OMSI
Everyday Encounters with Science

garibaygroup

Design Zone Exhibition Summative Report

Prepared for

Oregon Museum of Science and Industry

May 2013

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Executive Summary

Design Zone is a 6,000 square foot traveling exhibition developed by the Oregon Museum of Science and Industry (OMSI) as part of the *Access Algebra* project funded by the National Science Foundation (NSF).

Design Zone's primary objective is to engage visitors in algebraic thinking, with a special focus on reaching a target audience of 10- to 14-year-olds and their families. The exhibition is organized into three thematic areas: art, music, and engineering. Exhibits in each area are based on real-world design challenges in which math and algebra are used. Garibay Group was contracted to conduct the summative evaluation of *Design Zone*. Using a mixed methods approach, data were collected at three museums hosting the *Design Zone* exhibition.

Key Results

The summative evaluation found that the exhibition successfully met its intended goals and impacts.

Design Zone's visitors generally reflected the science/natural history museum-going population. Eightly-four percent of randomly surveyed visitors came in family groups and 81% identified as Caucasian. Although most children in these groups were younger than the target age range (58% with children in the 6- to 9-year range), more than one-third (37%) reported that their group included children in the target 10–14 age range.

The mean dwell time at individual exhibits was 4:33 minutes (exceeding the NSF indicator target of 2 minutes), and these dwell times were long enough for most groups to complete one or more challenges at each exhibit. Nearly three-quarters of the observed groups attempted at least one exhibit challenge; in more than one fourth of the groups, the respondent using the exhibit set a challenge for him or herself.

Parent panels were designed to help visitors discover the math and algebra at the exhibits and to use that math and algebra to meet the exhibit challenges. On average, about 40% of groups looked at these panels while engaging at an exhibit, and about 20% used the information in the parent panel as they engaged.

Evaluation also found strong evidence that visitors engaged in algebraic reasoning as part of working through exhibit challenges. We found that visitor engagement with algebra in the exhibition was complex and did not follow a prescribed path. As part of analysis, we developed an "algebraic thinking framework" which generalized visitors' modes of engagement with algebraic reasoning. Engagement was fluid, with visitors moving back and forth across modes as they approached the challenges. Completing challenges was easier when visitors discovered the key functional relationships and mathematical tools (which helped visitors quantify relationships) embedded within the exhibits. Ninety percent of children in the target age range (and 88% of children in the entire sample) engaged in one or more modes of algebraic thinking at the exhibits. Some 42% engaged quantitatively, and another 17% moved to more abstract levels of thinking (i.e., generalizing relationships).

Data also suggested that parental involvement made a difference in supporting children's engagement with algebraic concepts. When parents were

Executive Summary, cont'd.

engaged, 50% of children engaged in algebraic thinking using a quantitative approach or even by generalizing relationships. When parents were not engaged, only 31% of children used those modes of algebraic reasoning.

The exhibits also included several ways of representing quantitative information, including numerical data, graphs, and tables. In 77% of groups, visitors looked at one or more representations of data (at the exhibit at which we observed them), with children viewing more representations than adults (74% vs. 56%). The lower percentages for adults may reflect the fact that children were more likely to engage directly with the exhibits than adults were (100% vs. 34%).

A slightly lower percentage of groups visibly used the information in data representations. Nonetheless, on average, 55% of the groups had one or more member use a data representation at an exhibit. This includes slightly more than half (51%) of children and one-third of adults (33%) who used one or more representations of data in their interactions at an exhibit.

Overall 95% of the respondents surveyed agreed that they enjoyed their experience in the exhibition. When asked what they enjoyed most, respondents most often named specific individual exhibits or mentioned the hands-on and interactive nature of the exhibits; only 4% of the surveyed respondents mentioned math or algebra as the most enjoyable elements, however.

Among groups with children in the target age range who remembered using math in the exhibition, 94% agreed or strongly agreed that they felt comfortable with that aspect of their experience.

Nearly three-quarters of the target audience groups (74%) agreed or agreed strongly that they felt that "some of the exhibits were pretty challenging, but we figured them out in the end." There was even stronger agreement (82%) among target groups who had also agreed that they used algebra in *Design Zone*.

Seventy-one percent of groups with children in the target age range agreed that some of the exhibits reminded them of the math they did in school, and 86% of these groups agreed that the exhibits helped them think about ways that math is used in everyday life. School connections were most often about math concepts, representations, or activities done in math class, such as graphs and learning algebra, while everyday connections were most often about the physical similarities between the exhibits and objects or experiences encountered in everyday life.

Overall, *Design Zone* provided a challenging yet successful, comfortable, and enjoyable experience for families that met the criteria for the target audience as well as for the larger cross-section of visitors who engaged with these exhibits. The *Design Zone* exhibition, overall, met the goals for the project. Perhaps the major challenge remaining for the project (and for the informal math education field) is to find more effective ways to guide visitors toward more quantitative and, ultimately, more abstract ways of engaging in algebraic thinking on the exhibition floor. With that in mind, the report closes with a series of recommendations for refining the current exhibition.

Overview

Exhibition Overview

Design Zone is a 6,000 square foot traveling exhibition developed by the Oregon Museum of Science and Industry (OMSI) as part of the *Access Algebra* project funded by the National Science Foundation (NSF). The primary goal of *Design Zone* is to engage visitors in algebraic thinking, with a special focus on reaching a target audience of 10- to 14-year-olds and their families.

Approach to math content
The project team based its approach to algebra on those advocated by the National Council of Teachers of Mathematics *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics, 2000), project advisors, research on "early algebra," and promising practices from prior math exhibitions (including the use of challenges to engage visitors in math learning).

The project defined algebraic thinking as

- Finding and exploring mathematical patterns and relationships between quantities (functional relationships)
- Representing mathematical relationships in a variety of ways, including images, words, models, tables, graphs, and symbols
- Using mathematical relationships to describe, analyze, predict, and create

Approach to exhibit development
Based on research in informal education, the project team identified a number of design affordances (exhibit characteristics that the team hoped would foster certain behaviors in order to achieve project impacts). Design affordances include the physical design of the exhibit as well as accompanying text and graphics on panels or monitors, videos, and artifacts.

To engage family groups in math learning, exhibits were designed to include "family friendly" characteristics identified in the PISEC studies of family learning: multi-sided, multi-user, accessible, multi-outcome, multi-modal, readable, and relevant (Borun et al., 1998).

To foster the prolonged engagement necessary for discovering and exploring patterns and functional relationships, exhibits were designed to incorporate characteristics identified by the

Project Impacts
Desired project impacts were as follows:

Impact 1
The target audience of youth ages 10−14 and their families will use algebraic thinking skills.

Impact 2
The target audience will have enjoyable and memorable experiences with algebra/math.

Impact 3
The target audience will be aware that algebra is more than solving equations.

Impact 4
Groups of target audience members will feel comfortable engaging in algebra activities together.

Exhibition Overview, cont'd.

Exploratorium's APE (active, prolonged engagement) research (Humphrey, et al., 2005). These included posing challenges, offering multiple entry points, and allowing multiple outcomes.

In addition to the design affordances listed above, the team identified three design affordances specifically to support math engagement: creative challenges that could be met through algebraic thinking, parent panels (brief text panels in each exhibit designed to provide caregivers with key information about the underlying functional relationship, so that caregivers could support children's learning), and "math tools" (quantitative information made available to visitors and directly relevant to the functional relationships inherent in the challenges—through quantitative labeling and data displays).

The exhibition
The exhibition was organized into three thematic areas: art, music, and engineering (Figure 1). To reinforce this organization, each thematic area was color coded and a tower in each area presented a slide show of relevant careers. Exhibits in each area were based on real-world design challenges in which math and algebra are used.

For example, in the art area, visitors could engage with the exhibit "Balancing Art." Two stations are side by side, one at adult height and the other at a child's height. Each station consists of a balancing rod suspended at a central pivot point. Visitors hang colored pieces of different weights at regular intervals along the balancing rod (and from other pieces) to create a mobile. The weights and the intervals along the rod are labeled quantitatively (relative weights and distances). On a graphic panel, visitors are presented with three challenges—schematic diagrams suggesting configurations of pieces that create balanced mobiles but without information about which weights or distances to use. By attempting the challenges, visitors are encouraged to explore the relationship between weight and distance that creates a balanced mobile. The parent panel for this exhibit is designed to provide caregivers with concrete examples and representations of the relationship (including diagrams and equations) that can help them discover that relationship more quickly and thus support their children's learning.



Figure 1. Examples of exhibits from each of the three thematic areas in *Design Zone:* Music, Art, and Engineering.

Evaluation Design

Garibay Group worked with the OMSI team on the evaluation for *Design Zone* (Figure 2). Front-end, formative, and summative evaluation have guided the *Design Zone* team during each phase of exhibit development. This report discusses summative findings.

Goals and Research Questions

The primary goal of the summative evaluation was to assess the extent to which *Design Zone* met its goals. For each of the four desired impacts, the team developed a set of one-to-five quantitative indicators—measureable objectives that they hoped the target audience would achieve through their exhibition experience. (The indicators are listed Tables 8–11.) The summative evaluation was designed to determine whether these indicators were realized.

More generally, summative evaluation also focused on the ways in which visitors engaged with the exhibition, the nature of visitors' social interactions, and the extent to which visitors engaged in algebraic thinking.

Methods

Data were collected at three sites for this study—at OMSI and at two host sites, Pacific Science Center and Franklin Institute. We used a mixed methods approach (Green and Caracelli, 2003), collecting both quantitative and qualitative data. Methods included observations with follow-up interviews, surveys, and video.

Exit Surveys

Exit survey data were collected to assess visitors' overall visitor experiences. This method provided measures on overall outcomes, specifically the extent to which quantitative indicators were achieved.

Surveys asked questions about visitors' enjoyment, perceptions about the extent to which visitors used math/algebra, comfort, overall experience, and demographics. Surveys contained closed-ended, Likert scale, and open-ended questions.

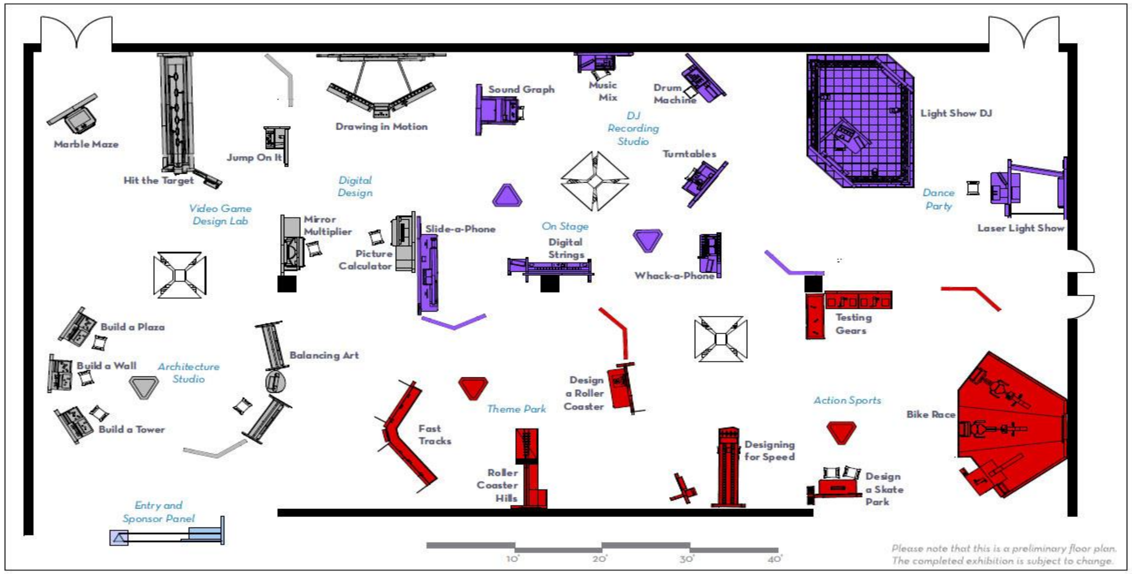


Figure 2. Floor plan of the 6,000 square foot *Design Zone* exhibition at OMSI.

