Research and Rolling Exhibits (RARE)

A Columbia University and

New York Hall of Science Collaboration

Project Evaluation Final Report

Prepared by Ellen Giusti

With Kathleen Condon

March 2009

Table of Contents

It's science and science is always interesting. Like, who knew there was so much stuff in the world that is included in science? Like, the whole world is pretty much science. (10 years old)

Introduction

Columbia University Materials Research Science and Engineering Center (MRSEC) and New York Hall of Science (NYHOS) partnered to create Research and Rolling Exhibits (RARE). The project's goal is to showcase current research in science and make it accessible to the general public. With support from the National Science Foundation, five Wondercarts (as they are now called) were created over three years, from 2005 through 2008. The Wondercarts highlight topical scientific research and focus on its relevance to the museum's target audience. The carts were programmed to engage families in conversation, letting their interest determine the direction of activities. In this manner Wondercarts differ from the Hall's scripted demonstrations, which tend to be one-way information delivery systems.

Overarching Objectives

- Engage and educate the NYHOS's family audience using portable, changing, hands-on exhibits about current research in materials science.
- Provide the Hall's Explainers, many of them minority students, with additional opportunities to explore current research in materials science and to build their skills and strategies for informal education through sharing their knowledge and technical skills with others.
- Prepare science teachers to be better prepared to bring current knowledge in materials science that is interesting and relevant to understanding life on Earth to their classrooms.
- Develop a model of University-Museum partnerships to bring current research to the public through museum exhibits and displays.

Cart Topics

Brainstorming sessions were conducted to discuss topics for each cart. Staff members from the two collaborating institutions met with the PIs, exhibit developer and the evaluators to discuss new topics and how to best interpret them. The exhibit developer provided creative ideas and the PIs made sure they were scientifically accurate. NYHOS Explainers and their managers were responsible for presenting the science to the public, using inquiry-based methods.

The following topics were selected for the five carts:

1. Groundwater Flow
2. Gecko Adhesion
3. Sports Safety Equipment
4. Crystals (Liquid Crystal and Piezoelectricity)
5. Chemistry of Food

Methodology

Each of the five topics was tested twice with NYHOS family visitors. First, front-end evaluation determined visitors' understanding of the topic and interactive exhibits designed to explore it. During this phase the exhibit developer included a broad range of materials pertaining to the topic to see which were more appealing, understandable and relevant to the cart's learning goals. Activities that proved too complicated or unwieldy for a rolling cart were omitted. The most effective elements were retained and modified for testing in a second iteration, formative evaluation.

Before each evaluative session began, the exhibit developer presented the activities to the Explainers and evaluators. The purpose was to train Explainers to present the activities to visitors and to orient the evaluators to the program. The activities were arrayed on 6-foot long tables so that three Explainers could facilitate several activities simultaneously. Although this did not accurately simulate the rolling cart experience, it allowed us to evaluate many more activities than would have been possible had we placed them on a cart.

Family groups were invited to "try out some new activities to help the Hall improve them." For purposes of the test, a family was defined as at least one adult and one child between 4 – 17 years old. Children's minimum target age was increased to 7 because we found that while younger children enjoyed the activities, the team believed that they were not able to understand the content sufficiently to supply useful feedback.

Each testing session was conducted in a similar manner. The evaluators observed family groups interacting with the activities and Explainers, noting conversation, questions and interactions on the instrument. When a group appeared ready to leave the area, an evaluator approached and asked the adult(s) if it would be all right to ask the child or children in the target age range a few questions to help the Hall learn what visitors thought of the activities. Response rate was high; families were usually willing unless they were hurrying to a scheduled program. The evaluators used a brief semi-structured instrument to interview the children about what they enjoyed and learned.

Specific objectives and findings for each cart follow.

RARE I. Groundwater Flow

Groundwater flow was the first topic selected for RARE. Front-end (or background) evaluation took place on Saturday February 5, 2006 with almost 50 museum visitors participating. Formative evaluation testing was conducted on Saturday June 3, 2006 with 54 museum visitors. The central component of the exhibit was an element called a Sandtank. It illustrates groundwater flow, the ways in which groundwater can become polluted and ways to prevent or remediate pollution.

Explainers helped visitors conduct experiments to understand how water flows underground, how contaminants can enter the system, and how well water can be tested to reveal the presence of contaminants. Explainers were adept at involving children, using questions instead of lecturing ("Where does the garbage go when it leaves your house?") and letting the children inject colored water representing contaminants into the system.

Objective

The purpose of the evaluation was to learn if NYHOS family visitors with children ages 4-12 years old were

- attracted to and engaged by the Sandtank and the four prevention/remediation displays
- able to understand science-based techniques to prevent or remediate groundwater and other types of water pollution

Exhibit Elements

<u>Sandtank</u>
A narrow container consisting of two sheets of glass was filled with sand and gravel. Water introduced at the top illustrated how rainwater flows underground. Colored water simulating polluted water was introduced, showing how it could enter the drinking water supply through aquifers and wells. The February 5th test focused on whether NYHOS family visitors would be attracted to the Sandtank display and understand what it illustrated.

<u>Supporting Activities</u>
The June 3rd prototype evaluation added activities focused on remediation—what can be done to prevent and/or clean up if pollution enters the system.

<u>Brita filter granules</u>
Using test tubes, water, diluted food coloring solution, and Brita filter granules, Explainers helped visitors understand how one common type of home water filter works.

<u>Sedimentation filter</u>
A transparent container with a drain at the bottom was filled with five layers of natural materials, starting with fine sand nearest the bottom, then moving through coarser materials, and finally ending with small stones at the top. When dirty water is poured over the stones on top, much cleaner water drains from the bottom. This is a simple model that presents an example of the early stages of filtration methods that municipal water systems use.

<u>Architectural Green Roof Model.</u>
A container with a drain at the bottom is filled with damp peat moss and a little coarse sand, then topped with some porous Astroturf to simulate actual grass on a building's roof. The end goal is to trap many water-borne pollutants before they reach the storm drains or local aquifers.

Using marked beakers, Explainers demonstrated that most water that is introduced into such systems stays put.

Oil Spill Cleanup
Using a beaker, water, crude oil, and a special non-toxic encapsulating polymer, Explainers showed visitors one way that even an environmentally hazardous substance like crude oil can be removed with the proper tools. The polymer binds to the oil to create a rubbery glob of completely encapsulated oil.

Findings

Visitors were attracted to the Sandtank display: virtually everyone who passed by stopped. Children as young as 4 years old were fascinated and remained engaged for up to 15 minutes. Observing the interaction made it clear that visitors, even young children, understood the activity, at an age-appropriate level: for example, 4- and 5-year-olds translated pollution to "dirty water." When water colored to simulate pollutants was drawn out of a "well" in the Sandtank, Explainers asked, "would you want to drink that?" followed by choruses of "no!" All interview respondents reported understanding, after seeing the demonstration that it illustrated how water becomes polluted.

Once attracted to and engaged by the Sandtank demonstration, the vast majority of participants stayed to interact with other demonstrations. Many visitors participated in all four supplementary activities. Visitor engagement was higher for the Oil Spill and the Brita demonstrations than it was for the Sedimentation and the Green Roof demonstrations. The oil spill and Brita involved dramatic chemical transformations and hands-on opportunities that may have sparked more visitor engagement.

While many parents were engaged as learners in the demonstrations, those with children 8-12 often stood back in order to allow their children to interact directly with an Explainer. However, parents with younger children 2 to 7 years old took a much more active role in facilitating their children's learning experiences. These parents often moved down to the child's eye level to observe the demonstrations, to monitor their children's level of interest, and to assist them in a variety of ways.

Explainers discussed concrete examples of pollutants that can enter the water supply—fertilizers and pesticides from home gardens, garbage in landfills, and more. Most adults and children age 8 and above understood that the devices displayed were meant to "clean the water."

> *[It was about water] pollution and how to clean it. (11 years)*

> *[It showed] different processes to get from dirty to clean drinking water. (adult)*

When asked informally during interviews to explain their understanding of the relationship between the Sandtank and the other demonstrations, adults and most children over 8 years of age were able to offer a big picture understanding—"This one shows how the water gets polluted and those show how you clean it up." It was not clear from their responses that visitors related the Sandtank display to the remediation/prevention demonstrations.

Most children in the 8-12 age group were unable to cite anything they had read or heard about in "real life" to the processes they saw demonstrated. Just one child said, "Oil on the ocean, animals die." Children were more likely to think literally about the question, for example: "[It reminds me of] my class on cleaning water, like our class trip to the watershed in Ellenville."

Adults typically were reminded of something in their lives or experience, for example:

> *We're thinking of putting a water purification system in our whole house. I don't want my body to be the filter!*

Most respondents who were interviewed about the activities agreed that they would like to learn more about them. Children were more likely to be interested in the oil spill cleanup material ("How did they make it? How did they come up with the idea?"). Adults wanted to know more about the immediately practical Brita filter ("The beads in the Brita filter—how do they work?").

