine -- it looked from the beginning that when we started playing with the frequency, the vibration wouldn't go on. So I don't know, maybe something was wrong. I don't know. I couldn't feel it vibrating, though. Maybe I was doing it wrong. I don't know. (Case 20, male, 40s)

Among other male respondents, we found dissatisfaction with the experience, but their criticism was often directed toward the exhibit. One man appeared to continue with a reasonably long engagement (5.2 minutes) in response to a challenging exhibit. Note that like the woman, this man generalized his comments to hands-on exhibits.

> *And with the hands-on thing, if it's too technical -- if it's simple and if the effects are pretty good, then people stay and try it until they're satisfied that they're fdone . . . Actually, we tried to get the frequency -- put it right on the frequency and put the plate on there. And it didn't work. (Case 20, male, 40s)*

In the case of the high APE engagement, the young woman appeared to take considerable satisfaction in learning something new, and said the exhibit was "fun to do." But even she mitigated her degree of enjoyment and satisfaction in the experience.

> *Yes. I liked this one…Well, not love it, but I liked it. (Case 33, female, 17)*

Comparisons among Exhibits

Physical Engagement

Time of Activities
Tracking-and-timing data will provide additional information about the overall frequency of time at exhibits and relative use by group types and genders. As an examination of Table 2 shows, however, the times of engagement for high APE engagements at one exhibit were much shorter than medium APE engagements at another.

Range of Activities and Independence from Labels
At *3-D Shapes, Floating Objects, Heat Camera*, and *Pulley Table,* visitors appeared to quickly assess how to engage at the exhibit without either reading the label or observing other visitors. Several visitors told us that they liked exhibits that allow them to "figure it out myself" and use the elements without instruction. Visitors appeared to use hints at how to engage at *3-D Shapes, Floating Objects*, and *Heat Camera* and, in some cases, used these as jumping off places for further exploration.

At *Pulley Table,* few people appeared to read the label at all. At *Gravity Powered Calculator* and *Visible Vibrations,* at least one member in each group read the label, and several indicated the label was important in determining how to use the exhibit elements. But at both of these exhibits, we found relatively few cases of visitors moving beyond the label-directed activities. In interviews, visitors told us that they initially read the label to understand how to use the exhibit elements. It may be that initial label use at exhibits establishes label "dependence" early in the engagement.

Appropriateness of Activities
At all exhibits, we observed appropriate use of the activities. At *Gravity Powered Calculator* and *Visible Vibrations,* many visitors appeared to require label assistance, but all activities in almost all engagements were appropriate to the overall conceptual design of the exhibit.

Multiple Entry Points
In general, there appeared to be consistency in how respondents approached and began engagement at exhibits. The exhibits with the greatest variation appeared to be construction exhibits. In these, engagements sometimes began by the examination of the artifacts of a previous visitor's experience. In one interview, respondents at *3-D Shapes* told us that they were reluctant to take apart objects others had built. At *Pulley Table,* respondents walked up to the table and turned a crank to see the effects that had been "engineered" by another visitor; only after that did they begin arranging pulleys themselves. At *Circuit Workbench*, respondents sometimes found working arrangements when they began an engagement.

At *Heat Camera,* we found the widest range of entry points. Smaller children were sometimes attracted by the hair dryer or other elements on the table in front of the bench and began engagement there. Many respondents began engagement by observing their own image and those of others, often family members, and beginning conversations and teasing. Only after the nature of the image was determined did experimentation begin.

Differences in entry points at *Floating Objects* were related to crowding. Respondents who engaged during times that were not as crowded were more likely to test the air flow with their hands before picking up balls. Respondents who waited in line to use the exhibit generally began by trying to float a specific ball and then moved on to multiple balls.

Intellectual Engagement

Visitor Questions
Visitor questions, while intellectual, also had emotional components. Furthermore, as one exhibit developer observed (Case 37), visitor questions at exhibits were often implicit rather than explicit.

The nature of questioning indicates doubt, a state that involves both lack of knowing and an emotional sense of disequilibrium. This can take a pleasant form such as surprise, which may indicate that doubt has been introduced into a situation. We saw these forms of questions in initial engagement at *Heat Camera, Floating Objects*, and *Watch Water Freeze*. Engagement at these exhibits appeared to involve manipulating variables to figure out what effects or results could be produced and to observe the limits of the phenomena. Clearly, these questions became more focused at *Downhill Race* where specific variables were tested against each other.

Another pleasant form of questioning had to do with a challenge or "Can I do this?" This general form of implicit question appeared to be connected to construction exhibits such a *Circuit Workbench* and *3-D Shapes*. But this form of challenge may be more appealing to some visitors than to others. The personal nature of this question appeared to be closely related to the application of existing skills and knowledge at these exhibits and some level of initial confidence. In addition, we saw parents taking a greater degree of social control of the experience, sometimes in ways that encouraged further exploration and sometimes in ways that limited it.

Intellectual Exploration and Conclusions and Conceptual Understanding
In comparison to the non-APE exhibits in Phase 1 of this study, we observed far more intellectual activity at exhibits that were developed around concepts of APE engagement. But conceptual understandings varied by the exhibit and by the previous experience and knowledge of the visitors. In cases where visitors actively explored phenomenon (*Heat Camera, Floating Objects, Downhill Race, Visible Vibrations*), we found that respondents could tell us things that surprised them, i.e., tell about new knowledge they had developed. At construction exhibits (*Circuit Workbench* and *3-D Shapes*), however, the respondents' intellectual processes would be better described as problem solving and testing the limits of their skills. At *Pulley Table*, as in some of the interactions we observed at *Circuit Workbench*, it was difficult to judge if children's conceptions of the phenomenon changed in any ways because some of the engagements and interviews were so highly managed by adults.

Metacognition
We found that visitors, both adults and children, were often aware of the overall processes they were involved in (e.g., finding out, building, constructing, exploring), but rarely did they make specific connections between their own activities and the scientific process. Even among individuals involved in highly scientific occupations (e.g., physicists and engineers), we found expectations that the museum experience should produce some acquisition of established scientific knowledge rather than understanding the scientific process itself.

Some respondents did appear to understand that there was a difference between the APE exhibits and others they had used. Generally, these experiences were described in terms of "ones that let me figure it out myself" or "explore on my own." Parents were more likely to assess this difference in exhibits, but in terms of experiences where their children needed help or ones that might take too much time.

Limitations
Clearly one limitation of APE engagement was the perception we found in both children and adults that exhibits need to "have a point." In other words, we did find some expectation of guided-discovery experiences. These expectations were generally more frequent among respondents with high levels of scientific knowledge themselves, who appeared to highly value this knowledge and its acquisition by others, and among children, who expected exhibits to have a quick payoff. Both *Heat Camera* and *Floating Objects* overcame these limitations with phenomena that intrigued almost all ages and backgrounds and moved visitors quickly into active physical engagement. In summary, many visitors were delighted to find opportunities to construct and explore, but others clearly expected a quick payoff from engagement or exhibits to serve as a demonstration of a point.

Social Engagement
One issue that we clarified in this phase of the evaluation was that APE engagement could occur both alone and in groups. Several of the highest APE engagements occurred with visitors using exhibits alone. A 17-minute engagement at *Circuit Workbench* in the first phase of the study and an 11-minute engagement at *Visible Vibrations* in this phase are clear examples of individual APE engagement. Interestingly, both of these engagement involved teens. Other medium and high APE engagements involved women and girls using exhibits alone (Cases 5, 31, and 7). One female respondent told us that using exhibits alone was less "risky," and a teenage girl wanted to

use things independently from her parents. We suspect that these teens and women had discovered what we observed in some other engagements, that is, knowledge is power, and it takes the form of social power when one participant perceived himself more knowledgeable than others in the group

In several cases, we observed fathers taking teaching-demonstrating roles with their children (Case 8, 12, 23, and 20). These adults did not attempt to engage in ways that answered any of their own questions; rather, they used their existing knowledge to direct children's engagements. This meant that quite often the children's activities were not self-initiated. In other words, they did not have intellectual ownership of their own engagement. In all these cases, the fathers explained to us that they did not think that their children would understand the exhibit unless they facilitated the engagement. Some other adults and children who were leading their group confirmed this assessment by not choosing to engage at these exhibits. This may have been the case, but the social roles of these fathers were that of a demonstrator-explainer. Each of these fathers initiated most of the activities and in some cases "corrected" novel ideas for engagement suggested by children. Most of these men told us about their own expertise during interviews – all were physicists and engineers. One clue to their motivation lies in the story one father told us about his grandfather's appreciation of simple, profound solutions to mechanical problems. It may be that a primary motivation for these engagements was not simply "learning" but the opportunity to share their own values and identity with their children. We want to stress that we agreed with the fathers' assessment of the exhibit level, and that these may have been very positive experiences for both fathers and their children. As one type of engagement, these father-child interactions probably add to an optimal mix of exhibit experiences. On the other hand, this form of social engagement appeared to transform the balance of these engagements from the construction of knowledge based on the exploration of phenomenon to transmission of information from an individual of greater expertise to one of less expertise.

We found rather low APE engagement among males using exhibits alone (Cases 3, 9, 13, and 2). In these cases, men appeared to have temporarily separated from their family groups. In interviews they told us that either they were dissatisfied when the APE exhibits did not have a quick "point," or that they wanted to share their knowledge with family members, or both.

In summary, we found that there were gender-based differences that appeared to prompt certain types of social engagements at APE exhibits, and, in some cases, to limit the overall level of APE engagement.

Social factors could also limit APE engagements in other ways. At *Floating Objects*, most people we observed had limited access to both airflow nozzles. This limited the ways in which they could use the exhibit. In interviews, exhibit developers explained other instances where one visitor could interfere with the activity of others. At *Watch Water Freeze*, some children sprayed the hose while other visitors were waiting for the ice to freeze. At *Downhill Race,* we saw younger children pushing wheels up the ramp (a developmentally appropriate activity) while adults and older children were testing variables. Exhibit design strategies, such as moving the hose to the back of the exhibit at *Watch Water Freeze* and multiple stations at exhibits such as *3-D Shapes* and *Circuit Workbench* appear to be helpful in increasing the levels of APE engagement.

Emotional Engagement

Source of Satisfaction
We found several types of emotional engagement became sources of satisfaction. One type of emotional engagement appeared to be connected to surprise. Respondents were surprised by the phenomena at *Heat Camera* and *Floating Objects*. They were also surprised that a mechanical device could calculate square root at *Gravity Powered Calculator*. This emotional satisfaction appeared to motivate further engagement.

Similarly, the challenge of the construction exhibits appeared to motivate further engagement, and respondents expressed satisfaction and pleasure when they completed tasks, e.g. constructing objects (*3-D Shapes*), getting desired effects (*Pulley Table*), and connecting circuits. Similar types of satisfaction were seen at *Gravity Powered Calculator* (e.g., hitting brass bars with marbles for a satisfying "ding,") or *Heat Camera* (e.g., using a cold soda can to "make hair" on a bald man's head). This type of satisfaction is closely tied to resolving doubt and demonstrating knowledge.