Evaluation Design, cont'd.

Data collectors orally administered surveys using random sampling, selecting respondents to ensure that data were valid and generalizable. In all, 900 surveys were collected at the Pacific Science Center and Franklin Institute. (Refusal rates were about 50%, with visitors citing a range of reasons from impending IMAX theater shows to tired and cranky children to needing to head home.)

Observations and Follow-Up Interviews
While surveys provided data about project impacts, observations and interviews focused on understanding the overall nature of the visitor experience, including understanding: 1) ways in which visitors engaged with the exhibits; 2) social interactions among groups; 3) use of mathematical representations; and 4) the extent to which, and ways in which, visitors engaged in algebraic thinking.

The majority of field observations were done unobtrusively, although we included a small sample (n = 5) of participant observations. In the unobtrusive observations, researchers observed groups and systematically recorded details about their interactions, behaviors, and modes of engagement. Observations were generally conducted at the exhibit component level and groups were observed at a component for the duration of their engagement with that component. We collected observations at all exhibit components and attempted, as much as possible, to obtain similar observation samples at each component.

We conducted 154 observations. Researchers focused as much as possible on observing visitor groups who seemed to have at least one child in the 10- to 14-year-old target age range (Figure 3). The majority (113) of observations were conducted using a randomized selection technique whereby researchers observed the first group to approach an exhibit that also fit the age criterion. The balance of observations (41) used purposive sampling. Since researchers were also conducting follow-up interviews after observations, we also included a second criterion to observe only groups where a parent was nearby so that at the interview stage, we could obtain parental consent to include children in the interview. The overall sampling approach strategy still allowed for collecting data from groups with children younger or older than the target range, since groups often had more than one child of varied ages. Additionally, at times when researchers could not find children in the target age range, they observed groups with children as close to that target age as possible using the random sample approach. In terms of sample characteristics, 69% of observations included children in the 10−to 14-year-old target age range, 27% were younger (5−9 years) and 4% were older (15−18 years).

Figure 3. While groups with children 10−14 years old were the focus of this study, observed groups often contained children who were younger or older than the target age range.

Evaluation Design, cont'd.

Observations were collected at OMSI, Pacific Science Center, and Franklin Institute. Number of observations varied by site, however, primarily due to the varying length and time of year of the exhibit run. Researchers took advantage of school breaks (winter and spring) to ensure higher visitation rates from families (as opposed to school groups) and to be as efficient as possible in data collection. At OMSI, researchers focused primarily on collecting video data (described later in this section), so collected fewer observations at this site.

Immediately after the observation, researchers interviewed the group they had observed to gain a deeper understanding of visitors' experiences and perspectives. Researchers used a semi-structured interviewing approach (Babbie, 1998), probing on a range of topics pertinent to the study (e.g., reactions, perceptions of main exhibit ideas).

Video Data

Researchers also conducted a small video study at OMSI as part of the summative evaluation with the goal of examining in more depth what aspects of an exhibit stimulated and supported algebraic thinking and to better understand what engagement with algebraic reasoning looked like in *Design Zone* (Figures 4 and 5). The research team selected three exhibits for the study—"Balancing Art," "Drawing in Motion", and "Slide-a-Phone"—because they engaged visitors in a wide range of activities and embodied different aspects of algebraic reasoning. Visitors were videotaped as they engaged with one of these exhibits (the researchers designated the exhibit prior to recruitment). Respondents were allowed to engage with the exhibit as long as they wanted (the longest interaction ran 19 minutes). After the video session, participants were immediately interviewed to gain a better understanding of their experiences.

Given the goals of this portion of the evaluation and the nature of video, researchers selected child-adult dyads as the focus of the study. Using purposive sampling, visitors were recruited as they entered the museum. Selection criteria included recruiting adult-child pairs with children ages 10–12 who were also not members of OMSI and did not home-school their children. We also strove for as even a mix as possible in gender among adult and child respondents.

Figure 4. "Balancing Art" set up for videotaping. Yellow arrow points to video camera.

Figure 5. "Drawing in Motion" set up for videotaping, with barrier, research in progress sign, and video camera. Yellow arrow points to video camera.

Evaluation Design, cont'd.

We collected a total of 13 videos. Adults in the sample included 8 females and 7 males. The children included 6 females and 7 males. Six respondents were 10 years old, 4 were 11, and 2 were 13 years old. Visitors received free admission to the museum for their participation.

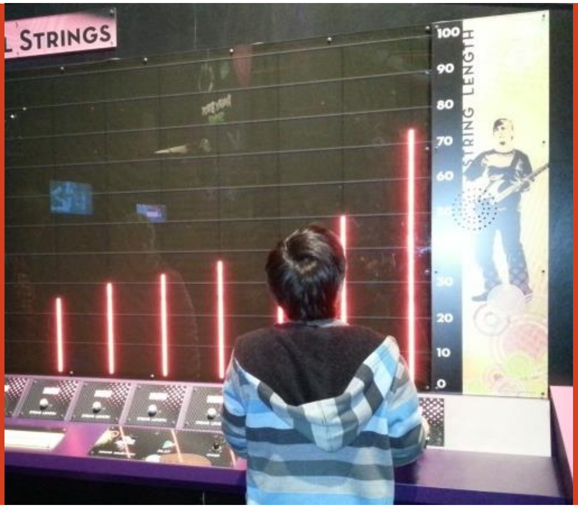
Analysis

For survey data, quantitative components were analyzed and basic descriptive statistics summarized in tables and histograms. We disaggregated data and conducted cross-tabulations to identify any major differences in responses or respondent characteristics. For open-ended survey responses, thematic coding was used to develop and calculate response categories. Typically, we present responses in percentages. (In some cases, these percentages do not add up to 100% due to rounding.) Where more appropriate, the actual number of responses (N) is provided.

Observation and intercept interview data were coded using inductive coding (Strauss and Corbin, 1990) which allowed researchers to identify emergent patterns and themes in the data without the limitations imposed by predetermined categories. As patterns and themes were identified, researchers used a constant comparison method to tease out the strength of patterns and themes (Miles and Huberman, 1994). In this iterative process each unit of data was systematically compared with each previous data unit, which allowed the researchers to continually identify, develop, and refine categories of data and patterns as they emerged. Coded data were then clustered and analyzed for interrelationships between categories. Researches also coded observations collected using random sampling, using a generalized framework developed for video analysis to systematically assess visitors' engagement with algebraic reasoning.

Video data were analyzed using inductive coding (Barron and Engle, 2007), which involved reviewing the video in its entirety with broad questions in mind and studying it progressively in greater depth in order to identify patterns of interaction which were then characterized for the corpus of video as a whole. A coding scheme was iteratively developed as three researchers independently coded video and then met to reconcile differences between their coding to reach consensus. Analysis resulted in an "algebraic thinking framework" which generalized visitors' engagement with algebraic thinking and their paths through various modes of engagement.

Results



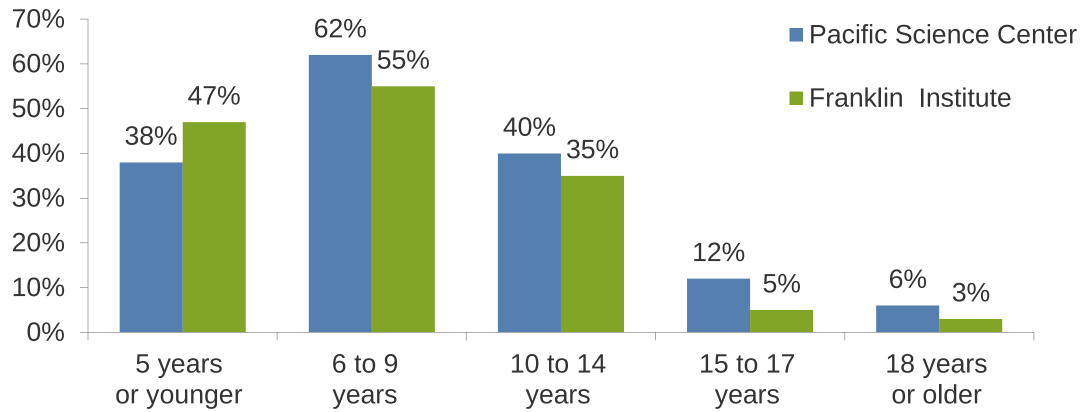
Visitor Demographics

The randomized sample obtained via exit surveys indicated visitors to *Design Zone* reflected the general science/natural history museum-going population.

Of the total sample, 84% of visitors surveyed came in family groups (85% Pacific Science Center; 76% Franklin Institute). There was a broad distribution of age ranges: more than half (58%) of families reported having children 6–9 years old in their group and more than one-third (37%) reported having children in the target 10–14 age range in their group (Figure 6).

More than a third (33%) of visitors indicated they had previously been to the museum.

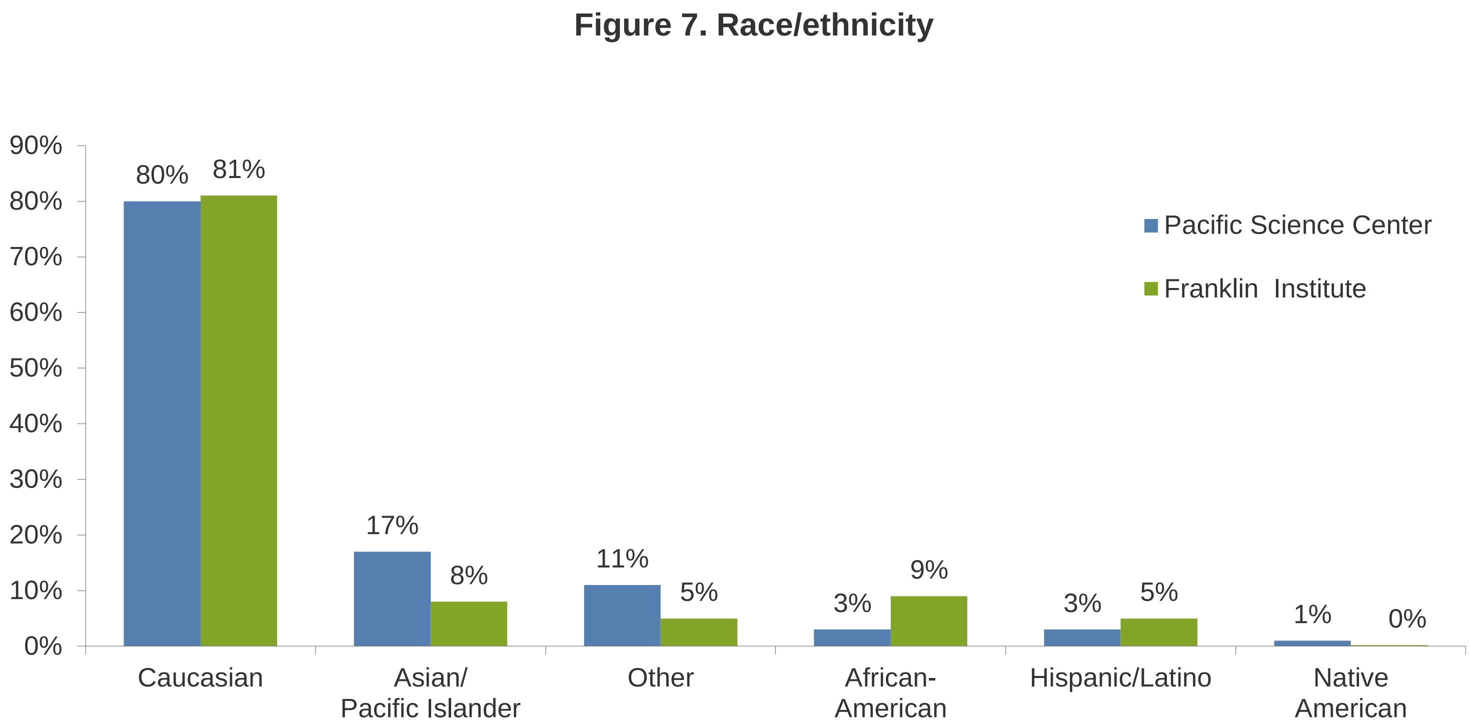
Figure 6. Visitor groups with children
(may have children in more than one age range)



n = 900

Visitor Demographics, cont'd.