The most interesting displays for children were the two that illustrated clear reactions—the Britta filter granules that cleared the blue dye from a water sample and the polymer that encapsulated the oil spill. Adults also found these activities engaging but were also able to

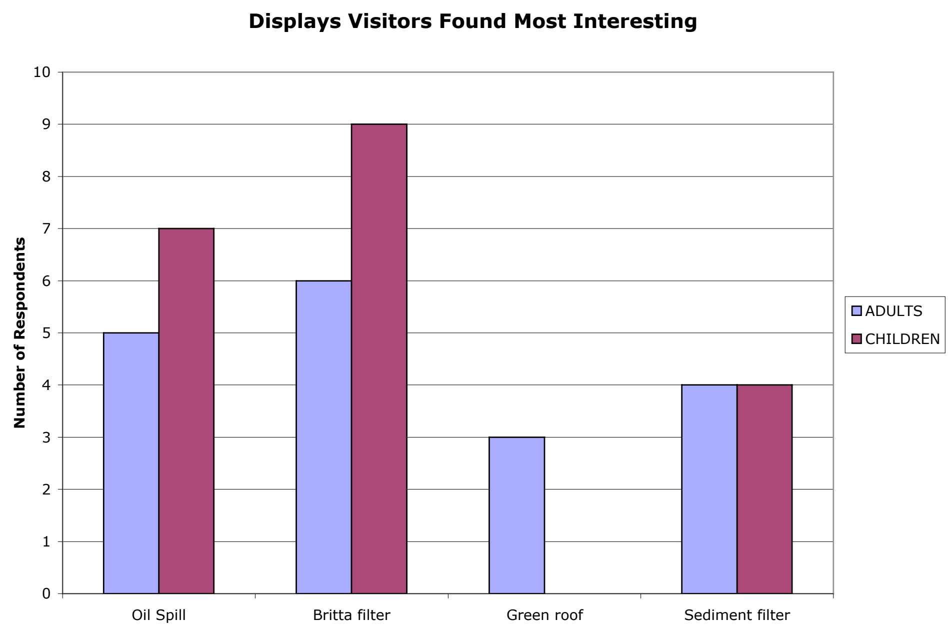

Figure 1. Most interesting displays

appreciate the more passive filtering displays. Children too found the sediment filter impressive: dirty water poured through dirt and stones came out clear.

Although the activities were not completely comprehensible to children younger than 8 years—particularly the science behind the displays—they were interested. Children of all ages were more engaged when Explainers pulled them into the action: scooping Brita beads, mixing dirt in the water, shaking the test tube.

Conclusions and Recommendations

- The tests illustrated the power of allowing visitors (adults and children) to guide the flow of activity according to their immediate interests. Conversation between visitors and Explainers was the key to the success of the experience. The tests validated RARE's primary objective—engaging visitors in current scientific research, showing them that it is connected and relevant to their lives.
- Explainers should encourage visitor participation during all demonstrations to create the kind of engagement that supports learning. As much as possible, they should invite visitors to actively participate in demonstrations through hands-on inquiry-based techniques.
- Overall, the displays effectively conveyed information about water pollution and its prevention and remediation. Children younger than 8 years old were only able to understand the activities at a very basic level, yet many of them were engaged by the hands-on activities. Older children and adults were engaged and understood the displays and aspects of the science involved.
    - Recommendations after the test of Sandtank alone suggested adding activities, particularly things that focused on solutions and alternatives to pollution.

  I think there should be a more positive tone. Now it's like, "This is what we're doing to the Earth." You're showing this to children so I think you should be more positive as well, showing alternatives, how it could be [made better]. (Father)

  Remediation activities were added to the second iteration of the cart.
- Explainers should identify practical applications for each remediation/prevention activity to provide personal connection for visitors.

  Everyone is connected to water because we drink it. If there could be a way to connect it to the water we drink, it would have more impact." (Father)

  This suggestion too was implemented during the second iteration when filtration systems were introduced.
- The majority of participants thought the Sandtank display would be "very interesting" for NYHOS visitors. Most respondents said the Britta and oil spill activities would be "very interesting" and the sedimentation and green roof displays would be "somewhat interesting."

RARE II. Gecko Adhesion

Front-end testing for the RARE Gecko Adhesion cart took place on Saturday November 11, 2006 with 33 children ages 4 to 16 years old participating. Our suspicions that children younger than 8 years old would not be developmentally mature enough to understand many of the principles involved were confirmed. Thus during the second iteration, formative evaluation conducted on Thursday, April 5, 2007, we raised the minimum age, interviewing 29 children ages 7 to 14 years old.

Objectives

The purpose of the tests was to find out if visitors were engaged by and understood the displays' main ideas:

- Primary: Close surface contact makes it possible for the gecko to stick (by Van der Waals forces); this principle holds true for other types of adhesion as well. Setae on geckos' feet help them make close contact with surfaces.
- Secondary: Forces are involved in gecko sticking and un-sticking:
  - Atomic forces (Van der Waals)
  - Shear (parallel, stronger) and tension (angle, weaker) forces
  - The molecular/atomic scale at which these forces take place is too small to see; this small scale is what enables the gecko to get so close to the surface.

Because the RARE carts are supposed to foster interactive, conversational learning, three types of visitor engagement were of particular interest:

- Watching and attending to Explainers as they demonstrated the activity
- Talking or interacting (asking questions or conversing with Explainers, talking to each other about the activities, or assisting Explainers with activities)

Exhibit Elements

In addition to seeing a live gecko in a glass tank, a variety of materials were on hand to demonstrate various examples of adhesion, all explained by the same underlying scientific forces on the atomic or molecular level.

<u>Live Gecko</u>

A live gecko in a glass tank demonstrated its ability to adhere to a vertical glass surface while Explainers helped visitors understand the phenomenon.

<u>Images</u>

Highly magnified images of setae and a 3-dimensional magnified image of a gecko's foot were meant to convey the special body parts that make possible gecko adhesion. Setae are invisible to the naked eye; a 3-d image seen with special glasses allowed visitors to "see" setae. 'Scope on a Rope produced images of the gecko's foot on a laptop computer monitor.

<u>Velcro</u>

Strips of Velcro were attached so that one end of each strip was sticking out far enough to grip. Using shear force it was impossible to pull the strips apart, but with tension force— pulling one end up at an angle—made it easy to pull the strips apart.

Post-it Notes
A bag of marbles was attached by a binder clips to the bottom edge of a Post-it note stuck to a board. To reinforce the concept of shear and tension force, visitors predicted whether the marbles would fall if the board was raised to the vertical or tipped at an angle.

Silicone Pads
This activity illustrated molecular adhesion principles of shear and tension forces. The two surfaces of the silicone pads, while not tacky to the touch were nonetheless harder to pull apart than the tape or Post-its, which did feel tacky.

Tape
Children are familiar with tape of all sorts. These sticky surfaces did not seem to engage children's sense of wonder or inquiry because they expect them to stick and do not question how this works.

Sticky Toys
Sticky toys that looked like geckos stuck to wherever they land or are thrown.

Phonebooks
The pages of two phone books were interwoven and proved impossible to pull apart.

Putty, Gum, Sticky Tack
These substances illustrated how polymer chains that create stickiness could be broken using oil or ice. Polymer chains are similar to gecko setae in forming close bonds with surfaces.

Video
A video shown during the second round of testing featured a robot gecko climbing like a real gecko, but in a slowed-down, schematized fashion. The video allowed visitors to observe the ways that a gecko's movements enable it to employ sheer and tension forces to stick and unstick its (artificial) setae, a process visitors could never have observed on an actual gecko.

Hairbrush
Added during the second iteration of testing, a hairbrush made an excellent 3-dimensional stand-in for a gecko's foot at unknown orders of magnitude by demonstrating how the bristles moved when pressed on a surface. This helped visitors understand how the gecko's setae conform closely to various surfaces.

Findings

The activities that fostered active participation—both hands-on manipulation and minds-on hypothesizing ("what would happen if…") were most effective. For example, the silicone paddles were popular because they provided a physical challenge; the post-it activities employed familiar items used in a provocative manner. Both were simple, easy-to-see demonstrations of the two types of force: children found them engaging and could relate them to prior experience. Unlike findings from the groundwater flow displays, adults tended to hang back and let their children interact with the materials and Explainers.

Gecko
Not surprisingly, the live animal was the main attractor, particularly for children; with the help of Explainers' inquiry-based instruction, it held their attention. Geckos, while recognizable from the TV commercial, do not do much apart from clinging to the glass wall. It was essential that Explainers step up to the challenge, pointing out that geckos can do something children know they cannot do—climb walls using just their hands and feet—and asking children to think about

how geckos can do this. The live gecko, however appealing, did not move much and was often hiding under a log. The robot gecko in the video conveyed the animal's ability to climb seemingly smooth, vertical surfaces.

> *[The video] shows how a gecko sticks on a wall and climbs. (Boy 8)*

<u>Images</u>

The highly magnified images of a gecko's foot effectively conveyed the special body parts that make gecko adhesion possible. The 3-d image seen with special glasses particularly engaged children, helping children visualize how the forces work to allow a gecko to climb smooth vertical surfaces.