Another form of emotional satisfaction resulted from being able to use exhibits as a group, especially family groups with multiple generations. We heard this from both adults and children at *Gravity Powered Calculator*, *Watch Water Freeze,* and *Heat Camera*.

A less frequent form of satisfaction was identified at *Watch Water Freeze*. Respondents we interviewed at this exhibited noted the beauty of the shape and colors involved in the central exhibit phenomenon.

Limitations
We found less-than-positive emotions involved in engagements at certain exhibits. One woman at *Visible Vibrations* told us that she felt "stupid" when she couldn't get interactive exhibits to work. Other respondents appeared frustrated by this exhibit when they could not get shapes to form on the plates.

Other less-than-positive emotions probably did not limit APE engagement per se, but they reflected an expectation for a certain type of exhibit experience at the Exploratorium. We also talked with a few adults who were dissatisfied with various exhibits because they did not have focused content messages.

Other Factors that Limit APE Engagement
We found several factors that appeared to limit APE engagement across all exhibits. We have already discussed three of these factors: levels of crowding, "response" set for guided-discovery exhibits, and the social roles taken by some adults in relation to other visitors. One factor, which we identified in Phase 1 of the study, is what we have termed "visit agenda." A second, identified in this phase, could be called "APE fatigue."

In the "visit agenda," the time involved to use an APE exhibit is clearly a limiting factor. In many cases, respondents told us that they chose either to not engage at all at an exhibit or to stop engagement because of time.

We're on a time limit. We have to be somewhere. We've got to move on. (Case 30, female, mid-30s)

To identify longer and higher-level APE engagements, our data collectors tried to find people with intense engagements at one exhibit and follow them to the next. In a clear case of "APE fatigue," however, a group that had just completed a long engagement at *Tippy Table* spent only 19 seconds looking over *3-D Shapes*. One woman explained:

It did seem like there were too many -- you know, all the angles on the triangles and all the shapes. Unclear maybe what we were supposed to do real quickly. That one just seemed a little challenging for some reason. I had been trying to make all of the things on there [Tippy Table]. (Case 20, female, 20s)

A frequent visitor explained that he and his son only do a few extended engagements on any one day.

Like last time we were here, we got stuck in that thing in the back corner where you make motions and it takes a picture. The kids really like that one. . . . You know, when we come here, we usually do that in two, maybe three exhibits. The rest we just kind of go right through. (Case 26, male, mid-30s)

In summary, while the focus of this study was on engagement at individual exhibits, visitors appeared to organize at least some of their ideas about their experience based on the visit as a whole. Their expectations for types of exhibit experiences appeared to be shaped by the context of the visit of a whole, and a variety of interactions of different length and intensity was preferred.

CONCLUSIONS

In this section we will summarize the major findings and themes to answer the overarching question of this study:

> *In what ways and to what extent did the nine selected exhibits stimulate and facilitate APE engagements among visitors?*

The nature of this question leads us to discuss conclusions in three areas: (1) the nature of APE engagement, (2) ways APE engagement was stimulated and facilitated among the cases we observed, and (3) the overall extent to which these nine exhibits stimulated and facilitated APE engagement.

The Nature of APE Engagement

The idea of APE engagement is a construct, and the nature of any construct can be identified by placing examples, such as the individual cases we observed, inside or outside that category. As we reviewed data collector debriefs and our additional categorization of high, medium, and low APE engagements, one essential element that we used was the extent of exploration we could find in the case. This is consistent with the original idea of APE engagement presented in the grant.

> *Constructivism, as developed by Piaget and his colleagues . . . emphasizes the need for cognitive-conflict to drive learning (Gallagher & Reid, 1983; Hewson & A'Beckett Hewson, 1984). Such conflict lies in the surprise and paradox in many Exploratorium exhibits. Designing APE exhibits means providing visitors with tools to explore the conflict through experimentation, play, observation, and contemplation. (Exploratorium, Going APE!, p. 6)*

Looking at the data required us to ask if visitors had questions about the phenomenon. Having a question implies doubt. Based on visitor interviews, in which they told us they were surprised, were trying to figure something out, or didn't quite understand what is going on, we made assessments about their questions, both implicit and explicit. Without doubt, there is no cognitive conflict to resolve. But people have to believe that there is some possibility of resolving that doubt to continue engaging at all. In interviews with exhibit developers we heard about the efforts to find phenomenon at the "right level" of difficulty to encourage engagement.

Next, we had to ask how the visitors in that case tried to answer that question; in other words, what means did they use to resolve the conflict? In the Phase 1 study, we found that at guided-discovery exhibits, where the means to resolve the conflict were not available by observing and exploring the phenomenon, many of the people we observed read the label. They relied on "an authoritative demonstration provided by the museum." One of the underlying assumptions of the Phase 1 study was that exhibits that facilitate guided discovery or APE engagements are good ways to learn.

Twenty-five of the cases in this study involved groups of visitors. Sixteen of these cases involved multigenerational groups. Based on the observations and interviews, many of these

multigenerational engagements involved a wide range of teaching behaviors by adults: telling, explaining, providing direct information, stating principles and demonstrating them, and asking children to question and observe. In some cases, we found a predominance of these teaching behaviors, and very little actual exploration by the adult. But in other cases found both children and parents appeared to have the freedom to explore their own conceptual conflicts and all the group dynamics appeared to focus on joint exploration.

Ways in which Exhibits Stimulated and Facilitated APE Engagement

We identified several ways in which exhibits appeared to stimulate and facilitate APE engagement. None of these "ways," however, provides a simple solution to the challenging work of exhibit design. The strategies worked in concert with each other; some worked better for visitors and/or worked better with the specific phenomenon than others did. At exhibits with what we termed "high capacity for APE engagement," many of these factors were involved. Each of the ways in which APE engagement appeared to be stimulated and facilitated is discussed below.

Providing exhibit phenomenon open to exploration

One of the clear findings of Phase 1, supported by findings in this study, was the importance of the basic phenomenon involved in the exhibit. Comparing cases of visitors using the guided-discovery exhibits in Phase 1 with visitors using exhibits developed as part of the *Going APE!* project provided good evidence that some visitors were eager to question and explore when exhibits afforded this experience. But, like the exhibit developers we interviewed, we suspect that finding these phenomena is not an easy task. Identifying precise characteristics of a "phenomenon open to exploration" is not an easy task, either. One way is to compare cases with differing characteristics. Based on exhibits in this study, the phenomenon that appeared to stimulate the most immediate exploration were those in *Heat Camera* and *Floating Objects*. Non-APE exhibits in the first phase of the study are the clearest non-examples along with *Visible Vibrations* in Phase 2. Based on this comparison, phenomenon that were open to exploration provided

1. A clearly salient cause-effect connection that could be observed, if not immediately understood by visitors. Both *Heat Camera* and *Floating Objects* had central cause-effects connections. These connections were visible and identifiable not just to people using the exhibits but to people some distance away. In contrast, the phenomenon in *Bubble Suspension* – carbon dioxide released from dry ice -- was invisible. At *Water Standing on Air*, the effect could not be explored through manipulation, only observed.
2. An effect that in some way "doesn't make sense." The Exploratorium is well-known for the intriguing phenomenon in guided-discovery exhibits. The effectiveness of these exhibits is based on the central idea of cognitive conflict – something going on that just doesn't quite make sense. Both *Heat Camera* and *Floating Objects* are designed around these types of phenomenon, but so are many guided-discovery exhibits.
3. A manageable timeframe and scale through which a visitor can effect the phenomenon. Probably one reason for the popularity of physics-based hands-on exhibits is the timeframe of the phenomenon. Many phenomena in biology and astronomy have scales of size and time that are beyond what people can explore on a museum visit. Similarly, *Visible Vibrations* is designed around a phenomenon that takes time to form.

4. Phenomena that are easy to change. One of the major problems for visitors at *Visible Vibrations* was the number of steps they needed to perform to see an effect. At *Heat Camera* and *Floating Objects,* there was immediate payoff by moving and changing the balls in the airflow.

One of our concerns about this list of characteristics is that focusing exhibits only on such phenomenon could lead to an understanding of scientific process based on a limited range of phenomenon. In addition, scientific investigation is often a highly sequenced, multistep process. We want to stress that we identified APE engagements at all the exhibits in the study, and visitors' experiences would be less rich without encounters with the diversity of phenomena reflected among the range of exhibits.

Involving visitors in the process of scientific inquiry

We found APE exhibits engaging visitors in complete scientific inquiries or some specific stage of scientific inquiry. A full inquiry process might include: (1) observing and playing with materials to identify variables and develop some theoretical understandings, (2) identifying and formulating questions, (3) finding ways to explore the question, (4) iterative testing of the question to compare findings, (5) reaching some new conclusions based on the evidence, and (6) communicating that new knowledge in a public way. At *Heat Camera, Visible Vibrations, Floating Objects, Gravity Powered Calculator*, and *Downhill Race,* we found visitors engaging in rather complete scientific inquiries. At *Gravity Powered Calculator* and *Watch Water Freeze*, most visitors used these exhibits to engage in only one stage of a scientific inquiry, prediction and observation, respectively.

Circuit Workbench, Pulley Table, and *3-D Shapes* are construction exhibits. This is a close cousin of scientific inquiry, alternately termed engineering or development. In this study, engagement at these exhibits appeared to involve the application of existing knowledge and processes rather than the development of new knowledge. Just among these nine exhibits, we would conclude that the scientific-inquiry-based exhibits did a better job of stimulating and facilitating APE engagement among a wide group of visitors. Yet many classroom inquiry activities based on design tasks are developed on the rationale that design tasks allow people to identify and more deeply understand physical properties and relationships. We think many unanswered questions remain about these types of APE exhibits that we did not have the time or resources to explore in this study. Perhaps the greater range of expertise among groups of casual museum visitors was one factor in the cases we observed. The classroom setting can be assumed to have a greater degree of homogeneity of previous expertise related to these tasks. In addition, one author's experiences in these in team-based design activities indicated that the social nature of these activities becomes very competitive very quickly, and while this response to challenge is productive in some cases, it might not be in others. The issue of competition in learning tasks is one factor in designing activities that are equally accessible to females as well as males. Clearly, the nature of engagement at construction exhibits needs to be explored further.

Evoking immediate physical engagement by visitors of all ages

Immediate engagement at exhibits such as *Circuit Workbench* or *Floating Objects* began independent of label use. In addition, parents and children were free to initiate their own physical and intellectual engagement rather than focusing on others.

Providing labels with hints to launch exploration
At *Heat Camera, Floating Objects*, and *3-D Shapes*, visitors appeared to use labels to shape, but not determine, their experience. These labels provided launching pads for physical and intellectual engagement. Several visitors told us they avoided labels, if possible, until after initial attempts to use the exhibit. Combining exhibits elements that visitors can quickly identify how to use with labels to provide support for exploration appears to be a successful strategy.