Eighty-one percent of respondents identified themselves as Caucasian (Figure 7).



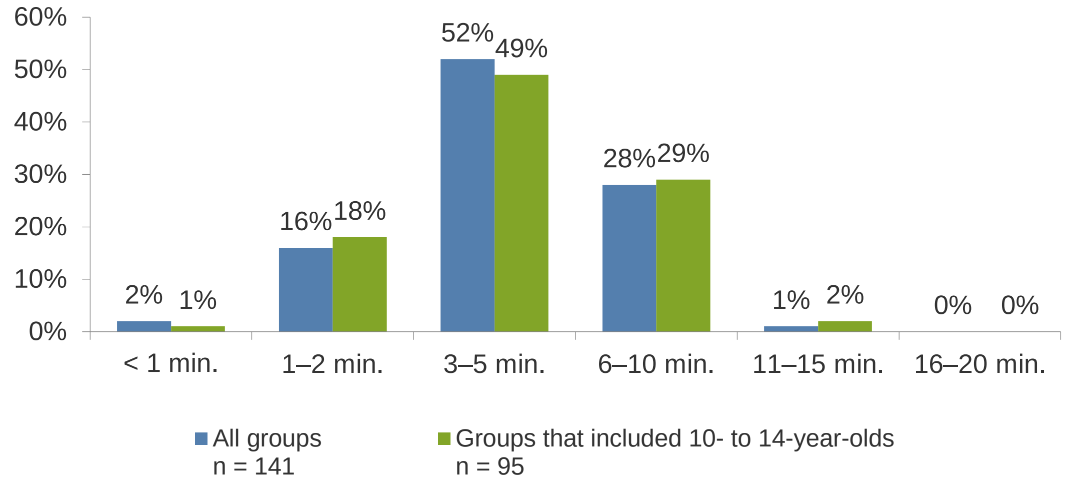
n = 900

Visitor Engagement: Dwell Time at Exhibits

The mean dwell time of 4:33 minutes exceeded the NSF indicator target of 2 minutes (median = 4:00 minutes). Disaggregated data showed that children in the target age range spent more time at the exhibits than did the overall sample, which included groups with children younger than the target range (mostly 7–9) (Figure 8).

While these times may seem unexpectedly long, remember that this sample excludes groups that included only preschoolers and children with no adult in sight. These dwell times were long enough for most groups to complete one or more challenges, either those set by the exhibit labels or ones that groups set for themselves.

Figure 8. Dwell time at individual exhibits

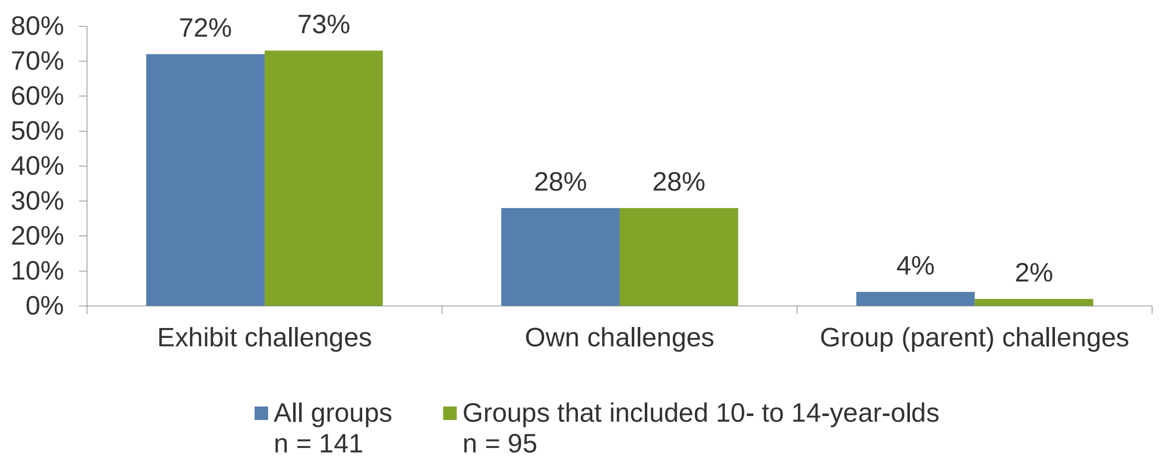


Visitor Engagement: Use of Challenges

The challenges introduced on exhibit labels and monitors played an important role in the overall strategy for motivating visitors to engage in algebraic thinking. Of the groups observed during structured observations, 89% engaged in at least one challenge. These results did not differ much whether a group member was in the target age range or not. Eighty-six percent of groups that included 10- to 14-year-olds engaged in at least one challenge.

Groups most often attempted one or more of the challenges included on exhibit labels and monitors, although some developed their own challenges. Nearly three-quarters of the groups attempted at least one exhibit challenge. In more than a quarter of the groups, the member using the exhibit set a challenge for him or herself. A few worked with a challenge set by an adult in their group (Figure 9).

Figure 9. Challenges attempted by designated children and their groups



Visitor Engagement: Exhibit Behaviors

Video data from this study provided insights into the roles and behaviors of children and caregivers. These data demonstrated the important roles that caregivers could play while engaging, alongside their children, with the exhibits. These roles typically played out in different sequences of behaviors at each exhibit.

At “Balancing Art,” children took active control, selecting weights from the tray below the balancing rod and hanging them up. Their caregivers most often stood behind the children, watching them work and observing the balancing rod. This position often led parents to discover the parent panel, located to the side of the exhibit, which helped them understand and explain the direct mathematical relationship between weight and distance—thereby helping them to take on a teacher role.

In contrast, “Drawing in Motion” was designed to encourage two visitors to cooperatively use the exhibit. In this exhibit, one visitor moves a slider that controls motion along the X axis; the other visitor moves a slider that controls motion along the Y axis. Together they control a “pen” that draws on a coordinate grid.

Typically each caregiver and child stood in front of one of the sliders on either side of the control panel and parent panel. They usually cooperated with one another as they moved the sliders left and right, figuring out how to control the drawing on the screen and, in two cases, moving simultaneously to draw diagonal lines. Caregivers often took a leadership role, either telling children what to do directly or trying to teach them about the relationship between the sliders and the on-screen activity.

Most groups also found “Slide-a-Phone” to be a cooperative venture. In this exhibit, one visitor adjusts the overall length of a large sound tube, while another visitor beats out a rhythm on an attached drumhead. Visitors try to play “mystery” songs whose melodies are represented by a graph of tube lengths. Both caregivers and children took leadership roles at various times. Children often decided which role they would play, while caregivers were more prone to read the graph, tell the child what to do, and sometimes explain the key relationship between length of tube and pitch.

Caregivers took a facilitator role more often, although children sometimes contributed equally or even led discussions of the exhibit. To operate the “Slide-a-Phone,” visitors usually divided the labor so one person hit the drumhead while the other moved the tube.

At all three exhibits—“Balancing Art,” “Drawing in Motion,” and “Slide-a-Phone”—caregivers approached their roles as guides or teachers using a variety of techniques including:

1) giving specific information (like terminology);
2) explaining general concepts, often related to the rule or relationship that governed that exhibit;
3) explaining why the instructions were given in a certain way;
4) correcting mistakes in a way that helped the partner improve;
5) asking a series of guiding questions and drawing out desired answers; and
6) setting up a problem or challenge that helped guide the learner towards important discoveries.

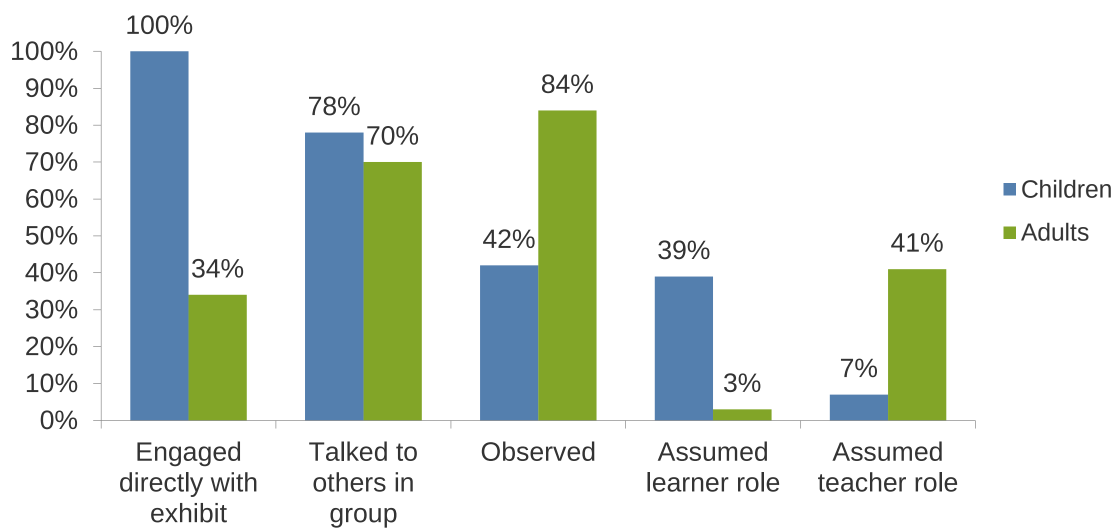
Many of these strategies seemed quite appropriate for an informal setting.

Visitor Engagement: Exhibit Behaviors, cont'd.

Based on observation data, 100% of the 10- to 14-year-olds we observed engaged directly with the exhibit, but about 40% spent some time observing as well (Figure 10).

In contrast, only about a third of the adults engaged directly with the exhibit, but 84% took an observer role. Some three-quarters of both caregivers and children talked with other members of their groups (children sometimes talked with children instead of with adults). Group interactions varied and we saw groups talk about a range of things such as how to use the exhibit, strategies for how to successfully complete a challenge or advice for meeting a challenge, and explanations. Adults took the role of guide/teacher much more often than children, who usually took the learner role.