> *I saw billions of hairs. They gotta get as close as possible. (Boy 8)*
>
> *I could see the tiny microscopic suction cups hanging on to the molecules of what it's holding on to. (Boy 10)*

The boy's comment illustrates a misconception conveyed by one of the images: gecko setae in super-magnification appeared flattened at the ends like suction cups. The 'Scope on a rope was less effective in conveying the essential information than the still images because the magnification was not powerful enough. It also may have created the false impression that gecko adhesion can actually be seen.

<u>Post-its and Velcro</u>

The most effective activities provided opportunities for physical engagement and relied on familiar materials. For example, Post-it activities were simple, easy-to-see demonstrations that the children found engaging and could relate to prior experience. While not strictly the same kind of stickiness as gecko adhesion, the Post-its were successful in conveying tension vs. sheer force. Demonstrating both sticking and unsticking, the Post-it was particularly effective in helping visitors understand how tension force is weaker than sheer force. Explainers used this to segue into a discussion of how geckos stick and release their feet from a surface.

Interestingly, many children deemed this the "most interesting" activity. The apparatus involved was decidedly low-tech, but being familiar, it made the point very effectively.

> *It makes you learn how the gecko can stick. (Boy 8)*
>
> *A post-it could carry that much weight until it was turned at an angle and fell down. (Girl 9)*

Velcro, another familiar substance, proved less effective than others and was eliminated for the second iteration tests.

<u>Silicone pads</u>

Silicone paddles illustrated the close atomic bond made when two smooth surfaces come together. Visitors could see and feel how things that are not tacky can stick really well due to forces occurring at an atomic scale. It was impossible to pull the paddles apart using sheer force, but when coached to wedge them apart at an angle (using tension force) children were able to separate them relatively easily. They liked the physical challenge involved in this activity, as well as the unexpected explanation.

> *[It was the most interesting activity] because of the forces: I never knew about pulling things apart. You can't take them apart unless they're at an angle. (Girl 11)*

The girl went on to give a fairly comprehensive explanation of how things stick together:

> *Atoms. They get close together and can't come apart unless they're at an angle. (Girl 11)*

This activity effectively conveyed the concept of sheer and tension forces and worked particularly well when paired with the Post-it activity.

<u>Hairbrush</u>
A hairbrush made an excellent 3-dimensional stand-in for a gecko's foot, at unknown orders of magnitude. Explainers used the brush and its bristles as an analogy to the gecko's foot to help visitors visualize how the gecko's setae conform closely to various surfaces. This physical prop reinforced the video and the 3-d photograph. Thus all 3 of the activities acted as a suite to help visitors grasp the idea that geckos have setae on their feet that enable them to get extremely close to a surface and form a bond.

<u>Tape, Sticky Toys, Sticky toys, Phonebooks, Putty, Gum and Sticky Tack</u>
These demonstrations were eliminated from the cart's second iteration because they had proved less engaging or less effective in conveying adhesion on the nano scale.

The Main Idea

During the first round tests most children recognized that the activities' overarching theme was how things stick together. Children took away the concepts of shear vs. tension force: they learned that when things are stuck tightly together it's best to use tension force to pull them apart.

> *Use tension force to get things off at an angle. (Boy 11)*

When asked what makes things stick together, during the front-end phase of evaluation more than half the children referred to sticky phenomena from their prior first-hand experience, mentioning glue and tape, suction or magnetism. During the second round activities Explainers can be credited with effectively conveying the cart's big idea: gecko adhesion is a different kind of stickiness. This time when children were asked how sticking works, no one mentioned suction or magnetism and only a few of the youngest children referred to glue on the gecko's feet. The majority of children said that Geckos' feet stuck because of the "millions of hairs" getting really close to a surface.

During the first round tests, none of the children applied the principles of tension force to how the gecko unstuck its feet from the glass. During the second round, Explainers modeled and children used their hands to illustrate how geckos' feet move on a glass surface. While few children mentioned "force" per se, many described shear and tension forces at work.

> *It sticks when the gecko climbs up the wall. The force and the hairs make it easy for it to climb the wall. (Girl 10)*
>
> *The hairs on their bodies. Because the hairs are like going in the wall and the walls are closing in on the hairs, and the atoms are fusing. (Boy 11)*

Conclusions and Recommendations

The activities succeeded in their goal of fostering interactive, conversational learning. Explainers demonstrated the activities, allowing visitors' questions and interests guide the interaction. Hands-on activities with familiar apparatus helped visitors understand complex scientific research on the nano level.

Visitors understood the main idea:

- Close surface contact makes it possible for the gecko to stick (Van der Waals forces). Setae on its feet help the gecko make close contact with surfaces.
- Atomic forces called shear (parallel, stronger) and tension (angled, weaker) forces are involved in sticking and un-sticking.
- The molecular/atomic scale at which these forces take place is too small to see; this small scale is what enables the gecko's setae to get so close to the surface.

While a live gecko is extremely appealing, it can be extremely uncooperative, either remaining motionless on the glass or worse still, hiding under the terrarium foliage. A large picture of a gecko (or several smaller ones) should be displayed and/or available on the cart so visitors can see what a gecko looks like (not like the cartoon in the commercial). Several visitors asked for information about geckos' habitat, food, habits, etc. Perhaps a video of a live gecko climbing could be shown along with the robot gecko to help fill this gap.

Explainers should try to avoid using the term Van der Waals force and other jargon that visitors cannot be expected to grasp or remember. They should talk about setae and how bonding involves two surfaces that are exceptionally close. Visitors could understand the difference between shear and tension forces at the atomic level because of the hands-on demonstrations.

The notion that a surface like glass is not perfectly smooth on the scale of gecko setae was omitted from the second series of gecko adhesion activities. Explainers made this point only in passing when pressing the brush against hands or asking visitors to poke their fingers in the brush. Perhaps a rutted surface along with the brush could simulate the setae/hairs gripping a "rough" surface on a comparable scale.

Figure 2 Explainers work with children on Gecko Adhesion activities and concepts

RARE III. Sports Safety Equipment

Examples of several types of sports safety equipment along with other relevant items were assembled for testing with visitors in the New York Hall of Science (NYHOS). Front-end trials were conducted on Tuesday July 24, 2007 with 27 children ages 6 to 15 years old. Formative evaluation trials were conducted on Saturday December 8, 2007 with 19 children between 7 and 17 years of age and 19 adults.

Objective

The purpose of the prototype tests was to learn how engaging visitors found the topic and whether they understood the cart's main ideas:

Sports safety equipment (similar to the human body) is made out of materials that are

- **Soft** and absorb impacts (such as the padding inside helmets and shoulder pads)
- **Hard** and deflect impacts (such as the material outside helmets and shoulder pads)

Many sports safety devices actually combine both hard and soft materials to provide added protection.

Sports safety equipment places a premium on being light and strong to enable the user to move easily, as opposed to something like a police officer's bulletproof vest, which provides a lot of protection but is heavy. Because front-end findings showed that visitors were confused when confronted with several messages, the main idea was streamlined for the second iteration, glossing over the equipment's performance-enhancing aspects.

Exhibit Elements

Helmets (Baseball and Hockey)

Explainers demonstrated head protection to all participating children: they tried on helmets and got whacked with a small baseball bat. The Explainers demonstrated how the hard outside would *deflect* the impact and encouraged each child to feel the soft inside padding used to *absorb* the impact.

Happy/Sad Balls

Children held seemingly identical balls in their hands and watched them drop on to a wooden plank. One ball bounced high, the other landed with a thud. Although they looked identical, one ball was made of material that deflects impact and the other of material that absorbs impact. Though not actually sports protective equipment, they were included to illustrate the types of materials that could deflect and absorb impact.

Shoulder Pads and Kidney Guard

Explainers had children try these on, then experiment with hitting each other on the shoulder area with a small baseball bat. To clarify what was happening, the Explainer said something like, "They're hard outside to deflect the impact and soft inside to absorb the impact."

Figure 3. Explainer demonstrates shoulder pads

Paintball protector (vest)
Although many children did not recognize this piece of equipment, Explainers used similar words to clarify its protective use: "There is something hard and soft to protect the player," but here they added, "The vest is light weight so the player can run around and dodge the paintballs." This element was omitted after the first trials.

Heart guard
Explainers demonstrated the use and protective feature of this device saying, "It's hard outside, soft inside." The heart guard was unfamiliar to the children, but impressive.

Shin Guards
This demonstration was similar to that of the helmet and shoulder pads: an Explainer "whacked" the shins of a child wearing the shin guards, explaining that they are hard on the outside to deflect impact and soft on the inside to absorb it.

Impact Sensor
Explainers demonstrated the way the sensor senses hard impacts by dropping it on a hard surface. Due to unreliable performance this apparatus was eliminated during round 2 testing.

Cutaway Soccer or Track Shoe
Added during round 2 formative testing, an Explainer showed the sports shoe cut in half and asks participant to feel the hard outside (deflecting) and softer (absorbing) inside materials.

Findings

Overall, the display demonstrations succeeded in attracting and engaging visitors. The majority of children including teenagers who walked by the cart stopped to see what was going on. The most popular ("most fun") items were the helmets, shoulder pads and happy/sad balls.