Rewarding novel ideas and behavior
At *Heat Camera* and *Floating Objects* in particular, the nature of the phenomenon provided reward for clever and inventive solutions by both adults and children. In contrast, *Gravity Powered Calculator* and *Visible Vibrations* appeared to lead to ideas of "correct use" of the exhibit and disincentives for novel ideas.

Enabling participation free from physical inference from other visitors
At *Heat Camera,* visitors could "do their own thing" without interrupting or interfering with others' ideas or experiments to contrast variables. At *Gravity Powered Calculator* and *Floating Objects*, however, the layout allowed one visitor to easily interfere with the setup of another's experiment. Multiple stations, large viewing areas, and redundancy among stations (e.g. *3-D Shapes* and *Circuit Workbench*) appeared to eliminate interference problems.

Allowing members in a group to use the exhibit together
Keeping track of group members, especially children, in larger visiting groups was an important element for many of the respondents. Exhibits such as *Watch Water Freeze* and *Heat Camera* helped groups numbering as many as six visitors to stay together. Both of these exhibits featured flexible seating for several people. This appeared to lessen the number of "hurry-up-and-finish" signals from group members not using the exhibit.

Preventing interference with engagement by providing multiple stations
One of the strategies we heard in exhibit developer interviews was the use of multiple stations to give visitors ownership of their own experience. Multiple-station exhibits in this study included *Pulley Table*, *3-D Shapes*, and *Circuit Workbench*. We found examples of this type of interference at *Floating Objects*, especially with children grabbing balls and nozzles. At *Pulley Table*, on the other hand, we observed more than one group engaging at the exhibit without interfering with the other; we also observed productive conversations between members of different visiting groups. At *3-D Shapes* we also found multiple groups using the exhibit successfully. At *Circuit Workbench* the multiple stations have varying levels of difficulty, and while this motivated extended engagement among some visitors, it also encouraged visitors to begin at more difficult stations -- not always a productive way to start using this exhibit.

Providing access to engagement at multiple levels of previous knowledge to level the social playing field
The advantage we found for APE engagement at *Heat Camera* and *Floating Objects* was very much the intellectual parallel to the physical strategy for ownership of engagement exemplified in multiple stations. While social engagement can support exploration, we also found that it could interfere with questioning and exploration. Having a "doubt" or a question is as much a psychological state as an intellectual process. Adults with the "responsibility" of guiding children's engagement appeared to rely on existing knowledge about which they were relatively

"certain." Their intellectual energies were focused on teaching things they already knew. Children's intellectual engagement may or may not have involved solving a cognitive conflict.

Providing tasks requiring optimal time range for APE engagement in the context of a museum visit

We found many visitors with a visit agenda to "see all the exhibits" at the Exploratorium. Several respondents told us that they chose not to use exhibits in the study because they would take too much time. Most respondents were first-time or infrequent visitors. This indicates that there may be an optimal time range for an engagement that allows extensive and iterative physical and intellectual engagement but is not so time-consuming that visitors will choose not to engage. Respondents told us that they left *3-D Shapes* because making more than one object took too long, given their expectations to see many of the exhibits in the museum. In addition, the time that was required to set up and produce patterns at *Visible Vibrations* may have been beyond this optimal level for most visitors. We found some high APE engagements ranging from about 5 to 20 minutes, which may be an optimal time range for APE engagements in the context of an entire museum visit.

Providing resources for extended engagement

All the exhibits appeared to provide resources for extended engagement. For example, *Circuit Workbench* provided wires and plugs for different tasks at different stations. *Watch Water Freeze* included polarizing lenses, a sprayer, and an accessible surface for water to freeze. *3-D Shapes* offered many geometric shapes that were interchangeable among multiple stations. *Floating Objects* provided balls and two nozzles that allowed multiple sets of questions to be asked.

Extent of APE Engagement

Each of the nine exhibits in Phases 1 and 2 of the study stimulated and facilitated APE engagements among some visitors. But some exhibits, based on the definitions of APE engagement provided by the team, appeared to have a greater capacity for APE engagement among a wider range of visitors than did others. As one of the exhibit developers (Interview 3) explained, in an overall ranking of "goodness" of an exhibit, this analysis and ranking might look quite different. These tiers reflect a ranking on the overall extent of APE engagement based on observations, interviews, and analysis of people using the nine exhibits during Phases 1 and 2 of this study. Given the resources for additional data collection, we would ask some additional questions that could further inform these rankings. In addition, the exhibit development team may want to include in the category of APE exhibits some types of engagement that we categorized as less APE-like. But, based on the criteria in Appendix C, and the proposal, ranking exhibits in these tiers provides an additional way to understand the findings of the study.

Based on data collected from casual visitors and interviews with exhibit developers, the exhibit with the highest overall level of APE engagement was *Heat Camera.* Cases in this study had substantial engagement times, the highest range of activities, and the widest range of visitors involved both emotionally and intellectually in the engagement. Visitors did not interfere with each other's engagement, and social interactions added to productive engagement. In addition, this exhibit appeared to move some people through the entire scientific inquiry process, from identification of salient variables to drawing conclusions that, for a few people, expanded a theory they had about an underlying scientific mechanism.

In the next tier of extent of APE engagement, we would put *Downhill Race* and *Watch Water Freeze* (aka, *Ice Painting*). Different factors, however, appeared to influence the extent of APE engagement at these two exhibits.

Downhill Race involved many respondents in a complete scientific inquiry process. Like *Heat Camera*, initial engagement involved the recognition of a counterintuitive phenomenon. At *Downhill Race,* once respondents recognized that the wheels that they had predicted would win did not, in fact, win, they were captivated. Respondents could begin engagement immediately because the task was easy to understand. The label, when it was used, supported problem solving but did not direct engagement. Participation involved a wide range of activities, and the resources provided by the exhibit were well-suited to help visitors answer their questions, e.g. regarding wheels of various sizes, weights that moved. Emotional engagement focused on the challenge of understanding, and when that mental light bulb went off, facial expressions and body language clearly displayed the satisfaction. Adults and older children participated together, individually in teams, and had conversations in which they made predictions. In addition, multiple members of visiting groups used the exhibit at the same time, alleviating the "hurry-up-and-finish-so-we-can-see-everything" factor. Visitors from different visiting groups could use the exhibit at the same time, alleviating the "hurry-up-and-finish--it's-our-turn-next" factor. But the experience at *Downhill Race* was not accessible to everyone. Visitors who already understood the concept chose not to participate. When younger children attempted to participate, their developmentally appropriate use of the exhibit elements (i.e. rolling wheels up the ramp) interfered with other visitors' engagement. Some parents identified this by watching other people use the exhibit and decided not to use the exhibit.

Watch Water Freeze (aka *Ice Painting*) did appear to allow participation by visitors of differing knowledge levels and ages. Visitor engagement appeared to focus on only one early stage of scientific process, observation. Yet even respondents with higher levels of scientific background found new ways of seeing a familiar phenomenon and identified new and more complex variables. They also appreciated the beauty of the phenomena, which drew their attention to more complex variables such as color and shapes. In addition, visiting groups with multiple generations appeared to be able to participate at the same time. The group seating and the phenomena were accessible to different ages. Members of different visiting groups participated together, and even talked to each other. We observed some interference between visitors, with some becoming impatient and interfering with others' engagement, and we also found groups waiting and hurrying other groups to finish.

In the third tier of extent of APE engagement, we have three exhibits. These are among people's favorites in the study. *Circuit Workbench* was clearly a favorite among exhibit developers and other team members. It sparked interest in the idea of active prolonged engagement. *Gravity Powered Calculator* is the author's favorite exhibit among this group; she had one of those "Aha" moments about the relationship between mathematical formulas and phenomena. The third exhibit is *Floating Objects*, and it was one of the visitors' favorites. We would emphasize that all of these are in many ways good exhibits. But the extent of APE engagement that we observed at each exhibit was limited. Again, factors that limited APE engagements were different at each exhibit.

Circuit Workbench clearly stimulated and facilitated some APE engagements, but only among a restricted range of visitors. The prototypical APE engagement we saw at this exhibit was a 13-year-old boy who moved into a flow experience and even displayed some disorientation when he finished. This exhibit provided many resources for engagement, and labels, generally read after some initial engagement, provided support and confirmation. But like other construction exhibits, this one evoked and perhaps required some underlying knowledge and experience to participate. Few parents with younger children even attempted this exhibit. In addition, like *Pulley Table* and *Gravity Powered Calculator*, the level and nature of the underlying content appeared to motivate some adults to direct children's experience. One woman, a science education professor participating with her daughter, realized she had taken over the engagement during her interview. Although she had clear goals to facilitate her daughter's experience, this exhibit was so closely connected to her identity and values about what is important to learn that she moved into a telling-demonstrating role.

Gravity-Powered Calculator appeared to attract parent-child pairs as well as adults, but like *Circuit Workbench*, parents with older children immediately moved in to the management-teaching role. Still, we did find full-APE engagements at this exhibit, with a woman using this exhibit alone, and a father with a younger child. Both adults had considerable scientific background. But the father was able to manage his 4-year-old son's manipulation of objects (an age-appropriate engagement) while he himself formulated and explored some higher-level questions. Unlike these two visitors, most people we observed at this exhibit focused their engagement on only one stage of the scientific process; prediction, and this involved only a limited range of activities. Most of these activities were the ones suggested by the label. For a few visitors with considerable scientific background, however, we found prolonged active engagement involving underlying mathematics and physical principles.

Floating Objects shares many APE exhibit characteristics with *Heat Camera.* Of all the exhibits in the study, *Floating Objects* is the one we suspect could benefit most from redesign. Like *Heat Camera*, the exhibit attracted a very wide range of ages and levels of scientific background. The counterintuitive phenomena surprised most visitors and leveled the social playing field. While visitor questions were implicit rather than explicit, the exhibit focused engagement on a fairly complete scientific exploration from the identification of variables through testing of hypotheses. Only a few adults moved into management roles, and when they did, children's novel ideas and enthusiasm seemed to overpower these impulses. The two nozzles and balls with different characteristics provided rich resources for exploration, and the label hints launched some visitors into full-scale exploration. But visitors could and did interfere with each other's activities at this exhibit. Most visitors did not have access to both nozzles, and people interrupted others' experiments. In addition, waiting visitors hurried the current exhibit users to quickly end an engagement, and in some cases, this appears to have cut off a scientific exploration at an early stage. Multiple stations and placing this exhibit away from heavy traffic flow might produce more and higher-level APE engagements.

Finally, we found the lowest level of APE engagement at three exhibits, *Pulley Table, 3-D Shapes,* and *Visible Vibrations*. Again, reasons for these assessments are based on various criteria.