Figure 10. Interactions between respondents as they engaged with the exhibits
(Groups with designated children in the 10- to 14-year-old age range)

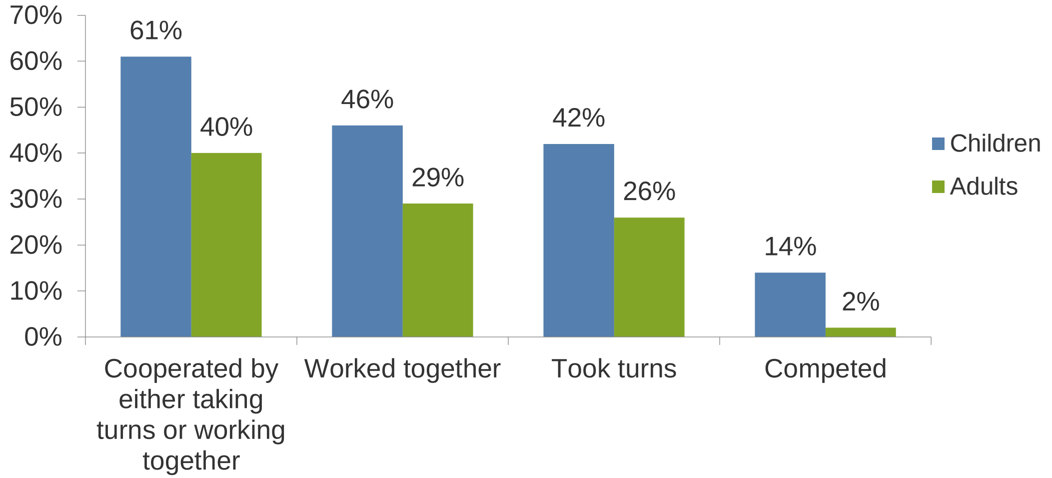


n = 96

Visitor Engagement: Competition and Cooperation

Some *Design Zone* exhibits (for instance, "Bike Race") encouraged competition while others, such as "Drawing in Motion," were designed to encourage cooperation among visitors. Respondents engaged in both competitive and cooperative behaviors across the range of *Design Zone* exhibits, with cooperative behaviors, such as taking turns and working together, predominating (Figure 11). The results for adult caregivers reflect the fact that caregivers spent much of their time observing rather than directly engaging with the exhibits.

Figure 11. Group interactions as they engaged with the exhibits
(Groups with designated children in the 10–14 year age range)

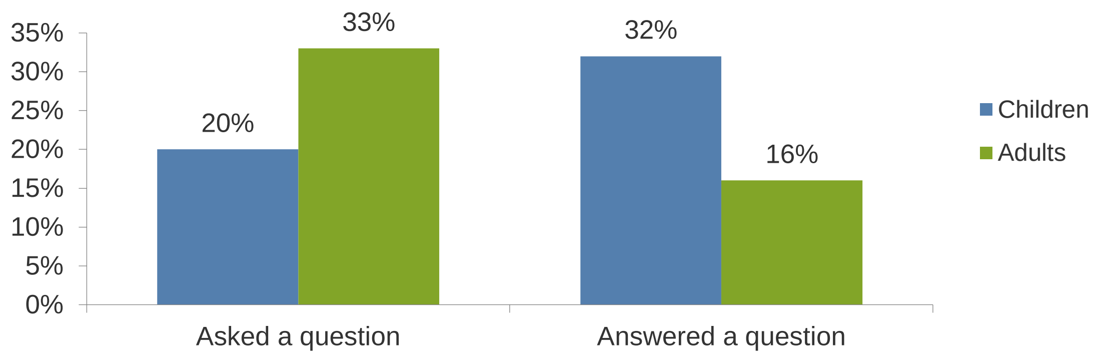


n = 96

Visitor Engagement: Questions

On average, 43% of groups asked questions (and either answered them or attempted to) as part of their engagement at an exhibit. Caregivers more often asked questions and children more often answered them (Figure 12). When data were disaggregated for groups with children in the target age range, the pattern of adults asking more questions held.

Figure 12. Group interactions: Posing or answering questions
(Groups with designated children in the 10- to 14-year-old age range)



n = 96

Visitor Engagement: Questions, cont'd.

About a quarter of the groups asked questions as they figured out the basics of how an exhibit worked (e.g., "What is this one supposed to do?" "Where's the shift key?" "Why wasn't it working?").

Some 15% of groups asked questions as part of meeting a challenge or understanding the relationships that helped them meet that challenge (e.g., "How many reflections did you count?" "What song was I playing?" "Why do you think that wheel's faster?" "Where's it going to hit next?").

The remaining questions included those asked by groups trying to figure out which exhibit to try next (e.g., "Do you want to try this?" "What do you want to do next?"), questions about personal connections (e.g. "Does this make you think of music class?"), and attempts by parents to understand what their children were doing, sometimes after being disengaged for a time (e.g. "What are you building?" "What do we do here?" "What's your score?").

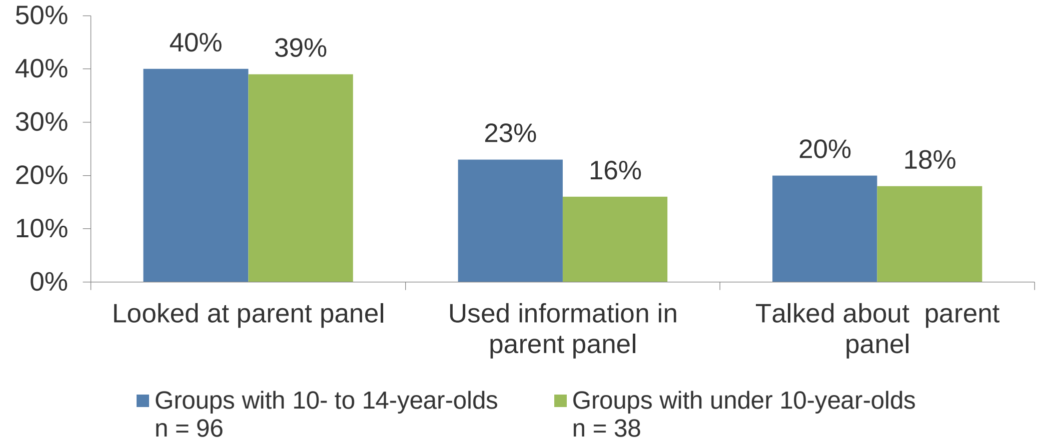
Few questions could be categorized as classic inquiry questions, the kinds that budding scientists might ask in trying to understand a physical phenomenon. When those sorts of questions were asked, they most often fit within the framework of whatever challenge the group was trying to meet. For example, a parent at "Roller Coaster Hills" asked his daughter to predict, "Where's [the ball] going to hit next?" A parent at "Designing for Speed" held up two wheels for comparison and asked, "Why do you think that one's faster?"

Visitor Engagement: Use of Mathematical Interpretation

"Parent panels" were designed to help visitors discover the math and algebra at the exhibits and to use that math and algebra in ways that would help them meet the exhibit challenges. Both groups with children in the target age range and groups with only younger children looked at and talked about the parent panels with approximately equal frequency (Figure 13). Groups with children in the target age range, however, were more apt to use the parent panel information to meet exhibit challenges than were groups with only younger children.

Parent panels included a range of information, in some cases graphs, tables, and equations, along with explanations about how to use these algebraic representations to meet the exhibit challenges (Figure 14). For instance, the parent panel at "Hit the Target" included a graph showing the relationship between the launch angle of the catapult arm and the distance it would throw a ball, along with an explanation of how to use that graph to achieve higher scores at this exhibit. At "Drawing in Motion," visitors made their own drawings on a coordinate grid, and the parent panel explained the underlying concept of slope and how to draw lines with different slopes.

Figure 13. Groups that looked at, used, and/or talked about the information in parent panels as they engaged with an exhibit



Visitor Engagement: Use of Mathematical Interpretation, cont'd.

The exhibits also included several ways of representing quantitative information, including numbers on weights, scales, and distances that were part of exhibits, illustrations of graphs and tables on labels and monitors; readouts of numerical data generated by visitors, and graphs and tables created in real time by visitors (Figures 14 and 15). For example, in "Designing for Speed," visitors rolled different wheels down a track and a monitor displayed the time it took each wheel to reach the bottom, creating a table of data.

We tracked how and how frequently visitors used whatever quantitative representations ("math tools") were available at a particular exhibit (regardless of its source) in order to measure the indicator set by the team, which stated that "During the visit, 60% of the target audience will use math tools provided." Note that such data representations were made available to visitors in several different ways.

For instance, in some cases, tables of quantitative information were presented to visitors in labels (e.g., "Digital Strings").

In other cases, visitors generated the data as they played at the exhibits (e.g., "Designing for Speed"). Likewise, graphs were sometimes presented in challenge labels and parent panels (e.g., "Hit the Target") and sometimes generated by visitors (e.g., "Sound Graph"). Including all these types of data representations, in over three-quarters (77%) of groups, visitors looked at one or more representations of data (at the exhibit at which we observed them), with children looking at more representations than adults (74% vs. 56%). The lower percentages for adults may reflect the fact that a large percentage of adults did not engage directly with the exhibits.

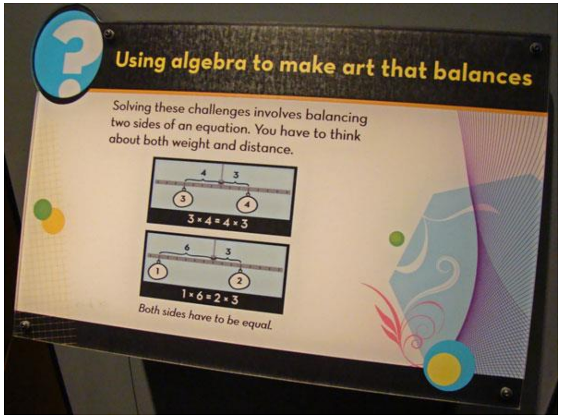


Figure 14. Parent panel for "Balancing Art" that used an equation to help visitors complete the challenge.

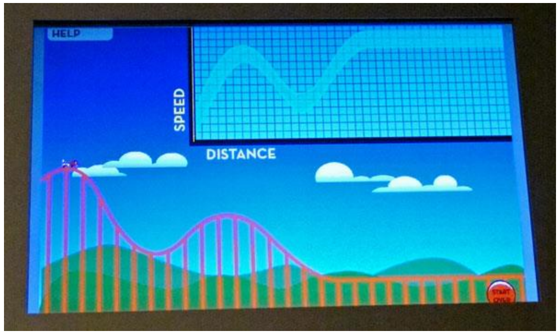
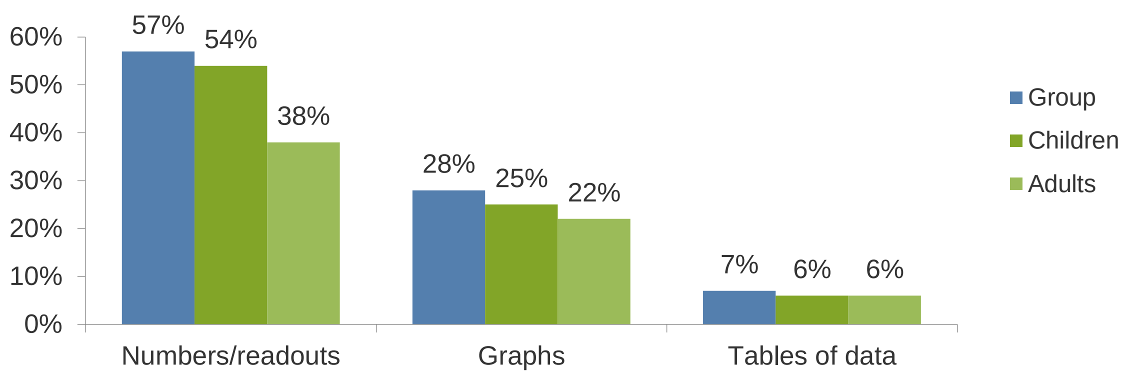


Figure 15. "Design a Roller Coaster" had an on-screen graph to represent data to the visitor.