During the first round of testing we asked children how interesting they thought visitors might be in activities involving sports equipment. Figure 4 illustrates results.

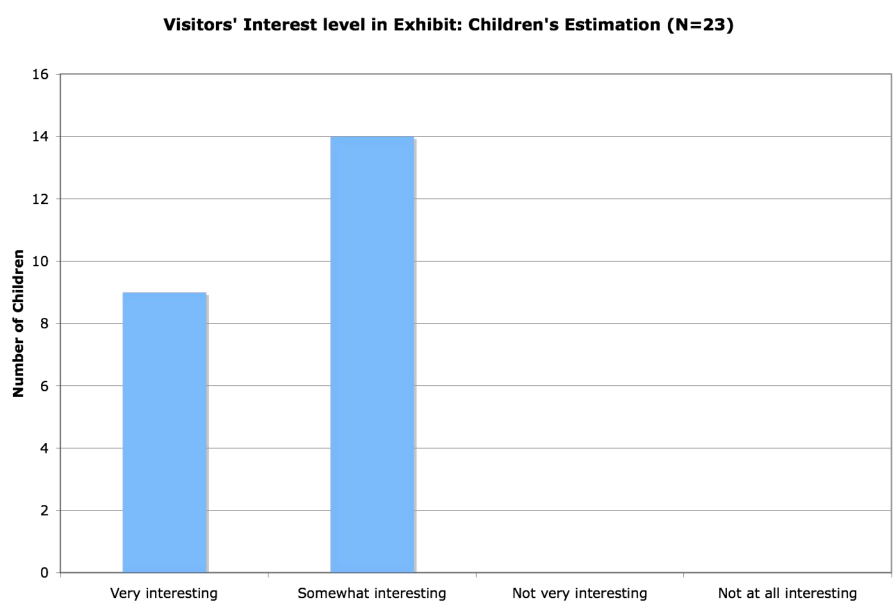

Figure 4. Children's Estimates of Visitors' Interest Levels

Helmets and shoulder pads

Explainers demonstrated protection by having a child don a helmet or shoulder pads and whacking him or her on the head or shoulders with a small baseball bat. After each whack, the Explainer asked, “Did you feel that?” and each time the child said “no.” Everyone understood that a helmet protects the head from impact and injury. The Explainers showed how the hard outside *deflected* the impact and encouraged each child to feel the soft inside padding that *absorbed* the impact. Explainers said: “The outside is hard, it spreads out all the energy. The inside is soft, and sucks up the energy.” Children seemed to find it amusing to get hit on the head and feel nothing.

Figure 5. Testing helmet protection

Helmets and shoulder pads were used most often to introduce the topic’s main concepts; the other guards—heart, kidney and shin—were typically used to repeat or reinforce the message. Explainers asked participants why they thought the impact didn’t hurt and how did the equipment protect them. They encouraged users to feel the *hard* outside that would *push away* the impact and the *soft* inside padding that would *squish* to absorb or *suck up* impact. The child being hit seemed to find it amusing to get hit on the head and feel nothing. Friends or siblings who were allowed to whack were even more amused.

Table 1. Vocabulary used by Explainers: Absorb Impact

Words	Number of time Used
Soft	11
Suck up/hold in	6
Absorb	5
Squish or squishy	4

Analogies to the soft protective material did not confuse children. Children had no problem understanding what was meant by “The inside is soft, and sucks up the energy” or “holds in the energy” and could easily see this as opposite to the hard/deflect concept.

Table 2. Vocabulary used by Explainers: Absorb Impact

Words	Number of time Used
Hard	11
Bounce off	7
Spread out	4
Push	3

Explainers did not use the term "deflect," but said energy "reflects" off hard surfaces, possibly because they believed that younger visitors would not understand "deflect". Explainers frequently spoke of "energy" when explaining the phenomena. They introduced a concept that was confusing to some children: "spreads out," as in "The hard outside spreads out all the energy from the bat." Comments from children who were confused by this suggest that they perceived "spreads out" as related to "absorb" and not "deflect," as Explainers intended.

<u>Happy/sad balls</u>
Participants held seemingly identical balls in their hands and dropped them on a wooden plank. One ball bounced high, the other landed with a thud. Participants were surprised by the behavior of seemingly identical balls. They had difficulty understanding the explanation: "One of the balls is made from material that *deflects* energy and bounces high, the other is made from material that *absorbs* energy and doesn't bounce." A number of factors may have contributed to this difficulty: 1) the children could not apply the hard and soft distinctions they had just observed to a new context; 2) they could not see or feel the difference in the two materials; 3) the balls were outside the context of protective apparatus used in sports.

Eventually the Explainers found a thematic bridge—comparing the two balls to sport shoe materials that *absorb* impact to the feet and legs during running and *deflect* impact during jumping. This proved effective in both explaining the balls' behavior and relating it to the sports safety equipment theme.

<u>Cutaway soccer or track shoe</u>
Explainers showed a sport shoe cut in half and asked participant to feel the hard outside and soft inside materials. Children felt the hard cleats and perceived them as helping the athlete run faster, not as protection from running on a hard surface. The inner soft lining, which is quite thin seemed to provide the foot little protection from impact. Most children seemed to understand at least that the shoe's hard sole protected the foot. However, few participants either played soccer or ran track, so Explainers tried to transfer the principles to basketball, which many of them were more familiar with. A basketball shoe would be more relevant to the NYHOS population.

How the Equipment works

Most participants understood exactly what visitors were supposed to come away with on the most basic level: protective sports equipment prevents injury, for example:

> *How people keep themselves safe that play sports.*

We asked the children if they could think of one or two ways the materials protect people from getting hurt. We were looking for *deflect* and *absorb* impact, the two concepts that Explainers emphasized in demonstrating the equipment. Children in both test sessions were able to describe both kinds of protection, hard/push away and soft/squish.

> *Like the helmet is hard, so if a ball hits your head, the energy gets reflected, then the padding sucks up the rest so it won't damage your head. (Boy 9)*

Conclusions and Recommendations

- Overall, this RARE cart's simple message—safety equipment used in sports protects the wearer in two ways: hard materials on the outside push away impacts and soft materials on the inside suck up impacts. This basic message came across clearly to children 7 years old and older.
- Participants were engaged, finding the topic personally relevant. All children are required to wear protective gear when playing sports and not just team sports (they wear helmets for bicycling, elbow, wrist and knee guards for roller blading or skate boarding). The cart helps children understand why this is important and not just some silly adult rule.
- A shoe cutaway is important because it is the only piece of equipment that shows foot protection. Every sport has specialized shoes for protection (and performance enhancement). The soccer or track shoe used in this cart was not particularly relevant to NYHOS visitors or illustrative of the protection message. A basketball shoe cutaway would be a better choice.
- Explainers need to work on how to relate the happy/sad balls to the cart's message about protective sports equipment. The balls were popular and fun, but the phenomenon they illustrated was hard to align with the sports protection theme. The principle is the same as the sports gear, but cannot be delivered in the same manner. One ball illustrates the hard material that deflects energy on impact, the other ball represents the soft material that absorbs energy on impact.

RARE IV: Liquid Crystals and Piezoelectricity

Crystals was selected as the subject for the fourth RARE cart, focusing on two specific kinds of crystal: liquid crystal and piezoelectricity. Cart activity prototypes were tested with 16 children in the Hall on Saturday, May 16, 2008 and with 30 children on Saturday, July 12, 2008. All participants were in the target age range of 8 to 17 years old.

Objective

The purpose of the tests was to find out if visitors understood the cart's main ideas:

- Crystals (even Liquid Crystals) are composed of a regular molecular structure. (A concept originally included in the learning goals, *Liquid Crystals are pure substances that show properties of both liquids and solids over a specific temperature range,* was omitted for the second iteration.)
- When energy (heat or electricity, for example) is applied to a crystal it changes.
  - In the case of Liquid Crystal, when energy is applied the molecules change shape.
  - In the case of Piezoelectricity ("Piezo" means pressure in Greek) applying pressure to a crystal like quartz changes its shape, producing energy in the form of electricity.

Exhibit Elements

Temperature Sensitive Liquid Crystal Demos

<u>"Mood Rocks" and Liquid Crystal Sheet</u>
Visitors touched the "mood rocks" (actually, cholesteric liquid crystal sheets applied underneath plastic hemispheres) and the liquid crystal film sheet to observe how the heat from their hands caused a change in the liquid crystal molecules evidenced by a change in color.

Liquid Crystal Display Demos

<u>Corn Syrup and Cross Polarizers</u>
A good transition activity between cholesteric liquid crystals and Liquid Crystal displays, visitors rotated a bottle of corn syrup between two polarizing film disks, (or alternately, turned the filter sitting over the bottle) to observe how the color of the liquid changed. This is a simple model to show how a "twist" can cause a visual change in a substance that performs similarly to liquid crystals.

<u>Calculator and Polarizer</u>
Visitors viewed a calculator's liquid crystal display (or a liquid crystal display in a visitor's cell phone or digital watch) through polarizing film. They observed that the display could be "turned off" or made opaque when the polarizing film is twisted in a certain direction.