At *3-D Shapes*, we found parents and children using the exhibit, but only with parents focusing on children's engagement. Among adults with higher levels of APE engagement, however, we did find a greater level of accessibility than at some of the other construction exhibits. Connections to family identity, scientific identity, and artistic identity all played central roles in what visitors chose to construct. At some level, visitors could begin engagement without label direction, and there was label independence in the decisions of several visitors' about what to construct and how to construct it. But we found limited ranges and numbers of activities among visitors at this exhibit. Visitors told us that this was due to the amount of time they were willing to allot to any one exhibit in the course of a visit.

At *Visible Vibrations*, another exhibit on our lowest tier, the time required to produce an effect was one of the factors that appeared to prevent APE engagement. Producing the pattern also appeared to require a level of subtle adjustments of the apparatus that many visitors did not understand. It may be that this exhibit operated on such a different scale from other Exploratorium exhibits that visitor expectations interfered with their use of the exhibit. Most visitors, even those making considerable efforts, appeared to give up at a certain point. In addition, most engagements at this exhibit were highly label-dependent, and adult-child engagements were parent-directed. Yet this exhibit can and did lead to one full-scale scientific investigation involving several stages of a scientific inquiry.

Based on the observations in this study, *Pulley Table* stimulated engagement within a limited group of visitors. Visitors with considerable knowledge about the phenomenon decided not to engage. Those who did engage, primarily adult-child groups, moved quickly into the adult-directed teaching mode of social engagement. Like similar engagements at *Circuit Workbench*, motivations for these social roles appeared to be tied to expertise, values for certain types of scientific knowledge, and family and individual identity of the adult. *Going APE!* exhibit developers and other team members had different assessments of the engagements at this exhibit. Frankly, we were surprised at the limited APE engagements we found. This exhibit had multiple stations, the movement of objects appeared intriguing to us, and visitors could and did walk up to the exhibit and know immediately what it was about and how to use it. We suspect that two factors may have affected our findings related to *Pulley Table*. First, it was placed directly in a busy traffic pattern, and this may not be the best context for exhibits that clearly cue extended engagement. Second, it is a construction exhibit, and we think there are several unanswered questions about these types of visitor engagements.

Two of the three exhibits we placed in this tier, based on observations and interviews in this study, were construction exhibits. In the first study, we characterized the motivating question for *Circuit Workbench* as "Can I do it?" This is a form of personal challenge, and it appears highly related to self-concept and confidence. Cases at *3-D Shapes* showed some competitive behavior as well as some personal connections related to occupation. At *Pulley Table*, we found the clearest instance of direct instruction, and other visitors told us about this grandfather's desire to share his knowledge with his grandchild. Based on these observations, we believe it would be useful to explore more deeply how visitors explain their motivations for using these exhibits. Are motivations tied to self-concept and capability? Is there something about the nature of producing objects or "making it work" that elicits emotions of power and confidence? Are visitors less

likely to identify "new" things they learned in these engagements because the motivation for using the exhibit is tied to doubts about whether or not they can do it? What about the people who chose not to engage at these exhibits? Gender-based differences need to be further explored. One woman explained that it was less "risky" to use an exhibit by herself. Do these exhibits seem "risky" to some people? What kinds of risks do visitors fear so much that they choose not to engage? It appears to us that the basic cognitive conflict that motivates engagement at these exhibits is somewhat different from those focused on investigation and exploration.

Final Thoughts

As we were concluding our work on this study—a study that explores important issues in informal science learning—we realized that we needed to crystallize some of the big issues implicit in the study's findings. We also wanted to point to several areas fruitful for further exploration in the fields of informal science and family learning.

During our work on this project, we came to understand that one of the things that APE exhibits do is ask visitors to replace a traditional model of trusting and valuing authority-based transmitted knowledge with more self-directed inquiry. One of the underlying assumptions of APE exhibits is that self-directed inquiry is a trusted and valued way of knowing and understanding. In the larger sense, science itself depends on people's flexibility in moving back and forth between these two ways of knowing. First incorporating past scientific understandings and then developing new knowledge through inquiry. In this study, we found just how very difficult that can be.

In some cases, we observed transmission of knowledge to be a natural strategy that adults relied on, particularly when they perceived an exhibit to be "too hard" or "above the heads" of children in the group.

Another interesting phenomenon occurred when some visitors engaged with exhibits alone. Among women and teens using exhibits alone, there were indications that they did this in order to maintain ownership of their self-directed inquiry and to avoid interference from the authority of others.

As could be expected, we found several cases where engagements involving transmission of knowledge took considerable amounts of time. At first, it might appear that these were APE engagements. But, we found that these longer, authority-based engagements did not translate into cases of self-directed inquiry. It should be noted that the converse was also true; there were a number of instances where relatively short engagements were clearly APE engagements. This leads us to urge caution in using any one criterion to classify an engagement as APE.

In conclusion, we encourage the field of informal science learning to continue to explore the differences between authority-based and inquiry-based science learning experiences, some of which appear to be related to gender and social roles. This study is an important step in that direction.

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APPENDIX A: TOPICAL FRAMEWORK

February 18, 2004

Research Question

In what ways and to what extent did the nine selected exhibits stimulate and facilitate APE engagements among visitors?

Visitor Engagement

A. Physical Engagement

In what ways and to what extent did the nine selected exhibits stimulate and facilitate APE physical engagement among visitors?

1. Overall
   a. What was the range of physical engagement at each of the APE exhibits?
   b. What was the range of physical engagement at the APE exhibits as a group?
   c. How meaningful was the physical engagement at the APE exhibits?
   d. What were the limitations to meaningful physical engagement with each of the APE exhibits?
   e. What were the limitations to meaningful physical engagement with the APE exhibits as a group?

2. Time at Exhibit
   a. How long did visitors spend at the APE exhibits?
   b. What were the mean, median, mode, and range for each exhibit?
   c. What were the mean, median, mode, and range for the APE exhibits as a group compared with the non-APE exhibits?
   d. Was there a statistically significant difference between the amounts of time visitors spent at APE vs. non-APE exhibits?
   e. What types of visitors (in terms of ages, abilities, and background) spent different amounts of time at different exhibits?
   f. To what extent and in what ways did crowding affect time at exhibit?

3. Range of Activities and Independence from Labels
   a. What was the range of ways that visitors meaningfully engaged with APE exhibits?
   b. What types of distinct activities did the visitor do at each exhibit?
   c. What was the range of activities visitors engaged in at each specific exhibit?
   d. In what ways and to what extent did visitors interact in meaningful ways at each exhibit?
   e. In what ways and to what extent did visitors interact in meaningful ways at the APE exhibits as a whole?
   f. In what ways and to what extent were there limited types of activities at each exhibit?

g. In what ways and to what extent were there limited types of activities at the APE exhibits as a whole?
h. Which exhibits elicited the widest range of meaningful physical engagement? Which elicited more limited ways of interacting?
i. What was the range of meaningful ways in which the visitors used the labels at the exhibits?
j. In what ways and to what extent did visitors primarily follow the instructions on the labels at each exhibit?
k. To what extent and in what ways was visitor engagement label-independent at each exhibit?
l. In what ways and to what extent did visitors use the APE exhibits in ways independent from the labels? In what ways and to what extent did visitors use the APE exhibits in ways cued by the labels?
m. To what extent and in what ways did visitors at each exhibit engage in diverse and yet meaningful interactions?
n. Which exhibits elicited the most meaningful behavior and which the least?

4. Appropriateness of Activity
   a. How did different types of visitors engage with different exhibits?
   b. In what ways and to what extent did visitors participate in age/background/ability-appropriate activities at the APE exhibits?
   c. What evidence was there that certain segments of the population were excluded from meaningfully participating with certain exhibits?

5. Further Exploration
   a. In what ways and to what extent did visitors explore each exhibit after their initial engagement?
   b. How completely did visitors use the APE exhibits?
   c. Under what conditions did they end their physical interaction and leave the exhibit?

6. Multiple Entry Points
   a. What were the various ways that visitors entered each exhibit?
   b. In what ways and to what extent did visitors enter the exhibit in different ways?
   c. In what ways and to what extent did different types of visitors (e.g. those of similar age/ability/backgrounds) tend to enter the exhibit in similar or different ways?

7. What Else?
   a. What else did we learn about how visitors physically engaged with APE exhibits?

B. Intellectual Engagement

In what ways and to what extent did the nine selected exhibits stimulate and facilitate APE intellectual engagement among visitors?

1. Overall
   a. What was the range of intellectual engagement at each of the APE exhibits?

b. What was the range of intellectual engagement at the APE exhibits as a group?
c. How meaningful was the intellectual engagement at the APE exhibits?
d. What were the limitations to meaningful physical engagement with the APE exhibits as a group?
e. To what extent and in what ways was there an indication of open-ended exploration and discovery vs. developing an understanding of specific exhibit content?

2. Visitor Questions
   a. What questions did visitors have as they were engaged with each exhibit?
   b. What types of questions did visitors tend to have at the APE exhibits as a group?
   c. What was the range of questions visitors had?
   d. What was the nature of the questions?
   e. To what extent and in what ways did exhibits elicit driving questions that prompted further engagement?
   f. What were the driving questions visitors formed at each exhibit?
   g. What questions did visitors leave the exhibit with?
   h. In what ways and to what extent were the questions that visitors generated similar and different?
   i. In what ways and to what extent were the questions those visitors generated independent of the labels?

3. Intellectual Exploration
   a. In what ways and to what extent did visitors follow their questions with a range of follow-up activities and further intellectual exploration?
   b. What was the nature of these follow-up activities?
   c. In what ways and to what extent were the visitors' follow-up activities similar and different?
   d. In what ways and to what extent were the follow-up activities that visitors engaged in independent from the labels?

4. Conclusions and Conceptual Understandings
   a. What was the range of visitor understandings at each exhibit?
   b. At which exhibits, did visitors tend to develop similar understandings connected directly to the label information?
   c. At which exhibits, did visitors develop the widest range of conceptual understandings?

5. Metacognition
   a. In what ways and to what extent were visitors to APE exhibits aware of the scientific inquiry processes they were engaged in?
   b. To what extent and in what ways did they reflect on these scientific inquiry processes?

6. Limitations
   a. What were the limitations to meaningful intellectual engagement with each of the APE exhibits?

7. What Else?

a. What else did we learn about how visitors intellectually engaged with APE exhibits?

C. Social Engagement

In what ways and to what extent did the nine selected exhibits stimulate and facilitate APE social engagement among visitors?

1. Overall
   a. To what extent and in what ways was there meaningful social engagement at the APE exhibits?
   b. What was the range of social engagement at each of the APE exhibits?
   c. What was the range of social engagement at the APE exhibits as a group?
   d. What were the limitations to meaningful social engagement?

2. Questions
   a. What questions did visitors ask each other?
   b. What concepts and issues did visitors ask each other questions about at each exhibit?
   c. In what ways and to what extent did visitors ask a range of questions at each exhibit?
   d. In what ways and to what extent did visitors ask similar and label-directed questions?