Visitor Engagement: Use of Mathematical Interpretation, cont'd.

Figure 16 breaks out data by type of representation (e.g., readouts, tables, graphs).

Figure 16. Respondents who looked at representations of data at an exhibit
(Groups with designated children in the 10–14 year age range)



n = 96

Visitor Engagement: Use of Mathematical Interpretation, cont'd.

Children were more apt to attend to numbers and readouts than adults because they generally were more directly involved with the exhibits. Younger children, in particular, often needed adult help to interpret and apply data arranged into tables or displayed in graphs. Comparisons of the percentages for the individual types of representations, however, must be interpreted with some caution. Numbers (e.g., on weights and scales) and data readouts were available at almost every exhibit, but tables were generated by visitors at only two exhibits ("Designing for Speed" and "Testing Gears") and presented on labels at a few others (e.g., "Build a Plaza" and "Mirror Multiplier"). Graphs were generated and displayed at more exhibits than tables were, but not as frequently as numbers and readouts.

Of course, the data in the representations were designed to be used by visitors as they tried to meet the challenges at each exhibit. For instance, groups used readouts to tell who completed the most turns in 15 seconds at "Testing Gears," used the graph of distance over time at "Bike Race" to tell how they were doing relative to competitors (and eventually who won the race), or compared the tabulated results of two or more time trials at "Designing for Speed" (Figure 17).

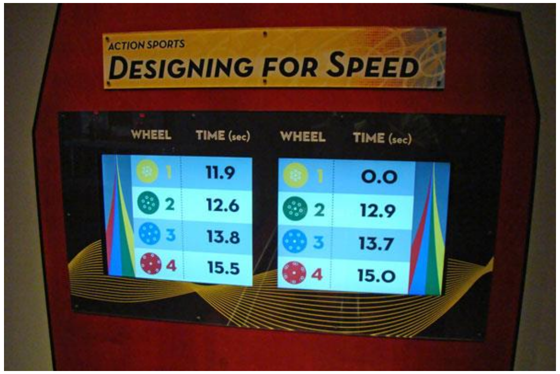
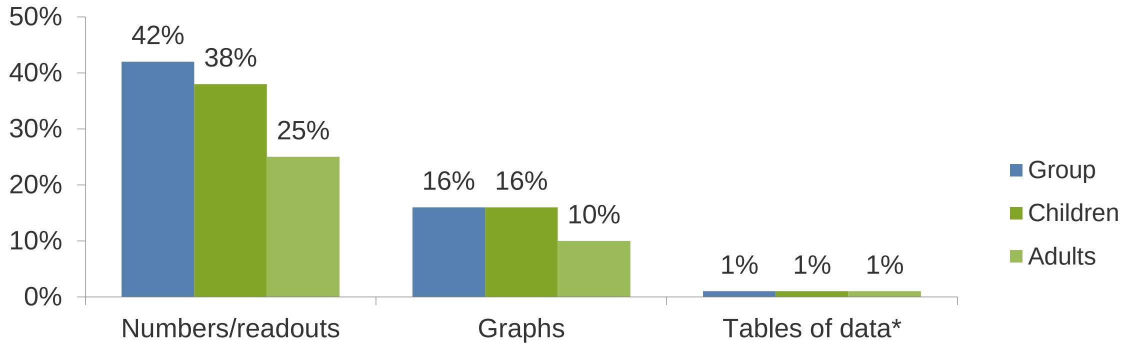


Figure 17. The "Designing for Speed" showed visitors a screen with tabulated race results.

Visitor Engagement: Use of Mathematical Interpretation, cont'd.

Compared with the results in Figure 16, a slightly lower percentage of groups we observed overtly used the information and data they found in data representations as they engaged with the exhibits (Figure 18).

Figure 18. Respondents who used the different representations of data as they engaged with an exhibit
(Groups with designated children in the 10–14 year age range)



n = 96

*Note that visitors often looked at only one or two of the numbers generated in tables at exhibits like "Designing for Speed" and "Testing Gears," rather than comparing numbers within a table. Picking out one or two numbers was coded as "numbers/readouts"; comparing numbers within or across a table was coded as "tables of data."

Visitor Engagement: Use of Mathematical Interpretation, cont'd.

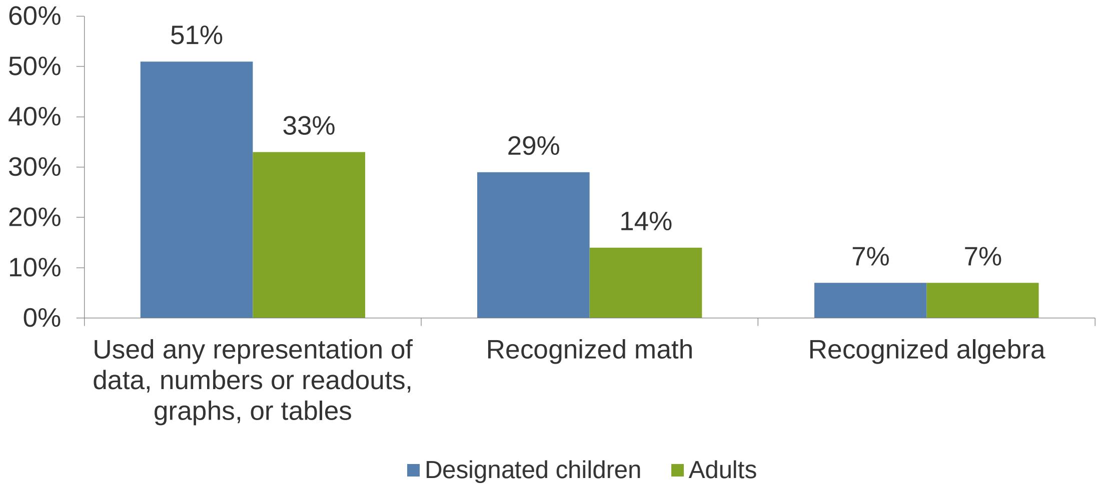
Nonetheless, on average, 55% of the groups had one or more member use a data representation at an exhibit. This includes just over half (51%) of children and one-third of adults (33%) who used one or more representations of data in their interactions at an exhibit. Because most visitors engaged with many exhibits during a visit, this implies that the 60% impacts and indicators target was easily exceeded when respondents' entire visit is taken into account.

Note that the findings on both data representations and parent panels have a bearing on whether a respondent felt like they were doing math or algebra at an exhibit. As discussed in the introductory section, the team's definition of "algebraic thinking" included finding, describing, and using patterns and predictable relationships between variables to meet the exhibit challenges. The majority of 10- to 14-year-olds (83%) described and/or used such a pattern or relationship, at least in qualitative terms. Only 23% of these youth, however, made a prediction.

Visitor Engagement: Use of Mathematical Interpretation, cont'd.

The *Design Zone* team was also interested in whether visitors *recognized* that they had used math and algebra in *Design Zone*. Of groups who used a quantitative representation, almost one-third of target-aged youth, but less than 20% of adults, recognized what they were doing as math and far fewer in both groups considered what they were doing at that exhibit to be algebra (Figure 19).

Figure 19. Respondents who used data representations that recognized they used math or algebra
(Groups with designated children in the 10- to 14-year-old age range)

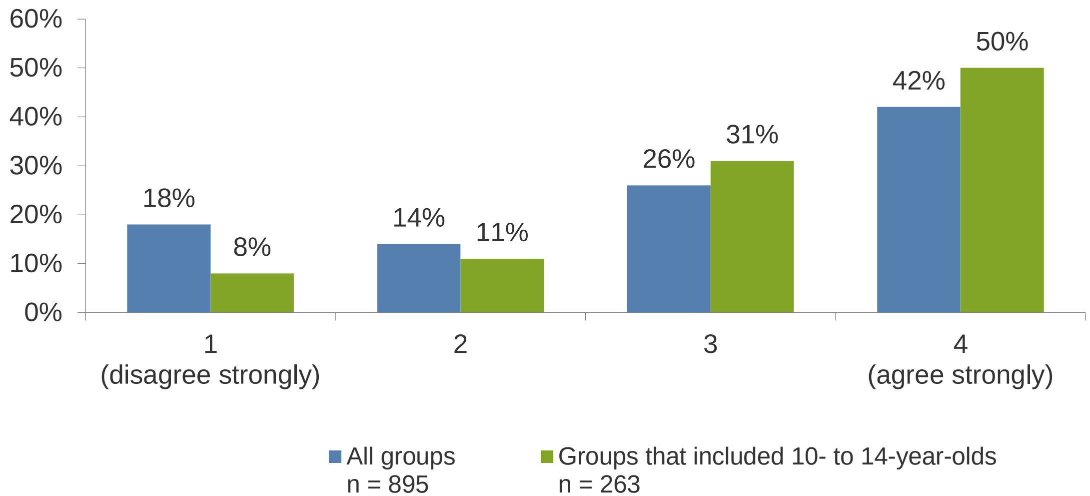


n = 96

Recognition of Math and Algebra Content

Exit survey data allowed us to determine the extent to which visitors recognized the math and algebra content. When asked about math in general, 68% of the total sample agreed (a 3 or 4 rating on a 1–4 scale) that their group had used math in the exhibition (Figure 20). For groups with children in the target age range, the level of agreement was higher (81%). The rating average for all groups was 2.91, while the rating average for groups that included 10- to 14-year-olds was 3.23.

Figure 20. Agreement ratings to the statement "My group and I used math at some of the exhibits in *Design Zone*."



Recognition of Math and Algebra Content, cont'd.

During intercept interviews, visitors discussed a range of impressions concerning what the exhibition was about. Some visitors focused on the themes—music, building things, playing games—while others emphasized more general ideas such as design and engineering. Still others talked about the science they had done and learned. Some visitors pointed out that math played a part in their overall experience. A smaller subset of these visitors, however, identified algebra as part of their experience. A few visitors congratulated the team on finding a "stealth" way to get kids to do algebra.

When respondents were asked, "If you were going to tell someone back home what this exhibit was about, what would you tell them?" the most frequently mentioned word in a textual analysis of responses to this question was "math," suggesting that visitors saw math as a major part of the exhibition. Other often-mentioned ideas were design, science, and music. "Algebra" was infrequently mentioned.