<u>Small Smart Window</u>
An actual "smart" window demonstrated how it alternately blocks or lets in light when a liquid crystal film is applied to the glass. Liquid crystal molecules in the film do not align (to let light pass through) until an electrical current is applied. This demonstration made a nice analogy for an LCD pixel when a colored piece of acrylic film was held behind the "smart" window.

Piezoelectricity Demos:

<u>Piezoelectric Vise</u>
Visitors slowly pushed the handle back and forth to compress the crystal inside the vise and saw the sparks that were produced.

<u>Piezoelectric "Popper"</u>
The main element of the "popper" comes from a BBQ lighter. A spring-operated hammer bangs a crystal inside to produce the spark. The spark ignites the fuel, producing a loud explosion.

Added for the second iteration testing:

<u>A real quartz crystal</u> illustrated what a solid crystal looks like.

<u>A squishy/springy crystal model</u> to show how crystal molecules compress or squish together when pressure is applied.

Findings

Overall, the demonstrations succeeded in attracting and engaging visitors. The majority of children in the target age range who walked by the cart stopped to see what was going on. This occurred particularly during a Popper demonstration.

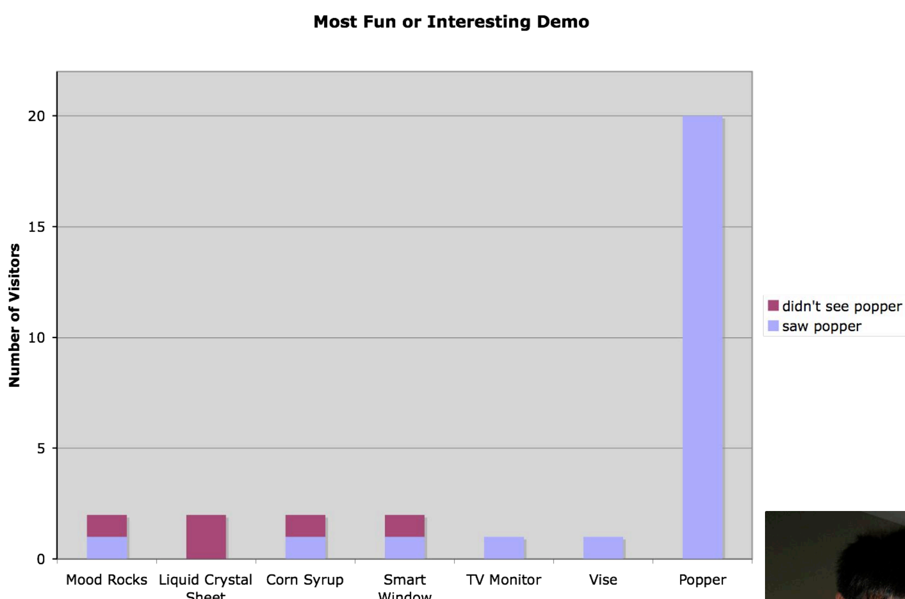

Figure 6. Most fun or Interesting Demo

<u>Piezoelectricity: Popper and Vise</u>
The Popper was the clear favorite in both the first and second iteration of testing. Color-coding in figure 6 indicates that not all participants who saw the popper chose it as their favorite. Among those who did favor it, the majority said the explosion was exciting, fun or cool.

Figure 7. Vise Demo

During the first round of testing the Popper's appeal typically did not translate into understanding. Children grasped the notion that electricity had something to do with the explosion, however they did not understand that applying energy/pressure to a crystal produced the electricity. The second round of testing showed marked improvement in children's understanding of the phenomenon due to revised Explainer input.

> *Quartz crystals can do stuff; it makes a spark to blow something up. It makes a spark when you hit it or squeeze it. (10 years old)*

However, it was difficult for young children (8-year-olds) to understand the non-intuitive notion that simply pressing on something could create a spark, or that electricity could be generated from a solid "rock."

Mood Rocks and LC Sheet
Children understood that energy in the form of heat made liquid crystal materials change color. Several of them were familiar with mood rings and adults too found the explanation engaging.

Corn Syrup Demo
While children found this demo compelling—the changing colors—they tended to conflate the corn syrup with liquid crystal. This is reasonable, since the explanations were all about "liquid crystal" and the syrup was the only "liquid" they could actually see. During round two testing liquid crystal's use inside TV monitors to create changing colors was introduced, making the corn syrup analogy more relevant.

Figure 8. Examining corn syrup through filter

Smart Window
Children seemed to have a relatively weak understanding of the scientific concepts involved in this demonstration. They may have had difficulty visualizing what was happening that made the window change appearance. The metaphor of a picket fence allowing light to come through between the pickets was not particularly effective. Comparing the demo to TV pixels was promising, since everyone has seen color TV but probably do not understand how it works.

Conceptual Understanding

Learning goals for this cart included many complex concepts. However, in addition to observing phenomena (e.g., color change) children were able to personalize the observations, relating what they observed to their own lives (e.g., "liquid crystals are in stuff we use every day"). This is potentially a very positive outcome for this RARE cart. Clearly children are fascinated about learning how things that they use work—TVs, computer monitors, cell phones and calculators. Crystals demonstrations were successful in conveying to children that while science is sometimes hard to understand, it is part of everyday life, not just a subject in school.

Revised and slightly simplified for round 2, the conceptual goals were still ambitious. The final set of activities and accompanying interpretation were largely successful in meeting this challenge. In addition to grasping some of the concepts most closely related to the observable phenomena (e.g., color change), children were also able to report their understanding of more abstract notions, such as the idea that liquid crystals change when energy is applied or that applying pressure to a quartz crystal will create energy in the form of electricity.

Figure 9 illustrates the number of visitors who referred to relevant science concepts in front-end interviews. Five additional concepts emerged during round 2 formative interviews. Four of them (pressure/push, force/energy, crystals are powerful, and molecules) related to piezoelectricity, reflecting the progress made in conveying its underlying concepts. The popper continued to attract and engage children, but the addition of a squishy model of a crystal molecule and a piece of solid crystal, along with carefully worded and concise explanations, led to real conceptual understanding as well.

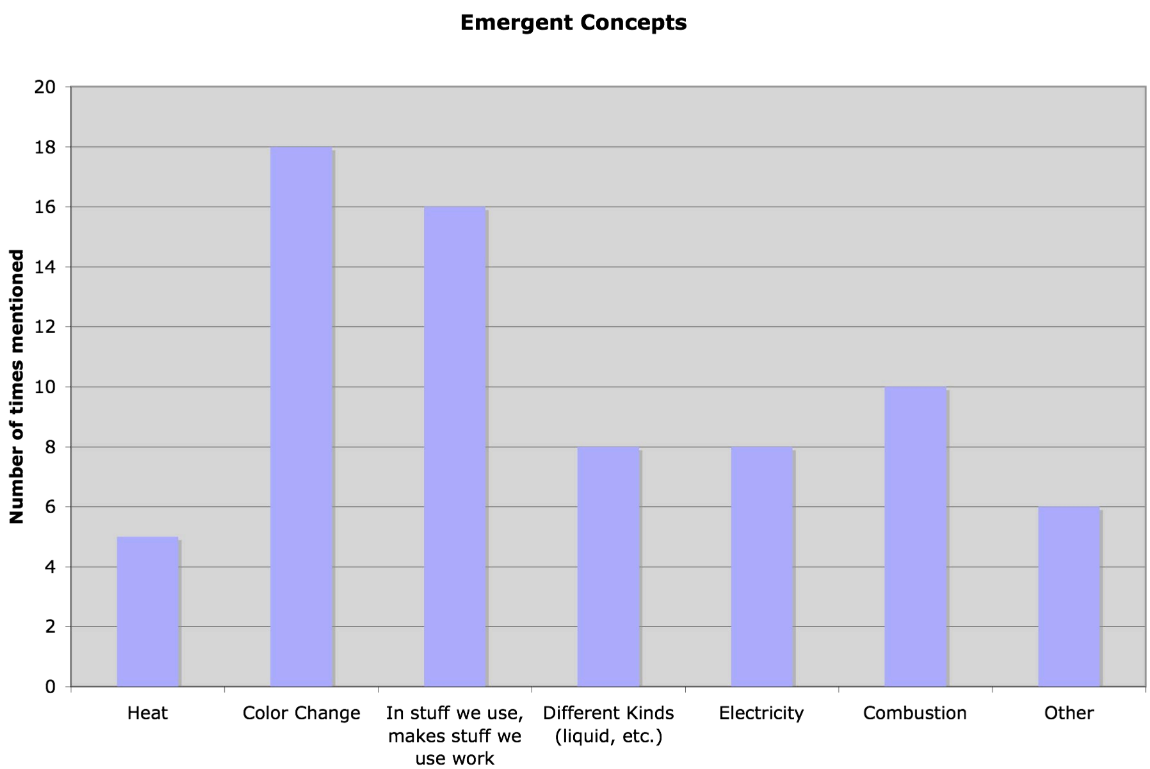

Figure 9. Emergent Concepts

The fifth new basic concept visitors came away with—the idea that crystals can take liquid as well as solid form—was cited by a number of visitors as something they had learned from the activities:

> *That crystals can be either solid or liquid. (8 years old)*
>
> *Actually, [I learned] that there are liquid crystals! (13 years old)*

When asked how interested visitors would be in these activities, first round testing participants were equally divided between "very interested" and "somewhat interested" ("not very interested" and "not at all interested" were not selected). After the second round, almost all interviewees predicted that other visitors would find these demonstrations "very interesting," citing the intriguing explanations of how everyday things work.