3. Range of Focus and Viewpoints
   a. What was the range of focus of visitor conversations at each exhibit?
   b. To what extent and in what ways were there meaningful conversations focused on a range of visitor-generated issues and concerns?
   c. What were the various viewpoints, opinions, and conceptualizations that were expressed at each exhibit?
   d. How did these constructions differ among visitors to different exhibits?
   e. How did these constructions differ among visitors at the same exhibit?
   f. To what extent and in what ways did visitor conversations indicate play, observation, investigation, and contemplation?
   g. To what extent and in what ways did conversations tend to converge towards the creation of an exhibit-centered common understanding?

4. Types of Social Engagement
   a. What was the range of types of social engagement that visitors demonstrated at each of the six exhibits?
   b. Which of the types of social engagement were similar across exhibits? Which were different? In what ways and to what extent?
   c. How did the various types of social engagement differ at specific exhibits, e.g. silence, teaching-learning, showcasing, watching and observing another visitor?
   d. To what extent and in what ways did visitors socially engage with each other at the different exhibits during play, observation, investigation, and contemplation?

6. What Else?
   a. What else did we learn about how visitors socially engaged at APE exhibits?

D. Emotional Engagement

In what ways and to what extent did the nine selected exhibits stimulate and facilitate APE emotional engagement among visitors?

1. Overall
    a. To what extent and in what ways was there meaningful emotional engagement at the APE exhibits?
    b. What was the range of emotional engagement at each of the APE exhibits?
    c. What was the range of emotional engagement at the APE exhibits as a group?
2. Source of Satisfaction
    a. To what extent and in what ways did visitors derive their sense of satisfaction from the process of engaging with the exhibits vs. accomplishing an educational goal?
    b. Which visitors participated in a flow experience, and under what circumstances? What was the nature of these flow experiences?
3. Limitations
    a. What were the limitations to meaningful emotional engagement with each of the APE exhibits?
    b. In what ways and to what extent did visitors feel frustrated and/or intimidated?
    c. In what other ways and to what extent was the visitor experience compromised at APE exhibits?
4. What Else?
    a. What else did we learn about how visitors emotionally engaged at APE exhibits?

Exhibit Design Characteristics

1. What aspects of APE exhibits' conceptual design contributed to APE visitor engagements? (Conceptual design elements are the main ideas and strategies, e.g. missions or challenges, intended to launch visitors in a particular type of engagement.)
2. What aspects of APE physical design contributed to APE visitor engagements? (Physical design includes concrete elements such as an interactive interface, the label, arrangement in space, and seating.)
3. What aspects contributed to meaningful physical engagement at APE exhibits?
4. What aspects contributed to meaningful intellectual engagement at APE exhibits?
5. What aspects contributed to meaningful social interaction at APE exhibits?
6. What aspects of the exhibit designs contributed to meaningful emotional engagement including feelings of satisfaction and flow at APE exhibits?
7. What aspects contributed to feelings of frustration, intimidation, and dissatisfaction?
8. To what extent and in what ways were visitors aware of the differences between APE and non-APE exhibits? Did they recognize that APE exhibits elicited a qualitatively different type of experience?

APPENDIX B: EXHIBIT DESCRIPTIONS

Phase 1 Exhibits

Ape Exhibits

Circuit Workbench. At this construction APE exhibit, visitors are given real-world missions, such as "make a bicycle-light generator," and use banana-plug wires to build circuits that underlie those real world devices. The exhibit has six stations, which vary in difficulty level. Visitors can try the challenges (for which there is a solution given under a flip-up), or they can construct any other circuits they wish to make. At each station, there are extra components that aren't needed in the mission so that visitors can make many different circuits. Components include batteries, generators, incandescent lights, LED lights, motors, switches, and variable resistors. Visitors may also use the wires to connect components across stations. (*Going APE!* Exhibit Development Team, 2003b)

Downhill Race. This is an investigation APE exhibit, where visitors race two of six possible disks down parallel tracks to see which one rolls faster. Most visitors approach the exhibit believing that heavier disks will roll faster. In fact, disks with more of their mass located near the hub roll faster than those with more mass located near the rim. Visitors race disks to figure out which variable – mass or distribution of mass – seems more important. Four of the disks have fixed masses; two have adjustable masses (i.e., the location of the mass can be altered). (*Going APE!* Exhibit Development Team, 2003b)

Watch Water Freeze. This observation APE exhibit presents ice that is lit up from underneath. When visitors look at the ice through polarizing filters, they see extraordinary colors and crystalline patterns. Visitors can manipulate the ice by melting it with their hands, or by melting larger parts of it with a water sprayer that is part of the exhibit. After a few minutes, the water will refreeze, and visitors will be able to watch the crystalline structures form before their eyes. (*Going APE!* Exhibit Development Team, 2003b)

Non-APE Exhibits

Bubble Suspension. Visitors blow bubbles into a big, clear, acrylic cylinder and watch as their bubbles hover and swell on top of an invisible blanket of carbon dioxide gas, produced from a chunk of dry ice at the bottom of the exhibit. Because straight carbon dioxide gas is heavier than air, the bubbles sit on top of the gas instead of falling to the floor as they normally do. Because bubbles' membranes are semi permeable, carbon dioxide slowly seeps into them, which is why they get bigger and begin to grow heavier. Sometimes the membrane is stretched so thin the bubble seems to vanish; other times the bubble shell is frozen from finally being exposed to the dry ice. (*Going APE!* Exhibit Development Team, 2003b)

Touch the Spring. At this exhibit, visitors reach into a box to touch a perfectly normal-looking spring, but their hand goes right through it. The spring is actually a "real image" of a spring, produced by a very smooth, large curved mirror that is inside the box. (There's a real spring inside the box as well.) When visitors shine an attached flashlight onto the image of the spring, the reflections and shadows make it look even more real. That's because the flashlight's light

goes into the box, reflects off the mirror, hits the real spring inside, and bounces back out to the image. The real spring inside the box is lit up, and shadows are produced in such a way that the image of the spring looks like it's being lit up and shadowed. Exhibit Development Team, 2003b)

Water Standing on Air. A closed cylindrical glass tube contains some water. In the center of the tube is a screen or grate that the water passes through whenever the cylinder is turned upside down. When the cylinder is turned over quickly and smoothly, water does not pour through the grate; instead, it sits on top of the grate. In effect, water "stands on air." What's happening is that when the water covers all the holes in the grate, air cannot pass from the bottom half of the tube to the top half of the tube – air cannot "equalize" in the tube. (Water's surface tension keeps the air from coming through.) The water presses down slightly through the holes in the grate. This causes a compression of the air in the bottom half of the tube, and increases the air's pressure down there. At the same time, the water pressing down means that the air above the water is rarefied, so its pressure decreases. The difference in air pressure is what holds up the air. (*Going APE!* Exhibit Development Team, 2003b)

Phase 2 Exhibits

Construction Exhibits

3-D Shapes: A construction APE exhibit, *3-D Shapes* allows visitors to connect polygons of different shapes and sizes to make larger, 3-D shapes, such as "soccer balls," "hats" or anything they desire. The pieces (triangles, squares, rhombi, pentagons and hexagons) show the angles at each vertex, and can be connected together via Velcro. Eight experiment cards provide visitors with different "missions" such as "make a soccer ball," "make a hat," or "make a fortune (by creating a new toy)." Visitors may follow the missions or simply make any shape they wish. The exhibit, in the shape of a large octagon, allows multiple visitors to build shapes simultaneously. (*Going APE!* Exhibit Development Team, 2004)

Pulley Table: This construction exhibit consists of four separate but connected stations. At each station, visitors can build systems of pulleys – flywheels connected by stretchy belts. Each station also contains a "mission object" – a starting point or an endpoint to which the visitors' pulleys can connect to make an interesting thing happen. Station 1 contains a motorized flywheel, so visitors can create a set of pulleys that are always in motion. Station 2 contains a music box to which visitors can connect pulleys and make music (different songs play depending on the direction the pulleys are turned). Station 3 has a small umbrella that opens and flutters when turned by a visitor's pulley system. Station 4 contains a set of fans than visitors can spin by connecting to their pulleys. Visitors may place their pulleys and belts anywhere on the four tables, and may even make connections across the stations. The exhibit is large, allowing multiple visitors to build pulley systems simultaneously. (*Going APE!* Exhibit Development Team, 2004)

Exploration/Investigation Exhibits

Floating Objects: This exhibit is a rebuild of the well-known *Balancing Ball* exhibit. At *Floating Objects*, visitors can investigate the Bernoulli forces on balls of different shapes and sizes as they float in an air stream. There are two blowers, which can each blow vertically or be tilted at an angle. Visitors may float many different balls or shapes in the air stream to investigate

the effect of size, weight and shape on how high the object floats, how well the object spins when the blower is tilted, and the overall stability of the object in the air stream. Objects include two whiffle balls (one with holes and one without), a football, a golf ball, a small basketball, two small beach balls, and toy fruits and vegetables such as apples, pears and onions. Visitors may also pass an object from one blower to another. Two blowers also allow multiple visitors to share the exhibit. (*Going APE!* Exhibit Development Team, 2004)

Gravity Powered Calculator: At this exhibit, visitors roll little metal balls down a ramp. At the bottom of the ramp, the balls are launched horizontally, fly through the air, and land on a measuring ruler, which shows the horizontal distance the balls traveled. On the ramp, there is another ruler, showing how high up the ramp a given ball is placed. The fascinating part of the exhibit is that the horizontal distance the ball travels through the air is the square root of the distance up the ramp the ball was placed. For example, if the ball is placed at the 9 markers on the ramp, it will fall on the 3.0 markers on the floor. (Actually, for whole-number distances – 1, 2, 3, 4, 5 and 6 – the balls fall on metal rods, which make a pleasant bell-like sound.) The exhibit is a square-root calculator. Visitors can figure out the square root pattern by launching balls and thinking about the relationship between the starting point and the endpoint. Or, if they learn from the label that it calculates square roots (which most visitors do), they can simply test the machine by rolling balls from different points on the ramp. There is also a real calculator on the exhibit, so visitors can test the machine to see whether the square root of, say, 10 is really 3.16. (*Going APE!* Exhibit Development Team, 2004)

Heat Camera: This exploration exhibit shows visitors the infrared heat emanating from their bodies. Heat is represented as different shades of gray, with hottest shown as white and coolest as black. In effect, visitors look into a "mirror" of themselves that shows their heat rather than their visual image. Visitors can explore the heat radiating from different body parts, or compare heat from one person to another. Various objects are included to allow visitors to change or affect their heat, such as a hair dryer, an insulator pad for rubbing (heating by friction), and a metal plate with protruding stars and moons (for cooling and "tattooing"). In addition, some objects that reflect infrared or visible light are included, such as copper, Plexiglas and a regular mirror, allowing visitors to explore the reflection aspect of infrared radiation. The central location for viewing oneself is from a bench in front of the large display monitor. However, there is also a rear standing area, where visitors can watch others and even see a bit of themselves while waiting for the exhibit to become available. In this standing area, there are labels suggesting activities involving the copper, Plexiglas and mirror. Thus, the exhibit is designed to accommodate multiple visitor groups and even multiple ways to use the exhibit (i.e., some visitors can use it directly while others simply watch). (*Going APE!* Exhibit Development Team, 2004)