Here's a selection of responses that mention math and algebra:

> *It's making math fun.*
>
> *Math and play.*
>
> *Using math in different area of everyday life.*
>
> *Great for math applications, this reminds me of a class I took called Practical Math.*
>
> *Visual representation and application of math in the real world.*
>
> *Good ways to introduce math...I'd call it stealth math!*
>
> *A lot of algebra...math-driven design exhibits which are fun for kids.*
>
> *Algebra, a lot of algebra. I would say people who enjoy math would be more into it.*
>
> *Ratios, math, geometry, algebra without the children noticing.*

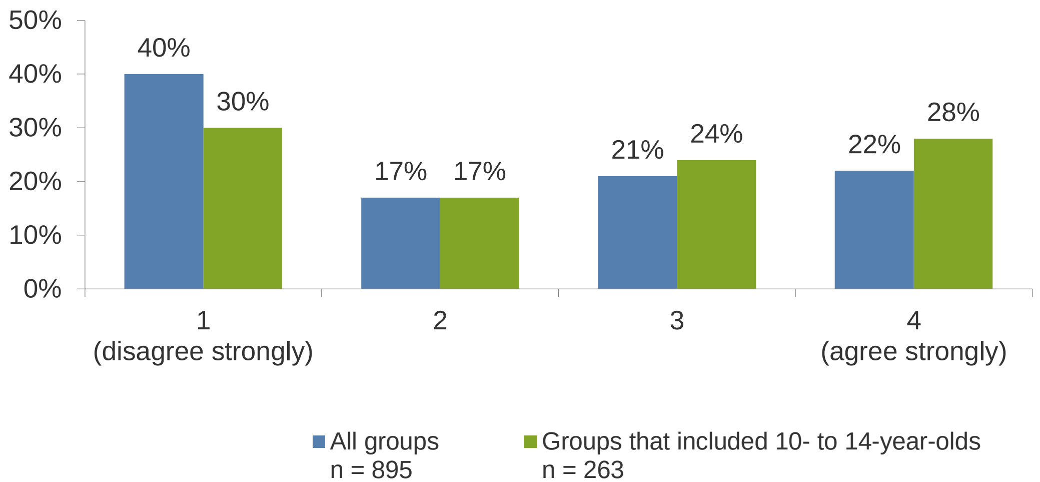
The following responses include math as part of a more complex description of what the exhibition is about:

> *Expanding people's ideas in what design is and how math affects design.*
>
> *It's a mixture of math, architecture, and design.*
>
> *The science and math behind the things we do.*
>
> *Science and math and how they're a part of everyday life. AKA "integrated curriculum."*
>
> *It's about kids, keeping kids interested in science and math.*
>
> *It's about math, concepts, making games, and help[ing] kids understand math.*
>
> *It was about puzzles, figuring out how stuff works, and using math.*

Recognition of Math and Algebra Content, cont'd.

Agreement ratings with the statement, "My group and I used algebra at some of the exhibits in *Design Zone*" were lower than for using math at the exhibit (Figure 21). Forty-three percent of the total sample and 51% of those with children in the target age range agreed with the statement (a 3 or 4 rating). The rating average for all groups was 2.25, while the rating average for groups that included 10- to 14-year-old was 2.51.

Figure 21. Agreement ratings for the statement, "My group and I used algebra at some of the exhibits in *Design Zone*."



Recognition of Math and Algebra Content, cont'd.

For both of the math and the algebra statements, agreement ratings were higher for groups with children in the target age range than for the sample as a whole. This suggests that the experience—at least in terms of seeing math and algebra—was more successful for the target audience than for the larger sample as a whole.

A follow-up question about what sorts of math respondents remembered doing gave insight into how visitors thought about the math at the exhibits. The two most frequent responses were doubtless influenced by the earlier questions: *algebra* (25% of the 779 responses) and *math* (15% of responses). Fifteen percent of responses, however, included the name of another branch of math: *geometry*.

More specific responses included words for mathematical operations, like *addition* (14% of responses) and *division* (3% of responses). The word "measuring" was included in 3% of responses, and things that were measured were also mentioned, like "speed" and "weights" (both 5% of responses). Of algebra-related terms, it was not surprising that "graphs" was mentioned more often than "equations" (11% vs. 2%), since the exhibits included more graphs than equations.

Recognition of a Different Kind of Math Experience

Although the *Design Zone* team was clear in its intention to design experiences different from those of school math, we wondered if the visitors appreciated that aspect of the experience. As seen in Table 1, below, large majorities of all subgroups agreed that *Design Zone* allowed them to experience math differently than from school math.

Table 1. Agreement ratings to the statement, "The exhibits allowed us to experience math in ways that were different from school math."

	1 (disagree strongly)	2	3	4 (agree strongly)	Rating Average
All groups n = 882	7%	7%	25%	62%	3.42
Groups that included 10- to 14-year-olds n = 261	5%	6%	24%	66%	3.51
Only groups with 10- to 14-year-olds who agreed that they used math n = 212	3%	5%	23%	70%	3.59
Only groups with 10- to 14-year-olds who agreed that they used algebra n = 138	2%	4%	20%	73%	3.64
Only groups who agreed that they used math n = 602	3%	5%	24%	68%	3.58

Recognition of a Different Kind of Math Experience, cont'd.

Respondents also made a number of comments that supported this finding, such as:

["Drawing in Motion" is more fun than drawing graphs at school] because you get to see it happen on [the screen].

We were having FUN.

I didn't really look at it as math until you asked.

You don't really think about applying math, that's what makes it so fun.

[The exhibit] wasn't straight forward about math. [I] didn't even see the word math a lot throughout!

There was no pressure.

There aren't any right or wrong answers, just experimenting with different variables.

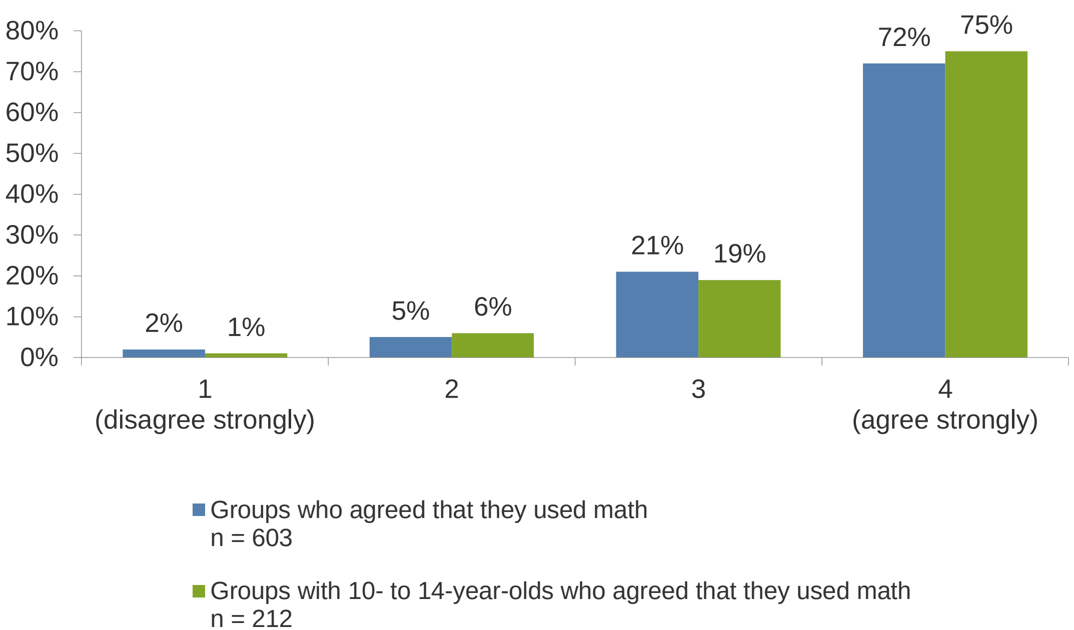
No one is judging. It's OK to make a mistake and you don't feel stupid.

These remarks suggest that although most respondents saw links between the math they learned at school and *Design Zone*, they recognized that the exhibition provided a very different set of experiences.

Comfort with Math and Algebra

Survey respondents were also asked to rate their comfort level using math at the *Design Zone* exhibits (Figure 22). Analysis of ratings from respondents who agreed they had used math in the exhibit (ratings of 3 or 4) indicated that comfort levels were generally high, with 83% of respondents providing ratings of 3 or 4. Ratings were somewhat higher (94%) for groups with children in the target age range. The rating average for groups who agreed they used math was 3.62, while the rating average for groups that included 10- to 14-year-olds who agreed they used math was 3.67.

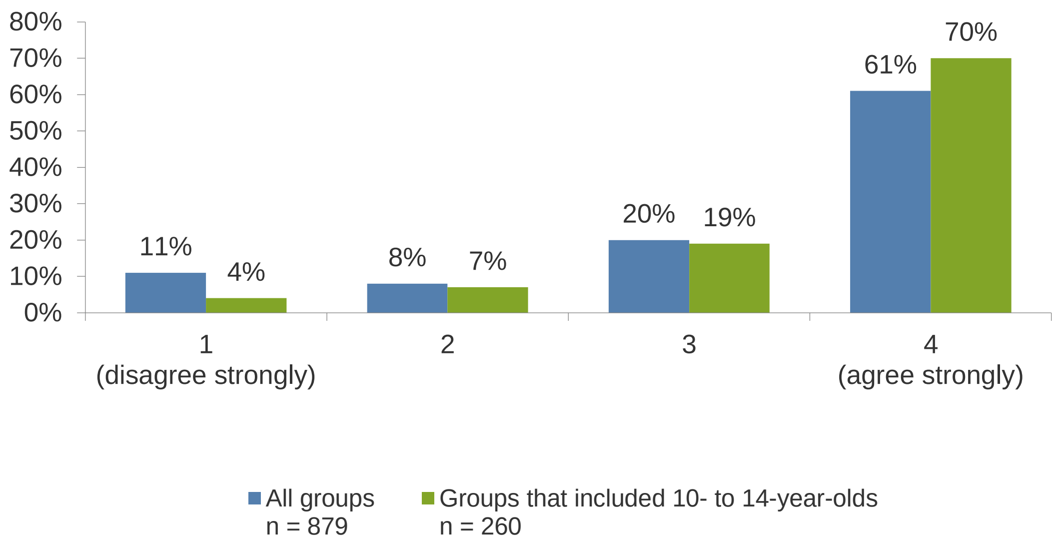
Figure 22. Agreement ratings to the statement, "My group felt comfortable using math at the *Design Zone* exhibits."



Comfort with Math and Algebra, cont'd.

Because we wanted to determine comfort with math across the entire visitor sample (not just those who agreed they had used math), we asked this question of all survey respondents. Looking at the entire sample (Figure 23), agreement ratings are somewhat lower, with 81% agreeing that they felt comfortable. (Note that groups with 10- to 14-year-olds gave ratings that were relatively high, with 89% providing 3 or 4 ratings.) The rating average for all groups was 2.51, while the rating average for groups that included 10- to 14-year-olds was 3.30.

Figure 23. Agreement ratings to the statement, "My group felt comfortable using math at the *Design Zone* exhibits."



Comfort with Math and Algebra, cont'd.

In a follow-up question, exit survey respondents were asked to give the reason for their ratings about their comfort doing the math at *Design Zone*. When their open-ended answers were coded, five categories emerged (Table 2).

Table 2. Reasons for comfort ratings with math

	Agreement levels with the statement "My group felt comfortable using math at the Design Zone *exhibits."*			
	Answered 1 (disagree strongly) n = 95	**Answered 2** n = 64	**Answered 3** n = 151	**Answered 4 (agree strongly)** n = 501
Aspects of exhibit design, such as label explanations and interactivity	6%	3%	46%	46%
How easy or difficult the math was	4%	19%	17%	30%
Group members' backgrounds and feelings about math	14%	13%	21%	24%
Group members' ages	41%	39%	18%	10%
Did not do math	35%	22%	6%	1%

Comfort with Math and Algebra, cont'd.