> *Because it's science and science is always interesting. Like, who knew there was so much stuff in the world that is included in science? Like the whole world is pretty much science.* (10 years old)

Conclusions and Recommendations

- The fact that electricity is inside a quartz crystal is not intuitive or easy to understand. The ball and stick model of a crystal molecule was highly effective, illustrating that the balls represented the atoms and the sticks the electrical charges that keep the atoms in place to form the crystalline structure. Explainers frequently alluded to "crystal" and "molecule," using the model to explain the structure of a crystal. The model was flexible to allow Explainers (and visitors) to twist it so that visitors could visualize what happens on the molecular level when force is applied to a quartz crystal.
- A solid crystal reinforced visitors' prior knowledge and expectations of what is meant by "crystal." It also helped visitors who, due to limited English language or other reasons, did not know what a solid crystal looked like.
- The Popper excited people and drew them over. It may have distracted visitors from other simultaneous activities during evaluation, but when the cart is operational, this will not be an issue because there will be only one Explainer presenting only one activity at a time.
- Should Explainers use a sequential flow format to present liquid crystal concepts or present demos at random depending on visitors' interests? This will depend on Explainer's comfort level with materials and visitors' interests. A majority of visitors during evaluation began with liquid crystal phenomena and then moved to piezoelectricity. If the popper is used to attract visitors, piezoelectricity may be the place to start. Explainers must experiment with the order that will lead to strongest visitor understanding. Visitors' interest and questions will influence each interaction because the goal is dialogue, not scripted demonstration. An Explainer astutely commented: "kids' interest level depends on how well the subject is presented." Presentation works when questions (inquiry method) and hands-on opportunities are used, not a lecture.
- When visitors hear "liquid crystal" they do not immediately associate it with "LCD", a term with which they may be familiar. Children have heard of LCDs and are interested in how they work. They all have or have seen watches, cell phones, calculators, TVs, and computer monitors. This aspect of the liquid crystal demonstrations engaged children because it exploits their innate curiosity about how their world and in particular, their world's cool gadgets, work.
- Participant responses dramatically illustrate this cart's success in conveying an important and foundational concept in science education: the idea that science is part of everyday life and indeed is much more than just a subject to be studied in school.

RARE V: The Chemistry of Food

Food was selected as the subject for the fifth and last RARE project. The activities explore the role of chemistry in food. Prototypes were tested with 19 visitors ages 7 to 13 years old on Saturday, November 1, 2008. With modifications based on the November findings, a second round of testing was conducted on December 6, 2008 with 16 children between the ages of 7 and 12 years old.

Objective

The purpose of front-end tests conducted in November was to find out if visitors understood the cart's four main ideas:

- **Trapped Gas in Food:** Trapped gas bubbles are one way to create different food textures or sounds.
- **Emulsifiers:** Emulsifiers help keep different ingredients mixed together. An emulsion consists of millions of tiny droplets of one liquid suspended inside another liquid (usually oil and water). Certain chemicals and substances, called emulsifiers, help keep the different ingredients mixed together.
- **Starchy Foods:** Long starch molecules help hold ingredients together smoothly. Starch molecules are carbohydrates (made up of carbons, hydrogen and oxygen molecules), long chains made up of sugar molecules. Starch is often used to thicken sauces in cooking because the long chain molecules act to stabilize the surrounding molecules by holding them in place. Another name for carbohydrate is polysaccharide (poly = many, saccharide = sugar). Other types of polysaccharide thickeners come from seaweed!
- **Kitchen Chemistry:** The choice of physical ingredients can determine the taste or nutritional value of foods. We can also test for these ingredients.

The objectives were modified and simplified for testing during a second iteration as follows:

Main Idea: Explore Interesting or Unusual Ingredients Found in Food, Specifically:

- Ingredients occurring naturally (like starches) or added to foods (like iron) can be found in different types of food products.
- Substances occurring naturally or added to food products create their physical properties, such as texture, color, and taste (and are sometimes added to increase the health value of food).

Exhibit Elements

Trapped Gas in Foods

Pop Rocks

Carbon dioxide is added to Pop Rocks candy when it is made to give it a “popping” texture. The CO_2 is trapped inside and doesn’t come out until water is added. Visitors used a dropper to drop water on Pop Rocks or dropped Pop Rocks in a cup of water to release the CO_2 and hear the pop.

Rice Krispies

During the cooking process, each piece of rice expands and a network of air-filled pockets forms inside. As liquid flows into the crispy kernel, it puts pressure on the air inside until the walls shatter, forcing out a “pop.” Visitors used a dropper to make the Rice Krispies “pop.”

Marshmallow Vacuum

Air is added to marshmallows to give them a “fluffy” texture. The air pressure inside the marshmallow is roughly the same as the air pressure pushing from the outside, so it retains its shape. An Explainer inserted a marshmallow into a vacuum chamber and pumped the air out, asking visitors to guess what would happen. Surprising participants, the marshmallow expanded in the vacuum and shrank when air flowed back in.

Emulsifiers

Colorful Milk

Milk is mostly water but it also contains proteins and tiny droplets of fat suspended in solution. When an Explainer added liquid soap, the weak chemical bonds that hold the proteins in solution are altered because of the soap’s bipolar characteristics: the detergent's hydrophilic end dissolves in water while its water-fearing end attaches to a fat globule in the milk. The food color molecules move about, providing an easy way to observe all the invisible activity.

Oil and Water

Explainers added a small amount of oil to water, and then asked visitors to watch what happened. Oil and water don’t mix. But adding a little detergent or mustard powder to an oil and water solution acts as an emulsifier because it helps break the oil into smaller particles that stay mixed well in the water.

Starchy Foods

Cornstarch “Quicksand”

A mixture of cornstarch and water sometimes acts like a solid and sometimes like a liquid, an example of a suspension. A suspension is a solid finely divided and dispersed in a liquid. Explainers demonstrated that when compressed, the long starch molecules are forced closer together, trapping the water between the starch chains to form a semi-rigid structure. When the pressure is released, the cornstarch flows again.

Iodine Starch Test

Iodine is a visible indicator for starch molecules. In the presence of starch, iodine changes from orange-brown to black-purple. Explainers helped participants use a Q-Tip dipped in Iodine to put “test spots” on foods like a cracker, potato chip and apple chip.

Alginate Gummy Worms
The long molecules in the alginate polysaccharides made from seaweed thicken the liquids they are placed into by joining together and "cross-linking" to each other. Explainers mixed the alginate liquid into a basin of salt water to create a cross-linked solution and pulled out "gummy worms." Explainers added, "Seaweed thickening agents, especially Carrageenan, are often put into *ice cream* to keep the ingredients from separating, and to prevent ice crystals from forming."

Kitchen Chemistry

Iron in Cereal
Many breakfast cereals are fortified with food-grade iron particles (metallic iron) as a mineral supplement. Total cereal is the only major brand of cereal that claims to contain 100% of the recommended daily allowance of iron. Explainers added water to Total Cereal in a Zip-loc bag to make mush. Using a neodymium magnet they pulled iron pieces out of the mush.

Turmeric Indicator
Turmeric spice is a visible indicator for bases. In the presence of strong bases turmeric changes from orange-brown to bright red. Using paper pretreated with Turmeric solution, visitors touched a Q-Tip dipped into Ammonia (base) to observe the color change on the paper.

Findings
Overall, the demonstrations succeeded in attracting and engaging visitors. The majority of children in the target age range and their parents who walked by the cart stopped to see what was going on. The most popular activities were the ones that provided the biggest surprises: Marshmallow Vacuum, and the Gummy Worms.

Figure 10. Marshmallow Vacuum test

Marshmallow Vacuum
Virtually all participants were surprised to see the marshmallow expand like a balloon when the air was removed from the chamber. As a 10-year-old boy remarked, "I thought it was weird how taking out the air made it bigger. I thought it would make it smaller." Interview respondents appeared to understand the phenomenon once it was explained to them. An 8-year-old boy said, "The air that is trapped is pumped out. I thought it was going out [of the marshmallow]. It got bigger: the air inside [the marshmallow] was pushing out while we were taking [the air] out [of the container]."

The misconception found in the first round of tests seemed to be resolved during the second iteration: visitors no longer said that Explainers were pumping air into or out of the marshmallow ("If you put air in marshmallows, they get bigger." Girl 7). However, two points did not seem to be clear to participants, though none questioned them. First, none of the respondents seemed to know why there was air in the marshmallow to begin with; no one mentioned that air gives marshmallows their fluffy texture. And second, no one seemed to understand or want to know how the air remained trapped in the marshmallow.