Visible Vibrations: At this exploration exhibit, visitors sprinkle a bit of sand on a vibrating metal plate. At certain frequencies, which depend on the shape and size of the plate, the plate resonates with the vibration, creating areas of high vibration and areas of almost no vibration. The sand bounces to the areas of little or no vibration, and beautiful patterns emerge. Visitors can try vibrating the plate at different frequencies to make different patterns. They can also compare different plates that have different shapes, or even the same shape but different sizes. How does the size or shape affect the pattern that forms? The exhibit also offers memory buttons, which act

like radio channel buttons, “memorizing” certain frequencies for quick playback later. The buttons allow visitors to switch rapidly between two different sand patterns. (*Going APE!* Exhibit Development Team, 2004)

APPENDIX C: ATTRIBUTES OF APE ENGAGEMENT

Attributes of Visitor Engagement at APE and non-APE Exhibits
7/28/03

Physical Engagement

APE	Non-APE
Visitors will spend significantly longer periods of time.	Visitors will spend shorter periods of time.
The length of time visitors spend at the exhibit will not depend on their age, ability, or background.	Visitors will spend different lengths of time at the exhibit based on their age, ability, and background.
Visitors will do a number of different activities.	Visitors will do just a few activities.
Visitors will engage in a sequence of self-generated activities leading toward the solution of a problem or a discovery about a phenomenon.	Visitors will engage in a sequence of activities suggested in the label or implicit in the design of the interactive.
Visitors will demonstrate a range of different meaningful ways of interacting with the exhibit.	Visitors will engage with the exhibit in a limited number of meaningful but predictable ways.
Visitors will engage with exhibit in individualized ways appropriate to their age, ability, and background.	Visitors will engage with the exhibit in similar ways, regardless of their age, ability, or background.
Visitors will generate and pursue self-directed activities not mentioned in the labels.	Visitors will primarily do the activities suggested in the labels or implicit in the design of the interactive.
When visitor initial questions and hypotheses are answered, visitors will pursue further exploration.	When visitor initial questions and hypotheses are answered, visitors will leave the exhibit.
Visitors of various ages, abilities, and backgrounds will begin interaction at different points or with different activities (i.e. multiple entry points).	Visitors of various ages, abilities, and backgrounds begin interaction at points cued by the labels or implicit in the design of the interactive. Most visitors begin their interaction with the exhibit at the same place.

Intellectual Engagement

Visitors will generate a range of meaningful questions about the exhibit content or phenomenon.	Visitors will ask a few limited questions about the exhibit content or phenomenon.
Visitor questions will be followed by a variety of self-directed play, observation, investigation, and contemplation activities.	Visitor questions will be followed by a limited range of activities prompted by the labels or design of the interactive.
Answers to questions raised will be clearly tied to individual exploration and conversation with other visitors.	Answers to questions will be clearly tied to the exhibit.
Answers to the individual's questions will be articulated as a process of discovery or exploration.	Answers to questions will be articulated as a process of understanding a point communicated by the exhibit.
Visitors will articulate a wide range of appropriate conclusions and understandings based on their experience.	Visitors will articulate a limited range of appropriate conclusions or understandings.
Visitors' conceptual understanding of the phenomena will display a range of individual constructions and conclusions.	Visitors' conceptual understandings of phenomena will display similar constructions and understandings of phenomena.

Social Engagement

Visitors will ask each other a range of interesting questions.	Visitors will ask each other a limited set of interesting questions.
Visitor conversation will indicate play, observation, investigation, and contemplation.	Visitor conversation will focus on the intended use or point of the exhibit.
Visitor conversation will include discussions of multiple viewpoints, constructions, and understandings.	Visitor conversation with others will include discussions of a single or primary point of the exhibit. Conversation will be convergent toward a common understanding.
There will be a range of types of social interaction including silence, teaching-learning, and showcasing.	Visitors will engage in a typical informal science teaching-learning exchange.
Visitors will challenge each other to engage with the exhibit in unique and interesting ways.	Visitors will encourage each other to use the exhibit in a prescribed way.

Emotional Engagement

Visitors will feel satisfied with the journey.	Visitors will feel satisfied when they "get it."
Visitors will experience a sense of flow. They will lose sense of time.	Visitors will enjoy completing a prescribed activity.

Attributes of Going APE! Exhibits
6/18/03

Active prolonged engagement is accessible to visitors with disparate backgrounds.

- The exhibits engage visitors in multiple ways appropriate to their age and educational level.
- Visitors of different backgrounds are motivated to engage further at the exhibits.

Visitors drive their own activity with limited or no frustration.

- Visitors are not overwhelmed by multiple options: They know where to start and how to continue.
- Visitors feel satisfied with the amount of guidance or explanation at the exhibits.

Exhibits generate visitor-authored questions and activities.

- Visitors ask questions – of the exhibit and of each other.
- Visitors engage in activities that are suggested by labels but not fully directed by them, or are entirely independent of the labels.
- Visitors use the exhibit to find answers to their questions rather than solely seeking authoritative answers.

Exhibits stimulate conversations among visitors at the exhibits indicating inquiry, exploration, play, observation, and contemplation.

- Visitors' conversations suggest a focus on scientific process skills.
- Visitors' conversations seem to differ in quality at APE and non-APE exhibits.

Visitors achieve demonstrated cognitive or visceral understandings of phenomena.

- Visitors seem to be building or practicing skills in inquiry, exploration, play, observation or contemplation; and/or visitors seem to be constructing a conceptual understanding of the phenomena.

Visitor holding time increases at exhibits.

- Visitors spend more time at exhibits, and seem more engaged with them.

APPENDIX D: GROUP AND RESPONDENT DESCRIPTIONS

Table D.1: Group and Respondent Descriptions

Case #	Exhibit	Residence	# of R's by Case	Exhibit Use Group	Explo Visit Group	R 1	R 2	R 3	R 4	R 5
1	3-D Shapes	unknown	2	mother and daughter	other family, in-laws	female, age 5	female, late 20s			
5	3-D Shapes	Redding, CA	1	adult female alone	with another female friend	female, late 30s	female, late 30s			
13	3-D Shapes	East Bay	3	father, son, and son's friend	same	male, late 40s	male, teen	male, teen		
19	3-D Shapes	unknown	5	mother and son with interaction with a mom, dad, and son in same larger group	large birthday party	male, 7 to 10 years old	female, late 30s	male, 7 to 10 years old	female, late 30s	male, 40s
23	3-D Shapes	Belmont and San Jose, CA	2	adult dating couple	adult dating couple	male mid-20s	female mid-20s			
29	3-D Shapes	Sacramento and Fresno, CA	3	three young adult friends, mixed gender	same	male, 30s	female, 20s	female, 20s		
6	Floating Objects	Lake Tahoe, NV	2	an older and younger brother	brothers with their mom and five other people	male, eighth grade (13 years old)	male, college freshman (18 years old)			
15	Floating Objects	San Leadro, CA and Mexico	2	father and son	father, mother, and son	male, 40s	male, 17			

4	31	14	12	11	8	3	32	16	**Case #**
Heat Camera	Gravity-Powered Calculator	Gravity-Powered Calculator	Gravity-Powered Calculator	Gravity-Powered Calculator	Gravity-Powered Calculator	Gravity-Powered Calculator	Floating Objects	Floating Objects	**Exhibit**
El Sabronte, CA	Montreal, Quebec, Canada	unknown	unknown	San Francisco, CA	San Francisco, CA	Wichita, KS	Chico, CA	unknown	**Residence**
4	1	2	2	2	3	1	2	4	**# of R's by Case**
mother, father, and daughter--son nearby and less engaged	alone	father and son	father and daughter	man alone and child from another visiting group	father, daughter, and son	man alone	dating couple	4 adult friends, mix gender	**Exhibit Use Group**
female, mid 30s	dating couple	male, mid-30s	father, mother, son (10), and daughter	man visiting with family and friends	same	son, daughter-in-law, and three grandchildren	same	large group of 13 peer age friends	**Explo Visit Group**
male mid-30s	female, 30s	male, age 4	male, 50s	male, mid-30s	male, late 40s	male, about 60	female, late 20s	female, mid-20s	**R 1**
female, 10			female, 8		female, 11		male, late 20s	male, mid-20s	**R 2**
male, 14					male, 8			male, mid-20s	**R 3**
								male, mid 20s	**R 4**
									R 5

22	21	18	2	30	28	26	10	9	**Case #**
Pulley Table	Pulley Table	Pulley Table	Pulley Table	Heat Camera	Heat Camera	Heat Camera	Heat Camera	Heat Camera	**Exhibit**
TX	AZ	Bay Area	San Ramon, CA	Redding, CA	Calistoga, CA	Francisco, CA and visitors from Sacramento, CA	with a friend of sons indicating probably local	Utah	**Residence**
2	2	3	1	3	5	5	1	5	**# of R's by Case**
grandfather with granddaughter	grandmother with grandson	family--but father used alone and mother used with child	male, alone	mom and two adult daughters	grandmother, parents, and two sons	two fathers and two sons and grandfather of one child	male alone	father, mother, two sons, and adult, male friend	**Exhibit Use Group**
grandfather, grandmother, and granddaughter	grandparents with grandson	family	family	same	same	same	father visiting with 13 year old son and his friend, not at exhibit	male, 30s	**Explo Visit Group**
male, 60s	male, 10 or 11	female, mid-30s	male, mid-30s	female, 60s	female, grandmother	male, mid-30s	male, 40s	female, 30s	**R 1**
female, 3rd grade (8 or 9)	female, 60s	male, mid-30s		female, 30s	male, father	male, 6		male. 40s	**R 2**
		female, almost 6		female, 30s	male, father	male, 60s		male, 7	**R 3**
					male, 8	male, 30s		male, 5	**R 4**
					male, 10	male, 7			**R 5**

34	33	20	17	7	27	25	24	**Case #**
Visible Vibrations	Visible Vibrations	Vibrations (Pulley Table secondary)	Visible Vibrations	Visible Vibrations	Pulley Table	Pulley Table	Pulley Table	**Exhibit**
unknown	tourist	unknown	unknown	unknown	unknown	unknown	unknown	**Residence**
3	1	2	4	1	3	2	2	**# of R's by Case**
woman, daughter, and man (father or grandfather)	teenage girl alone	father and daughter	mother, father, daughter, and son.	woman alone	mother and 2 daughters	husband and wife	father and son--mother observing	**Exhibit Use Group**
unknown	father, mother and teenage daughter	large family group of 11 people	male, 40s	two female friends and respondents daughter, age 6	two sisters (mothers) and their children	husband, wife, and five children	father, mother, and son	**Explo Visit Group**
female, 3	female, 17	male, 40s	female, 30s	female, late 20s	female, late 30s	male, early 30s	male, early 40s	**R 1**
female, about 30		female, 8	male, teen		female, 5	female, early 30s	male, 11	**R 2**
male, about 60			female, about 9		female, 8			**R 3**
								R 4
								R 5