Positive Agreement
Respondents who *strongly agreed* that they felt comfortable with the math in the exhibits cited a variety of sources for their comfort. Nearly half, 46%, commented favorably on aspects of the design of the exhibits—such as the overall interactive approach—or the clarity and usefulness of the instructions (Table 2). For instance, they said the instructions and explanations on the exhibit labels and screens helped them feel comfortable.

The instructions were straightforward.

The instructions: what [the exhibit] does, what you need is clear.

Good instructions for people who may not have initially understood, so the "answer" was there.

The explanations on the signs are helpful.

Panels help guide successful experiments.

Others cited various advantages of taking a challenge-based, hands-on, and interactive approach to the exhibits.

That <u>because</u> it was hands on, regardless of the child's age, they could do it.

[The math] was integrated into challenges in a natural way.

Instant gratification, got to touch it.

Thirty percent of respondents mentioned how easy or simple the math seemed (which would represent the interaction of exhibit design with the respondents' backgrounds). Examples include the following:

It was very basic math.

It wasn't difficult at all.

Easy to interact with exhibits, and can go at your own pace.

It was simple enough, but still challenging.

Twenty-four percent of the comments related more to respondents' own backgrounds and feelings about math. These responses fell into several subcategories. Some respondents cited aspects of their personal backgrounds as the source of their comfort, such as schooling and an overall predisposition towards math, while other cited their own math-related careers, or even their companion's background in math, as a source of their comfort.

It's stuff that relates to school.

[I] remember it from school.

It's all the stuff we learned in high school.

I'm an engineer, I'm always comfortable.

I'm a science teacher, so this is easy for me!

Because I'm a CPA.

I'm a math major.

[My] husband's a math teacher.

I'm here with a math professor, and I'm a high school teacher.

I had a mathematician with me.

My son is good at it.

Others commented that they just like math, and they're good with it.

I'm a math head.

I like numbers.

I am good at math.

Math is like second nature.

Comfort with Math and Algebra, cont'd.

Ten percent of comments mentioned the role that the age of their group members played in their comfort with the exhibits. Many of these comments cited a good fit between the exhibition's math and the ages of children in their group.

Our kids had no problems playing, they had fun.

11-year-old was comfortable...age of [our] kids good for this exhibit.

[It was] kid friendly.

Despite respondents' agreement that they felt comfortable with the exhibition's math, some of their comments pointed to mismatches between the exhibition's math and some of the children in their group. While a few comments discussed a mismatch for older children, most concerned the idea of the exhibit not being as appropriate for younger audiences.

Needs more stuff for big kids, stuff for them to think about.

My kids are young, so they were using math but maybe not aware.

Definitely comfortable, but maybe not for a younger kid.

Among this group, several categories of responses occurred at low levels (less than 5%), but were still enlightening. For instance, a few respondents mentioned that the exhibit setting was low-pressure and thus not intimidating.

It was fun, no pressure.

Making it fun made it easier and not intimidating.

You get to play with it; it's all right to fail.

Some respondents noted that it did not feel as if they were doing math.

You don't really think about applying math, that's what makes it so fun.

They didn't realize that's what they were doing [referring to math].

I didn't really look at it as math until you asked.

A few respondents also mentioned how the exhibits contributed to their own comfort, or the comfort of their children, by using examples from everyday life.

The math seemed "every day."

It was applicable to what kids see every day, applying the elements of design and math to things the kids can relate to.

Finally, a few respondents mentioned the role of floor staff in making them feel comfortable with the math in the exhibits.

[There were] lots of explainers to help.

Started at "balance art" and an explainer showed us how to use the math for it. That basically got the ball rolling for us.

Comfort with Math and Algebra, cont'd.

Negative Agreement
For respondents who *disagreed strongly* with the statement about feeling comfortable using math, 35% said they did not do any math at the exhibits (Table 2). Forty-one percent of responses related to the ages of the children in their groups as part of what contributed to their lack of comfort. These respondents primarily noted they felt the exhibit was aimed at children older than those in their group. Here are some examples of things they said:

> *The kids were too young to understand math.*
>
> *With kids 7, 5, and 4, they don't understand much about math.*
>
> *My kids are young. My youngest likes blocks and went to build, not too much thinking went into that.*
>
> *Not worth explaining to a 7-year-old.*
>
> *Age appropriateness was lacking.*

Another 14% cited, negatively, their own backgrounds and feelings about math.

> *I haven't done math in years, makes me realize I'm not as intelligent as I think I am.*
>
> *Math is a weak area for me.*
>
> *We lost a lot of math skills.*
>
> *I hate math, so it's never easy for me.*
>
> *I don't like to use math, stay away from math!*

Six percent of these respondents commented on specific aspects of the design of the exhibits (vs. 46% of those who strongly agree that they felt comfortable with the math). Not surprisingly, these respondents' comments were negative.

> *Some of the instructions were confusing. Also, [it] wasn't clear what we were supposed to accomplish for some exhibits.*
>
> *It goes back to the explanations thing. It says "use algebra to do this" and didn't explain.*

Four percent of these adults said that the math was too hard for them.

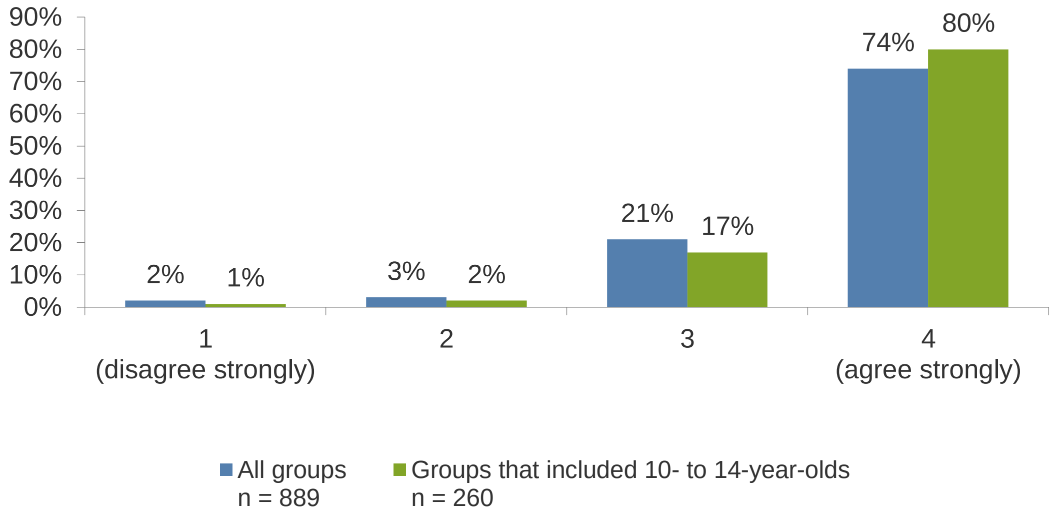
It was hard.

I didn't feel like doing math, too complicated.

Enjoyment

Ninety-five percent of the respondents surveyed agreed that they enjoyed their experience, rating it a 3 or 4 on a 1–4 scale (Figure 24). Those in the target age range reported higher levels of engagement (97%) than the sample as a whole. The rating average for all groups was 3.68, while the rating average for groups that included 10- to 14-year-olds was 3.77.

Figure 24. Agreement ratings with the statement, "We really enjoyed our experiences in *Design Zone*."



Enjoyment, cont'd.

Although there was seemingly little room for improvement, respondents who also agreed with the statement that they had used math or algebra at *Design Zone* tended to rate their enjoyment even higher, reaching the 100% level (rating of 3 or 4) for target audience members who agreed they used algebra (Table 3).

Table 3. Agreement ratings for the statement, "We really enjoyed our experiences in *Design Zone*" for groups who agreed they used math or algebra in the exhibition.

	1 (disagree strongly)	2	3	4 (agree strongly)	Rating Average
Groups who agreed that they used math n = 603	1%	1%	20%	78%	3.75
Groups with 10- to 14-year-olds who agreed that they used math n = 212	1%	1%	17%	82%	3.80
Groups with 10- to 14-year-olds who agreed that they used algebra n = 138	0%	0%	13%	87%	3.87

Enjoyment, cont'd.

When asked what they enjoyed most, survey respondents provided a range of answers. Most named specific individual exhibits that they recalled as especially fun and/or engaging. Especially popular exhibits included "Hit the Target," "Bike Race," "Balancing Art," "Digital Strings," the three roller coaster exhibits, "Laser Light Show," and "Marble Maze." Respondents also often mentioned the hands-on and interactive nature of the exhibits.

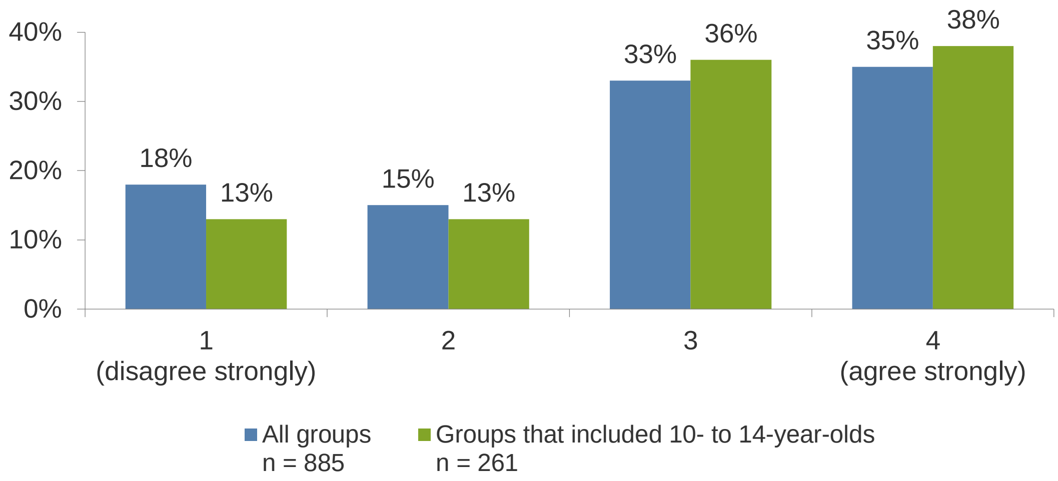
Only 4% of the surveyed respondents mentioned math or algebra in their answers as what was most enjoyable:

> *I liked how they pointed out the math. It was explicit. Great to have interesting activity and then say it's math.*
>
> *Really smart way to trick kids into learning math.*
>
> *Demonstrates math graphically so it's easier to understand.*
>
> *How math and physics come together through design.*
>
> *Algebra. I love an exhibit with math in it.*
>
> *Algebraic connection, how real life is tied in to math.*
>
> *I like the use of algebra to teach basic concepts, making algebra applicable.*

Perception of Challenge

Nearly three-quarters of the target audience groups, 74%, agreed or agreed strongly (ratings of 3 or 4) with the statement, "Some of the exhibits were pretty challenging, but we figured them out in the end." As did 68% of the entire sample (Figure 25). The rating average for all groups was 2.85. The rating average for groups that included 10- to 14-year-olds was 3.00. This indicates that *Design Zone* met the NSF indicator: "During the visit, a majority of the target audience (51% or more) will feel challenged, but successful."

Figure 25. Agreement ratings for the statement, "Some of the exhibits were pretty challenging, but we figured them out in the end."



Perception of Challenge, cont'd.

We found respondents expressed stronger agreement with "challenged but successful" in groups which agreed that they had used math or algebra (Table 4).

Table 4. Agreement ratings for groups who agreed they used math or algebra in the exhibit to the statement "Some of the exhibits were pretty challenging, but we figured them out in the end."