This activity provided visitors with a hands-on opportunity to participate in the experiment—to use a finger to anchor the vacuum chamber—and also asked them to predict the results. The "special effects" caused sheer amazement and were effective in capturing and holding visitors' attention. As the marshmallow grew, one mother commented, "Oh my goodness," and a child exclaimed, "Holy Macaroni!" As the marshmallow collapsed, a father declared, "That's crazy!" Another mother asked if the vacuum chamber was for sale in the Hall's gift shop.

<u>Gummy Worms</u>

Again a surprising "special effect" engaged visitors—when one liquid was poured into another, long slimy "worms" were formed. Interviews revealed weak understanding of what caused the phenomenon. Participants grasped that seaweed was involved, but the more generalized concept that alginate is used to give foods a thicker consistency and to keep different ingredients mixed together did not come across. Nor did the more technical explanation that alginate molecules do this because they are long and join together, cross-linking.

Figure 11. Gummy worms!

This demonstration provided an opportunity for active engagement—using a fork to mix the alginate in water and then pull the worm-like results out. The dramatic emergence of the "worms" engaged even those not holding the fork and prompted frequent exclamations of astonishment, as when one child exclaimed, "Holy smoke!"

The demo's takeaway message turned out to be "what's in food" rather than "long molecules thicken liquids by joining together and cross-linking to each other." It may be that introducing the idea "seaweed is in ice cream" was so astounding to visitors that it overshadowed this activity's big idea. Still, visitors were clearly astonished by the thickening process they observed.

<u>Iron in Total Cereal</u>

Seeing black iron emerge from Total Cereal mixed with water shocked participants: parents wondered if it was harmful (Explainers told them that the iron was probably not harmful, but may not have nutritional value in that form); children were horrified because they were not aware that iron is a nutrient the body needs. An 8-year-old boy exclaimed, "[I learned] there's actually little shaves of iron in Total. It's bad for iron to go inside you and it probably messes up your digestive system." An 11-year-old girl had the same reaction: "Total Cereal had iron in it. I'm glad I never ate it. I never heard of foods with iron."

This was a very engaging activity with a strong takeaway message of "what's in food." To better convey the message, Explainers should begin with a discussion of vitamins and minerals the body needs, among them iron occurring naturally in spinach, liver, etc., but adding that the iron occurring naturally in food is not the hard metal type.

Iodine Starch Test

Participants seemed to understand that starch occurs naturally in many foods and that iodine can test for starch because it is an indicator. For example:

The potato chip had a lot of starch; when you put liquid on top, it changed color. (Girl 9)

Figure 12. Iodine Starch test

The demonstration can be improved to convey more accurate information. For example, nobody mentioned that starch molecules have long chains and only one participant, a 7-year-old girl, mentioned that starch gives foods a smooth texture "like mashed potatoes." However, it would be difficult for participants to associate starch with smooth, mushy textures when all of the examples were crunchy chips and crackers. Several children came away with a misapprehension about the relationship between sugar and starch due to Explainers' misinterpretation: "[I learned that] starch is a kind of sugar, that there is starch in food and that it makes foods sweet." (Boy, 11)

Children were required to use their observation skills to decide which item had starch based on color change. It helped when Explainers put a drop of iodine on a plate to show them the original color with which to compare the change.

Pop Rocks Candy

During the first iteration of tests Explainers placed Pop Rocks on a paper plate and used a dropper to drop water on them. This was more effective than the second iteration when Pop Rocks were dropped into a plastic cup of water. When the Pop Rocks were completely submerged in water and sheltered by the walls of the cup, their sounds were less audible than when they were on the plate. In addition, while the plate method may have required children to stoop down to the plate to hear the popping clearly, the drinking cup method did not allow multiple children to hear simultaneously.

Children seemed to understand Explainers' discussion of air or gas (carbon dioxide) trapped in pockets within the food, often relating it to soda pop. An 8-year-old boy noted, "Popping candy doesn't pop until moist, it melts away the hard shell." Although several of the younger children had never seen, heard of or tried Pop Rocks, they nonetheless found the activity fun and interesting. Explainers should encourage children to look at the air pockets through a magnifying glass to make them more comprehensible.

Omitted Activities

<u>Rice Krispies</u>
This activity was eliminated after the first round of testing because 1) the Hall's ambient noise level made it hard to hear the pop and 2) children were not impressed. A box of Rice Krispies, with which most children are familiar, will be kept on the cart to reinforce the "trapped gas" message.

<u>Cornstarch Quicksand</u>
This demonstration did not convey its intended message: instead of being perceived as both a liquid and a solid, it came across as a floury mess and was omitted.

<u>Turmeric Indicator</u>
It was not difficult to understand that a chemical reaction was taking place when a clear liquid painted on orange paper turned bright red. This experiment did not convey the message about testing for "what's in food," because turmeric is an "indicator" for the base ammonia, a chemical not a food ingredient. It was omitted.

<u>Emulsifiers—Colored Milk and Oil and Water</u>
The nature of emulsification did not come across to children. The concept of the soap molecule's bipolar characteristics was completely missed in most interview responses. In the one case where this concept was referenced, it was interpreted in reverse: the substances were being separated as opposed to being mixed together. The oil and water mixing with soap or mustard powder was a ho-hum instead of an a-ha moment, perhaps in part because most children have never tried to make salad dressing.

Both emulsifier activities were omitted after the first round of testing: they were deemed boring, messy and unable to convey the message.

Is This Science?

At the end of the formative interview, children were asked if they thought these activities related to science. Two-thirds of them said "yes," they were related to science and went on to explain why they thought so. Most of the citations focused on process rather than content, such as testing, observing reactions, and experimenting. For example:

> *[It's science because we were] testing things. (Boy 8)*
>
> *When you found the iron in the cereal and when the potato turned a different color. Because of testing for reaction, like an experiment. (Girl 9)*
>
> *I know that it's a science experiment, but I don't know what kind of science it is. (Girl 9)*

A 12-year-old girl, who thought that all the activities related to science, explained that this was "because there are things [in the activities] that we don't see. Because science has elements in it, like in the periodic table."

The RARE Wondercart program effectively conveys ideas about science and its place in children's world. Young children are naturally curious and by definition, budding scientists. Wondercarts encourage children to acknowledge that their innate desire to experiment and discover is a mirror image of scientific processes.

Conclusions and Recommendations

Although the first iteration of the Chemistry of Food attempted to convey complex ideas about the topic, children generally came away thinking the main idea was "what's in food." Thus the second iteration of activities made that the main focus and children came away with most of the science concepts about food ingredients that the cart set out to address.

Interview responses suggest that RARE activities convey the notions that science is *not* something removed from daily life, and that scientific processes such as testing, experimentation, and observing for reactions can be applied to everyday things. Throughout, visitors were actively encouraged to observe—to look, to listen, and in the case of gummy worms even to feel—as well as to form scientific hypotheses and to test for results.

Explainers who conduct the activities should review concepts such as carbohydrates, sugars, starches, polysaccharide thickeners and sodium alginate in order to avoid inadvertently conveying misconceptions about these inter-related ideas. In reviewing this information, Explainers should understand that they are reviewing this content as background for themselves rather than as information to convey directly to the public.

Recommendations for Specific Demonstrations

Pop Rocks: Include an explanation of how carbon dioxide gets into Pop Rocks and why it stays inside until water is added. Use the plate instead of the glass to illustrate the popping.

Marshmallow Vacuum: Explainers should mention that air is intentionally added to marshmallows for texture and explain briefly how this is done. When using the word "vacuum," remember the 7-year-old boy who defined a vacuum as "something that sucks something in," and try to clarify that the vacuum (absence of air) around the marshmallow was created because the air has been sucked *out* of the chamber.

Gummy Worms: Decide whether or not the message that alginate molecules thicken foods because they are long and join together is important because it was not coming across in the demonstration as presented. Should visitors be aware that gummy worms (candy) are most often made from gelatin and not sodium alginate, and that ice cream is not made with sodium alginate, but instead is sometimes thickened with another type of seaweed-based thickener?

Iodine Starch Test: Including starch test examples in which "smooth texture" is more evident might make this point, as the crunchiness of the chips that were used may work against this idea. Explore options that might create a stronger contrast in iodine reaction, as some children reported having difficulty distinguishing these results. It might be wise to avoid mentioning the relationship between sugar and starch during this activity, as this seemed to confuse visitors.

Iron in Total: This activity is currently communicating all of its intended messages, but it could benefit from the addition of a hands-on component. Perhaps allowing visitors to touch and examine dry flakes of dry Total would address this. While visitors would not be able to see the metal in the dry Total flakes, this added activity would help to reinforce a point observed by one of the interviewees—and one that underlies many of the cart's activities—there are things in our food that we can't see, but are there nonetheless.