APPENDIX E: DATA SOURCE TABLE

Table E.1: Data Source Table

Case #	1	2	3
Debrief File 1	APE3_040221_AK_01	APE3_040221_ak-02	APE3_040221_CT_01
Debrief File 2 (X=no second debrief)	APE3_040221_DP_01	X	X
Transcript File	APE3_040221_DP_01	APE3_040221_ak-02	APE3_040221_CT_01
Exhibit	3-D Shapes	Pulley Table	Gravity Powered Calculator
Total Time (seconds)	105	93	138
Total Time (decimal minutes)	1.8	1.6	2.3
Residence	unknown	San Ramon, CA	Wichita, KS
Previous Visits	infrequent	first time	first time
# of R's by Case	2	1	1
Exhibit Use Group	mother and daughter	male, alone	man alone
Explo Visit Group	other family, in-laws	family	grandfather visiting with son, daughter-in-law, and three
R 1	female, age 5	male, mid-30s	male, about 60
R 2	female, late 20s		
R 3			
R 4			
R 5			
P	1	1	2
I	1	1	3
S	1	1	0
E	0	1	3
APE	1	1	2
Level of APE	Low	Low	Low

7	6	5	4	Case #
APE3_040221_JW_02	APE3_040221_JW_01	APE3_040221_DP_02	APE3_040221_CT_02	**Debrief File 1**
X	APE3_040221_MK_01	X	X	**Debrief File 2 (X=no second debrief)**
APE3_040221_JW_02	APE3_040221_JW_01	APE3_040221_DP_02	APE3_040221_CT_02	**Transcript File**
Visible Vibrations	Floating Objects	3-D Shapes	Heat Camera	**Exhibit**
241	122	100	285	**Total Time (seconds)**
4.0	2.0	1.7	4.8	**Total Time (decimal minutes)**
unknown	Lake Tahoe, NV	Redding, CA	El Sabronte, CA	**Residence**
unknown	first and second time visitors	first time	infrequent	**Previous Visits**
1	2	1	4	**# of R's by Case**
woman alone	an older and younger brother	adult female alone	mother, father, and daughter--son nearby and less engaged	**Exhibit Use Group**
two female friends and respondents daughter, age 6	brothers with their mom and five other people	with another female friend	female, mid 30s	**Explo Visit Group**
female, late 20s	male, 8th grade (13 years old)	female, late 30s	male mid-30s	**R 1**
	male, college freshman (18 years old)	female, late 30s	female, 10	**R 2**
			male, 14	**R 3**
				R 4
				R 5
3	4	3	3	**P**
3	4	3	4	**I**
1	4	2	4	**S**
4	4	3	4	**E**
3	4	3	3	**APE**
Low	**Medium**	**Medium**	**Medium**	**Level of APE**

11	10	9	8	Case #
APE3_040222_JW_02	APE3_040222_DP_01	APE3_040222_AK_01	APE3_040221_MK_02	**Debrief File 1**
X	APE3_040222_JW_01	APE3_040222_MK_01	X	**Debrief File 2 (X=no second debrief)**
APE3_040222_JW_02	APE3_040222_DP_01	APE3_040222_AK_01	APE3_040221_MK_02	**Transcript File**
Gravity Powered Calculator	Heat Camera	Heat Camera	Gravity Powered Calculator	**Exhibit**
50	45	255	157	**Total Time (seconds)**
0.8	0.8	4.3	2.6	**Total Time (decimal minutes)**
San Francisco	unknown, but there with a friend of sons indicating	Utah	San Francisco	**Residence**
infrequent	unknown, but had visited before	first time	infrequent, but frequent museum visitors	**Previous Visits**
2	1	5	3	**# of R's by Case**
man alone and child from another visiting group	male alone	Father, mother, two sons, and adult male friend	father, daughter, and son	**Exhibit Use Group**
man visiting with family and friends	father visiting with 13-year-old son and his friend, not at	male, 30s	same	**Explo Visit Group**
male, mid-30s	male, 40s	female, 30s	male, late 40s	**R 1**
		Male. 40s	female, 11	**R 2**
		male, 7	male, 8	**R 3**
		male, 5		**R 4**
				R 5
2	2	3	3	**P**
2	4	2	4	**I**
2	1	3	4	**S**
2	2	4	3	**E**
2	2	2	3	**APE**
Low	**Low**	**Low**	**Medium**	**Level of APE**

15	14	13	12	Case #
APE3_040228_AK_02	APE3_040228_AK_01	APE3_040222_MK_02	APE3_040222_DP_02	**Debrief File 1**
X	X	X	X	**Debrief File 2 (X=no second debrief)**
APE3_040228_AK_02	APE3_040228_AK_01	APE3_040222_MK_02	APE3_040222_DP_02	**Transcript File**
Floating Objects	Gravity Powered Calculator	3-D Shapes	Gravity Powered Calculator	**Exhibit**
68	339	46	510	**Total Time (seconds)**
1.1	5.7	0.8	8.5	**Total Time (decimal minutes)**
San Leadro, CA and Mexico	unknown	East Bay	unknown	**Residence**
first time	unknown	second visit	unknown	**Previous Visits**
2	2	3	2	**# of R's by Case**
father and son	father and son	father, son, and sons friend	father and daughter	**Exhibit Use Group**
father, mother, and son	male, mid-30s	same	father, mother, son (10), and daughter	**Explo Visit Group**
male, 40s	male, age 4	male, late 40s	male, 50s	**R 1**
male, 17		male, teen	female, 8	**R 2**
		male, teen		**R 3**
				R 4
				R 5
2	4	1	2	**P**
2	3	1	2	**I**
3	1	2	2	**S**
4	4	1	2	**E**
2	3	1	2	**APE**
Low	**High**	**Low**	**Medium**	**Level of APE**

19	18	17	16	Case #
APE3_040228_JW_02	APE3_040228_JW_01	APE3_040228_DP_02	APE3_040228_DP_01	**Debrief File 1**
X	X	X	X	**Debrief File 2 (X=no second debrief)**
refused interview	APE3_040228_JW_01	APE3_040228_DP_02	APE3_040228_DP_01	**Transcript File**
3-D Shapes	Pulley Table	Visible Vibrations	Floating Objects	**Exhibit**
1020	390	360	90	**Total Time (seconds)**
17.0	6.5	6.0	1.5	**Total Time (decimal minutes)**
unknown	Bay Area	unknown	unknown	**Residence**
unknown	frequent	unknown	unknown	**Previous Visits**
5	3	4	4	**# of R's by Case**
mother and son with interaction with a mom, dad, and son in same	family--but father used alone and mother used with child	mother, father, daughter, and son.	4 adult friends, mix gender	**Exhibit Use Group**
large birthday party	family	male, 40s	large group of 13 peer age friends	**Explo Visit Group**
male, 7 to 10 years old	female, mid-30s	female, 30s	female, mid-20s	**R 1**
female, late 30s	male, mid-30s	male, teen	male, mid-20s	**R 2**
male, 7 to 10 years old	female, almost 6	female, about 9	male, mid-20s	**R 3**
female, late 30s			male, mid 20s	**R 4**
male, 40s				**R 5**
3	4	2	2	**P**
3	5	1	1	**I**
5	4	2	1	**S**
4	4	1	2	**E**
4	4	2	1	**APE**
Medium	**High**	**Medium**	**Low**	**Level of APE**

23	22	21	20	Case #
APE3_040306_AK_02	APE3_040306_AK_01	APE3_040228_MK_02	APE3_040228_MK_01	**Debrief File 1**
X	X	X	X	**Debrief File 2 (X=no second debrief)**
APE3_040306_AK_02	APE3_040306_AK_01	APE3_040228_MK_02	APE3_040228_MK_01	**Transcript File**
3-D Shapes	Pulley Table	Pulley Table	Visible Vibrations (Pulley Table secondary)	**Exhibit**
340	33	62	312	**Total Time (seconds)**
5.7	0.6	1.0	5.2	**Total Time (decimal minutes)**
Belmont and San Jose, CA	TX	AZ	unknown	**Residence**
she had not visited before but he had	first time	infrequent, but frequent to Arizona Science Center	unknown	**Previous Visits**
2	2	2	2	**# of R's by Case**
adult dating couple	grandfather with granddaughter	grandmother with grandson	father and daughter	**Exhibit Use Group**
adult dating couple	grandfather, grandmother, and granddaughter	grandparents with grandson	large family group of 11 people	**Explo Visit Group**
male mid-20s	male, 60s	male, 10 or 11	male, 40s	**R 1**
female mid-20s	female, third grade (8 or 9)	female, 60s	female, 8	**R 2**
				R 3
				R 4
				R 5
3	1	2	3	**P**
4	1	2	2	**I**
5	2	2	3	**S**
5	3	2	3	**E**
4	1	2	3	**APE**
High	**Low**	**Low**	**Medium**	**Level of APE**

27	26	25	24	Case #
APE3_040306_JW_02	APE3_040306_JW_01	APE3_040306_DP_02	APE3_040306_DP_01	**Debrief File 1**
X	X	X	X	**Debrief File 2 (X=no second debrief)**
refused interview	APE3_040306_JW_01	APE3_040306_DP_02	APE3_040306_DP_01	**Transcript File**
Pulley Table	Heat Camera	Pulley Table	Pulley Table	**Exhibit**
10	570	>60	300	**Total Time (seconds)**
0.2	9.5	under 1 minute	5.0	**Total Time (decimal minutes)**
unknown	San Francisco and visitors from Sacramento, CA	unknown	unknown	**Residence**
unknown	frequent (member) and first time	first time	unknown	**Previous Visits**
3	5	2	4	**# of R's by Case**
mother and 2 daughters	two fathers and two sons and grandfather of one child	husband and wife	father, mother, and son	**Exhibit Use Group**
two sisters (mothers) and their children	same	husband, wife, and five children	father, mother, and son	**Explo Visit Group**
female, late 30s	male, mid-30s	male, early 30s	male, early 40s	**R 1**
female, 5	male, 6	female, early 30s	male, 11	**R 2**
female, 8	male, 60s			**R 3**
	male, 30s			**R 4**
	male, 7			**R 5**
0	5	1	3	**P**
1	4	1	3	**I**
0	5	2	2	**S**
1	5	2	3	**E**
0	5	1	3	**APE**
Low	**High**	**Low**	**Medium**	**Level of APE**

31	30	29	28	Case #
APE3_040313_AK_01	APE3_040306_MK_03	APE3_040306_MK_02	APE3_040306_MK_01	**Debrief File 1**
X	X	X	X	**Debrief File 2 (X=no second debrief)**
APE3_040313_AK_01	APE3_040306_MK_03	APE3_040306_MK_02	APE3_040306_MK_01	**Transcript File**
Gravity Powered Calculator	Heat Camera	3-D Shapes	Heat Camera	**Exhibit**
235	360	19	500	**Total Time (seconds)**
3.9	6.0	0.3	8.3	**Total Time (decimal minutes)**
Montreal, Quebec, Canada	Redding, CA	Sacramento and Fresno, CA	Calistoga, CA	**Residence**
first time	infrequent and first time	first time	frequent	**Previous Visits**
1	3	3	5	**# of R's by Case**
alone	mom and two adult daughters	three young adult friends, mixed gender	grandmother, parents, and two sons	**Exhibit Use Group**
dating couple	same	same	same	**Explo Visit Group**
female, 30s	female, 60s	male, 30s	female, grandmother	**R 1**
	female, 30s	female, 20s	male, father	**R 2**
	female, 30s	female, 20s	male, father	**R 3**
			male, 8	**R 4**
			male, 10	**R 5**
3	5	0	4	**P**
4	5	1	3	**I**
3	5	1	4	**S**
4	5	0	4	**E**
4	5	0	4	**APE**
High	**High**	**High**	**Medium**	**Level of APE**

34	33	32	Case #
APE_040222_AK_02	APE3_040313_JW_01	APE3_040313_AK_02	**Debrief File 1**
x	X	X	**Debrief File 2 (X=no second debrief)**
refused interview	APE3_040313_JW_01	APE3_040313_AK_02	**Transcript File**
Visible Vibrations	Visible Vibrations	Floating Objects	**Exhibit**
135	660	192	**Total Time (seconds)**
2.3	11.0	3.2	**Total Time (decimal minutes)**
unknown	tourist	Chico, CA	**Residence**
unknown	first time	infrequent	**Previous Visits**
3	1	2	**# of R's by Case**
woman, daughter, and man (father or grandfather)	teenage girl alone	dating couple	**Exhibit Use Group**
unknown	father, mother and teenage daughter	same	**Explo Visit Group**
female, 3	female, 17	female, late 20s	**R 1**
female, about 30		male, late 20s	**R 2**
male, about 60			**R 3**
			R 4
			R 5
1	5	5	**P**
0	5	5	**I**
2	0	5	**S**
4	4	5	**E**
2	5	5	**APE**
Low	**High**	**High**	**Level of APE**

APPENDIX F: PROTOCOL--CASUAL MUSEUM VISITORS

Data Collection Protocol

Data Set: _____ Exhibit Name: _____
(APE3_YYMMDD_ Your Initials_X)

Data Collector: _____ Date: _____

Observation Start Time: _____

Reason for selecting respondent:

Social Group (describe):

OBSERVATION NOTES:
(Focus on physical, social, intellectual, and emotional aspects of the engagement.)

Observation End Time: _____

INTERVIEW NOTES:

Keep in Mind the Overarching Question: In what ways and to what extent did the nine selected exhibits stimulate and facilitate APE engagements among visitors?

Opening Statement: Hi, I'm (name), and I'm working with the Exploratorium. We are studying this exhibit. Would you help me by giving me your opinion by answering a few questions? It will take about 10 to 15 minutes.

Establish Rapport: [Ask while you are moving them to the table.]

1. Is this your first time to the Exploratorium? Have you been here before?

2. Where are you from?

Confidentiality and Anonymity:
We want to tape record the interview so we can check our notes and make certain we have accurately understood what you have said. All your comments will be reported confidentially and anonymously. Do I have your permission to record? [Turn on tape recorder at this point]

Interview Questions:

Physical Engagement

1. Can you tell me a little about what you were doing at the exhibit?
Probe: I noticed you were also [doing xyz]. What were you doing?
Alternate Probe: What were you thinking about when you [doing xyz]?

Social Engagement

1. I noticed that you were talking with [so and so]. Can you tell me a little about what you were talking about? Probes--depending on response.

2. I noticed you and (so and so) were doing (xyz), what were you talking about then?

3. I noticed you were using the exhibit (alone, with another person, with a group). Is that generally how you like to use exhibits or was there a reason you used this one that way?

Intellectual Engagement

1. What was going through your mind when you were doing [xyz]. (Probe for different parts of the engagement)

2. What did you find out at this exhibit that you didn't know before?

3. Was there anything that surprised you at this exhibit?

4. What were you thinking about as you left the exhibit?

5. If you were going to explain this **exhibit** to a 3rd-grader, how would you explain it?

6. One thing the Exploratorium is curious about is how you used the text information at this exhibit. Do you have any thoughts about that? (Probes: Did you notice it when you first walked up? Which part? Did you look at it any other time as you used the exhibit?)

Emotional Engagement

1. Based on all the other exhibits you've used, how would you rate this exhibit with 1 being the worst exhibit you've ever used, and 10 being the absolute best. Remember, I didn't develop the exhibit-- and that we are really trying to figure out what is working and what isn't. Why did you give it that rating? [Listen very carefully to the reasons they give to understand the emotional aspects of their engagement.]

Approaching/Leaving and Exhibit

1. One of the things the Exploratorium is particularly interested in is what things contribute to visitors deciding to use a particular exhibit or deciding to leave an exhibit, and that I'm curious what your experience was.
Probes if needed:

- Was there anything in particular you noticed when you walked up to this exhibit?
- What were you thinking when you first started using the exhibit?
- What were you thinking about as you decided to leave the exhibit?

Ending Interview:
Do you have any questions you want to ask me? And "Thanks so much for your time!"

Interview End Time: _____

Debriefing Template

Data Set: APE3_YYMMDD_Your Initials_X

CONTEXT

Exhibit Name:
Data Collector:

Observation Start Time:
Observation End Time:
Total Time of Engagement:
Interview End Time:

Reason for selecting respondent:

Social Group (describe)**:**

NARRATIVE SUMMARY OF OBSERVATION

NARRATIVE SUMMARY OF INTERVIEW

ANALYSIS OF THE DATA SET

In this section, reflect on what you saw by (1) rating the APEy-ness of the engagement in each of the perspectives on a six point scale, (2) giving specific examples from your observation and interview for this rating.

Definitions for Levels of Engagement

0 – no indication of any engagement
1 – minimal engagement, very incomplete
2 – slightly more engagement but still incomplete/inadequate
3 – basic meaningful engagement. Level 3 is what we look at and say to ourselves "They've got it. This is acceptable. It is adequate."
4 – more meaningful engagement
5 – the best we could hope for. This engagement is what we look at and say to ourselves "This is awesome! If only all visitors did this!"

1. Physical

High APE Engagement **Low APE Engagement**

5	4	3	2	1	0

a. Why did I give this engagement this rating on physical engagement?

b. What else did I find out about the ways in which and extent to which the APE exhibits stimulated and facilitated APEy physical engagements among visitors?

2. Intellectual

High APE Engagement **Low APE Engagement**

5	4	3	2	1	0

a. Why did I give this engagement this rating on intellectual engagement?

b. What else did I find out about the ways in which and extent to which the APE exhibits stimulated and facilitated APEy intellectual engagements among visitors?

3. Social

High APE Engagement **Low APE Engagement**

5	4	3	2	1	0

a. Why did I give this engagement this rating on social engagement?

b. What else did I find out about the ways in which and extent to which the APE exhibits stimulated and facilitated APEy social engagements among visitors?

4. Emotional

High APE Engagement **Low APE Engagement**

5	4	3	2	1	0

a. Why did I give this engagement this rating on emotional engagement?

b. What else did I find out about the ways in which and extent to which the APE exhibits stimulated and facilitated APEy emotional engagements among visitors?

5. Overall Rating: To what extent and in what ways was this an APEy engagement?

High APE Engagement **Low APE Engagement**

5	4	3	2	1	0

a. Why did I give this engagement this rating on overall engagement?

b. What else did I find out about the ways in which and extent to which the APE exhibits stimulated and facilitated APEy engagements among visitors?

EXHIBIT DESIGN

1. What aspects of the exhibit's conceptual design contributed to APEy engagement?

2. What aspects of the exhibit's conceptual design inhibited APEy engagement?

3. What aspects of the exhibit's physical design contributed to APEy engagement?

4. What aspects of the exhibit's physical design inhibited APEy engagement?

OTHER REFLECTIONS

1. What do I know now that I didn't know before?

2. What am I more curious about now?

3. **What surprised me?**

4. **What conclusions am I beginning to arrive at? What can I look for in order to test these conclusions? What evidence is there that my conclusion is not accurate?**

NEXT STEPS

1. **What type of group at what exhibit do you need to observe to answer the overarching question?**

2. **What question do I want to explore in my next observation/interview?**

APE Phase II

Group Debriefing Protocol

Name of Author
Date of Debrief

One member of the data collection team should summarize the group debriefing at the end of the day. This debriefing should be e-mailed all other members of the data collection team:

Be sure to read the previous debrief before beginning your data collection.

Data Collectors Attending Debrief: (list all names)

What questions in the Topical Framework were you able to answer—partially or fully?

What were the focus areas from the previous day?

What did you, as a group, learn to clarify that would these areas?

What additional themes or issues (differences in perception) emerged from today's data collection?

What are the focus areas for tomorrow's data collection?

APPENDIX G: PROTOCOL--EXHIBIT DEVELOPERS

APE3 Interview Protocol Exhibit Developers
May 26, 2004
Version 2

Introduction

- Explain who we are (stress independent evaluators)
- No right/wrong answers
- Confidentiality ("Everything you say is confidential")
- Interview will take 45 minutes
- Ask permission to record (explain that we do it to refer to in addition to our notes.

Purpose of the Interview: As part of our evaluation study, we want to get your perspectives as one of the exhibit developers on the APE project.

1. Just to get started, tell me about your role on the APE exhibit development team? (Probe: Which exhibits did you develop?)

2. How is designing an APE exhibit different than designing a non-APE exhibit?

3. When you were designing APE exhibits, what were some of the things you considered in the design?

   (Probes: Were there things you considered to encourage physical engagement?

   Intellectual engagement?

   Social engagement?

   Emotional engagement?)

4. Are there any exhibits that you would point to that you consider especially good at encouraging APE engagements? What is it about this exhibit that makes you say that?

5. Are there any exhibits that you would point to that you consider less successful in encouraging APE engagements? What is it about this exhibit that makes you say that?

6. What things, outside the exhibit itself, do you think may contribute to APE engagement?

7. What things, outside the exhibit itself, do you think may block APE engagement?

8. One of the things that I ran into in interviews and debriefs when people were rating engagements--how APE they were--was the concept of open-ended or closed ended

experiences. Would you explain how the team members understand that concept? What do you think about it?

9. Let's talk about the extent to which the team developed exhibits that encouraged APE engagement.

   Where would you rate the extent to which the project developed exhibits? Let's use the scale of 6 high and 0 being low scale. (Probe: Why would you give this rating?)

10. If you were going to give advice to an exhibit developer from another science museum about developing APE exhibits, what would you say?

11. Are there any other things that you think we should consider in answering the big question of this study?

Thank you so much for taking the time to be interviewed. We appreciate you comments and perspectives.