Overall Conclusions

Evaluation ensured that that Wondercarts, once out on the museum floor, would have a positive impact on NYHOS visitors. But in addition, the carts have added value to the Hall's Career Ladder program: Explainers, themselves still teenagers, are learning about current scientific research and how to interpret it for the visiting lay public. In addition, with RARE's conversational approach to interpreting materials science. Explainers are learning to use inquiry-based methods when interacting with the public. Debriefing sessions with Explainers and their managers suggest that one of Wondercarts' goals—to start a dialogue with visitors—trains Explainers to let the demonstrations and learning flow from visitors' questions and interests. Explainers learn to focus on interactivity rather than delivering scientific content.

Wondercarts provide a scientific "wow" experience for visitors in the form of portable demonstrations, while developing Explainers' inquiry skills. Managers find it valuable to start interns out on carts because it teaches these 15-year-olds to interact with visitors. They are nervous at the outset but as their experience grows with practice, so does their confidence. Wondercarts are like NYHOS demonstrations on wheels, but they differ in their unscripted approach to content delivery. They are similar to: "apron tools"—objects Explainers keep in apron pockets to help them approach visitors and start a conversation.

The RARE carts, christened Wondercarts, are now out on the museum floor. The concept provides value added to NYHOS educational programming through its focus on interactive, conversational learning. Wondercarts differ from the Hall's demonstration program in that they are not scripted and aim to be visitor-directed experiences. This type of unscripted demonstration can be quite challenging for Explainers who provide it. They must learn the content well enough to respond to visitors without using rote memorization. They not only become conversant in content, but also gain confidence and skill in inquiry methods.

The five topics selected for Wondercarts succeed in helping visitors see the relevance of science to their daily lives. Science is not only a subject in school or something practiced by older white men in lab coats. Materials science is part of our world and we, children and adults, use it everyday. So it behooves us all to learn more about it.

- Groundwater flow, the first topic, was slightly more interesting to adults who are concerned about water pollution and how to remediate or prevent it. However, children were fascinated by some of the interactive displays and learned about the effects of dumping pollutants where they can get into our drinking water.
- Gecko adhesion delighted children and adults. First, the live gecko (although it didn't move much) was a draw. Sticking and unsticking various materials was fun for children and they learned the effective difference between shear (parallel, stronger) and tension (angle, weaker) forces. Geckos use both types of force to move across a vertical glass surface. Children mimicking gecko adhesion principles, learned how to pull apart tightly bonded surfaces by pulling them at an angle instead of trying to pull them straight apart.

- Sports Safety Equipment in some form or another is familiar to all visitors. These personal connections were valuable as children learned how the equipment worked to protect players in two ways. Physical interaction led to understanding that hard outer surfaces of helmets and shoulder pads deflect impact and soft inner linings absorb the effects of impact to protect the wearer.
- Crystals—liquid crystals and piezoelectricity—seemed at first glance to be a less personally relevant topic. However, children and adults all have devices with LCD screens and all were interested to learn what that actually meant. Children learned that liquid crystal, the active ingredient in a mood ring, responds to energy in the form of heat by changing color. They learned that a solid crystal (quartz) gives off energy in the form of electricity when force is applied.
- Food is also involved in science. Chemistry can show us what's in our foods either as a naturally occurring or added ingredient. Different substances behave in ways that affect our foods, such as long starch molecules potatoes or air that is added to foods such as marshmallows or Pop Rocks candy. Additives like iron in Total Cereal can be observed and may or may not be nutritionally beneficial. Young children, however, were not aware that iron is a nutrient the body requires.

RARE's underlying learning goal was to convey current scientific research to the Hall's family audience. Children take away at least two valuable lessons from the RARE program: first, science is ubiquitous, part of everything they do, eat, look at and play; and second, science is accessible and interesting because it is personally relevant to their lives.

Another of the project's underlying goals—to prepare science teachers to be better prepared to bring current knowledge in materials science that is interesting and relevant to understanding life on Earth to their classrooms—was beyond the scope of this assessment.

Lastly, the project aimed to develop a model of University-Museum partnerships to bring current research to the public through museum exhibits and displays. Clearly, RARE succeeded in this goal. A team of scientists from a world-class university collaborated with exhibit developers and educators from a nationally recognized institution of informal science to create a successful program. This is a model that can be duplicated to produce future exhibit projects that combine two kinds of expertise for the benefit of the general public.

Appendix: Demographic Data

Groundwater Flow I

Table 3. Age/Gender of Participants

Age	*Boy*	*Girl*
4 years	2	
5 years	1	2
6 years	3	
7 years	2	1
8 years	1	1
9 years	2	2
10 years	1	
11 years	1	2
12 years	1	
17 years		2

None of the adults had science backgrounds; most families had not visited the Hall in the last 12 months.

Some parents of the younger children helped them understand the display, using age-appropriate terms,

Families were from Queens, Manhattan, Brooklyn, Long Island, Westchester and New Jersey.

Gecko I

Table 4. Gender

Boys	20
Girls	13

Table 5. Age

Age	Number
4	1
5	1
6	3
7	5
8	7
9	2
10	5
11	5
12	2
16	1
17	1

Table 6. Residence

Queens	18
Long Island	7
Connecticut	3
Brooklyn	2
Westchester	1
No data	2

Gecko II

Table 7. Age/Gender of Participants

Age	Boys	Girls
7	2	2
8	2	1
9	1	2
10	6	3
11	2	3
13	3	0
14	2	0
Total	18	11

There was a mix of first-time and frequent visitors (members).

Sports Safety Equipment I

13 of the children were girls, 14 were boys.

21 children were visiting with camp groups, 6 with family.

12 children were visiting the NYHOS for the first time, 13 were repeat visitors and 2 did not provide data.

Most children said that someone in their family (or themselves) played a sport; 4 kids said no one in their family played a sport.

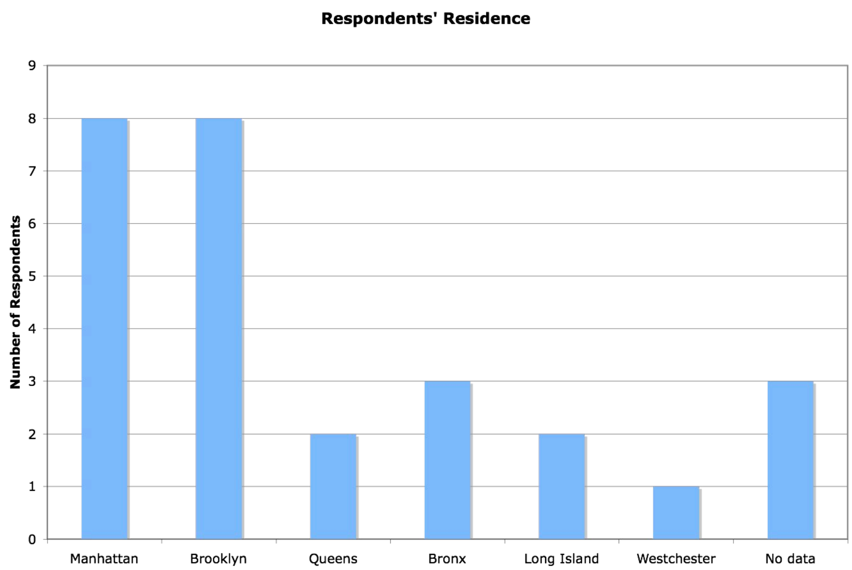

Figure 4. Residence

Sports Safety Equipment II

Some 19 children and 19 adults participated in the testing. Most of the participants (13 children) were between 7 and 10 years old.

14 boys and 5 girls participated in the trials.

Table 8. Children's ages

Ages	Number of Children
< 7 years	4 (not interviewed)
7 to 10 years	13 children
11 to 14 years	2 children
15 to 17 years	0

Crystals I

Table 9. Gender

girls	**7**
boys	9

Table 10. Residence

Long Island	4
Queens	12

Table 11. Science background in family

Yes	7
No	9

Table 12. Age	**Number in age**	**Type of group**
8 years old	4 (with family)	Family
9 years old	3 (with family group)	Family
12	1 (with family	Family
13	2 (with Hayden group)	Class
14	5 (with Hayden group)	Class
17	1	Family

Table 13. Number of visits	**Number of kids**
1	9
2	2
5	1
15	4

Crystals II

Table 14. Gender

Girls	15	Boys	15

Table 15. Residence

Long Island	10
Queens	6
Manhattan	2
Westchester	2
Brooklyn	1
New Jersey	1
Other US	2
International	2

Table 16. Age	**Number**
8 years old	10
10 years old	11
11 years old	3
13 years old	4
14 years old	1
15 years old	1
16 and over	0

Table 17. Number of visits	**Number of visitors**
1	13
2	6
4	1
6	5

Chemistry of Food I

Gender

Girls	13
Boys	6

Residence

Long Island	6
Bronx	3
Queens	2
Manhattan	2
Brooklyn	2
New Jersey	1
Other	3

Age	Number in age
7 years old	3
8 years old	7
9 years old	2
10 years old	4
11 years old	2
12 years old	1
13years old	3

Chemistry of Food II

Gender

Girls	11
Boys	5

Residence

Queens	5
Manhattan	2
Brooklyn	1
Connecticut	3
Westchester	2
Long Island	2
New Jersey	1

Age	Number in age
7 years old	7
8 years old	2
9 years old	5
11 years old	1
12 years old	1