	1 (disagree strongly)	2	3	4 (agree strongly)	Rating Average
Groups who agreed that they used math n = 602	11%	14%	35%	40%	3.05
Groups with 10- to 14-year-olds who agreed that they used math n = 212	9%	13%	36%	42%	3.11
Groups with 10- to 14-year-olds who agreed that they used algebra n = 138	7%	10%	36%	46%	3.21

Perception of Challenge, cont'd.

Those respondents who agreed strongly that they were both challenged *and* successful most often described a particular exhibit at which they eventually succeeded. Most of the exhibits were listed in at least a few of the responses. The most frequently mentioned exhibits, both mentioned in 8% of the responses, were "Hit the Target" and the roller coaster exhibits (respondents were usually not specific about which one). The other exhibits were mentioned in 2% or less of the responses.

Of those respondents who disagreed strongly with this statement, more than three-quarters said they did not find *any* exhibit to be challenging.

No challenges for me or my grandson.

Didn't find any to be challenging.

All pretty easy stuff for kids...no challenges.

It was easy. Would have liked for it to be more challenging.

Most of the other respondents in this group mentioned specific exhibits that they were unable to figure out or use.

The Picture Calculator. It took too long to figure out.

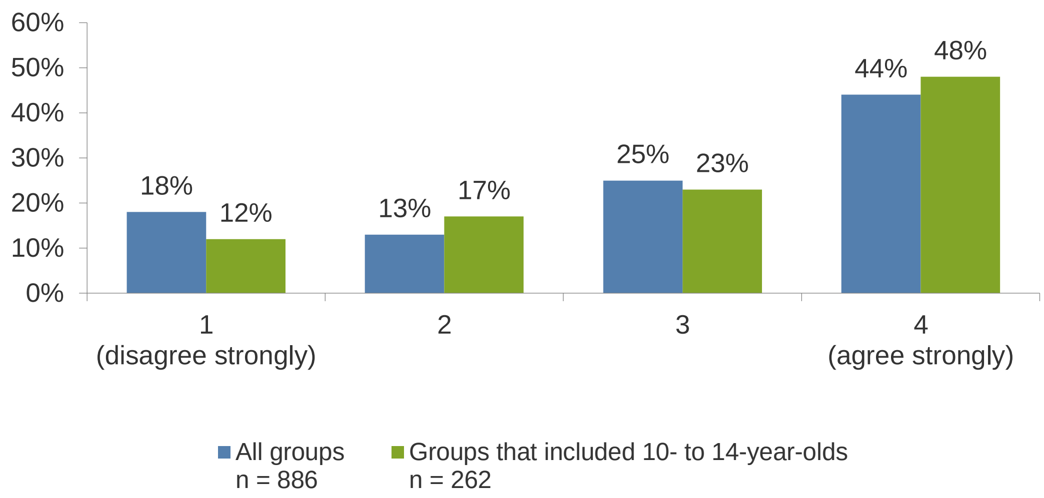
Child didn't understand the laser light show.

We gave up. The mirror maze ["Mirror Multiplier"] was challenging. It was hard.

Connections

Respondents were asked to rate their level of agreement to two statements about connections between what they were doing at the exhibits and the math they had done in school or the ways they used math in everyday life. We found good levels of agreement in both cases. Sixty-nine percent of all respondents and 71% of groups with children in the target age range agreed or agreed strongly (providing ratings of 3 or 4) with the statement, “Some of the exhibits reminded us of the math we did in school” (Figure 26). The rating average for all groups was 2.95. The rating average for groups that included 10- to 14-year-olds was 3.08.

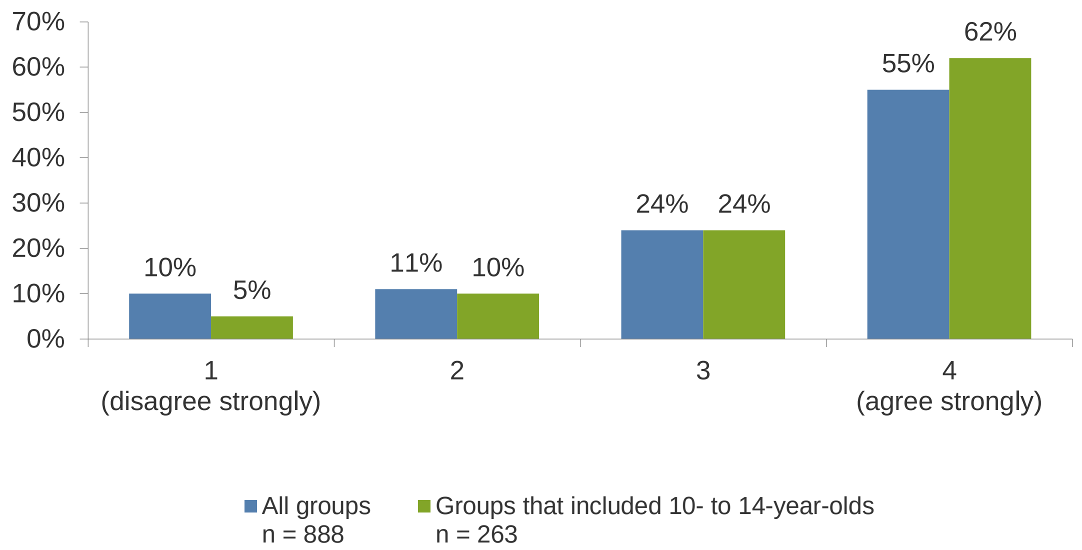
Figure 26. Agreement ratings to the statement, “Some of the exhibits reminded us of the math we did in school.”



Connections, cont'd.

Seventy-nine percent of all respondents, and 86% of those groups with children in the target age range, provided agreement ratings of 3 or 4 to the statement, "Some of the exhibits helped us think about ways that math is used in everyday life" (Figure 27). The rating average for all groups was 2.23. The rating average for groups that included 10- to 14-year-olds was 3.43.

Figure 27. Agreement ratings to the statement, "Some of the exhibits helped us think about ways that math is used in everyday life."



Connections, cont'd.

School connections were most often about math concepts, representations, or activities done in math class, such as graphs and learning algebra (Table 5).

Table 5. Examples of connections that respondents made between the exhibits and school experiences

Exhibit	Respondents were reminded of….
"Balancing Art"	Learning algebra in school, including balancing equations. (Respondents sometimes talked about specific teachers and what they had done in class.) The physical science concept of the lever: The "farther away you are from the fulcrum, the more power you've got." Using scales in school. For instance, one child remembered that in math class, they weighed pencils and paperclips and other things to see which was heaviest.
"Bike Race"	Graphs that the kids had used in school, for math or science.
"Drawing in Motion"	A coordinate grid and plotted points, done in fourth grade. A school activity where they moved between points based on coordinates like "7, 10." Graphs done in math where they just used their pencils. (But this exhibit was more fun "because you get to see it happen on [the screen].")
"Drum Machine"	Similar exercises in school, counting out beats in their music. A music class where they do percussion.
"Fast Tracks"	A project done in fourth grade called the marble roll, made of paper towel tubes, cut open and taped to lockers.
"Hit the Target"	Math in school, because it used a graph to display information. Graphs done earlier during the school year, which helped her, understand the exhibit's panels. A boy's science teacher, who would shoot him in class with Nerf guns. A similar catapult a girl had in her own science class that was adjustable with a small dial.
"Slide-a-Phone"	"It looks like a graph that tells you what the tones are." The graph made it like algebra to one respondent. Playing an instrument a couple of years ago in music class. The boy said they would beat on something and move it around and it would make different tones.

Connections, cont'd.

Everyday connections were most often about the physical similarities between the exhibits and objects or experiences encountered in everyday life (Table 6).

Table 6. Examples of connections respondents made between the exhibits and everyday life

Exhibit	Respondents were reminded of….
"Balancing Art"	Teeter-totters, especially how sitting on the beam in particular places changed how it worked. Mobiles made as art projects; mobiles made out of spoons as art.
"Bike Race"	Biking up a hill, because it's very tiring. Riding bikes every day to school or work.
"Drawing in Motion"	An Etch A Sketch.
"Drum Machine"	Noises people would make while they're thinking (like tapping a pencil).
"Fast Tracks"	A marble game that an adult had when he was growing up. Playground slides, because the steeper the real life [playground] slide, the faster it would be. Driveways during an ice storm.
"Hit the Target"	Baseball and basketball, because each involved a ball flying in an arc and landing somewhere, either in a basket or a glove. Basketball, because of the arc of the shot. Choosing golf clubs, because each has a different angle on the face which changes the height of the shot and therefore the distance of the golf ball.
"Marble Maze"	A physical game where they had to roll a marble through a maze. A cell phone game they have that has a similar style. In a workshop when a screw or a nut rolls off the table. Golf, because of the ball going into the little holes.
"Slide-a-Phone"	A trombone. A didgeridoo, from Australia. It doesn't slide but it sounds like this. Musical instruments they make like this at home sometimes with toilet paper and paper towel tubes. Using milk bottles with water in them as musical instruments. "Maybe a gigantic pencil?"

Algebraic Thinking

A primary goal of *Design Zone* was to engage visitors in algebraic thinking. This concept was "operationalized" to focus on patterns and functional relationships. The goal was to have visitors use algebraic thinking through a) finding and exploring mathematical patterns and relationships between quantities; b) representing mathematical relationships in a range of ways, including images, words, models, graphs, and symbols; and c) using mathematical relationships to describe, analyze, predict, and create.

Thus, we were interested in understanding the ways and extent to which visitors engaged in algebraic thinking as they used exhibits in *Design Zone*. To explore this issue in some depth, we conducted observations and included a video study at selected exhibits to obtain case studies of child-parent pairs (Figures 28–30). Based on these data, we developed a framework of ways visitors engaged with algebraic thinking. Table 7 describes this framework.

Figure 28. The "Balancing Art" exhibit, one of the exhibits in the video study.

Figure 29. A group at "Drawing in Motion," another exhibit where video data was collected.

Figure 30. The "Slide-a-Phone" exhibit was the third exhibit where visitors were videotaped for this study.

Algebraic Thinking, cont'd.

Table 7. Algebraic Thinking: Modes of Engagement

Mode	Description
Observe Phenomena	Visitors spend time observing what is going on at the exhibit, trying to make sense of it.
Explore through Trial and Error	Visitors engage and make choices, but apparently are not guided by an idea about what will happen. Visitors have not discovered the key variables or the relationship between them and are not applying that understanding to their actions. Visitors may use trial and error to make sense of an exhibit. They can often recognize when they have achieved something, but they don't predict in advance how to achieve it.
Find a Relationship (Qualitative)	As visitors undertake a goal or challenge, they apply a simple qualitative relationship that they use to predict what will happen ("I make this bigger, and then this gets bigger" or "If I slide the tube this way, the pitch will get higher"). At "Balancing Art," for example, visitors might achieve balance through visual symmetry (placing equal weights at what appear to be equal distances from the fulcrum, or center, of the rod).
Notice Numbers	In this approach to problem solving, visitors notice quantitative information, such as weight or distance, but may not use it to guide their choices in attempting challenges. For example, they might point out the numbers on the "Slide-a-Phone" graph, but then use the color coding to decide where to the stop the sliding tube.
Apply Numbers to a Relationship (Quantitative)	As visitors undertake a goal or challenge, they apply a specific relationship that uses numbers and, sometimes, mathematical expressions (like addition, multiplication, equalities, etc.). For example, at "Slide-a-Phone," visitors indicate, through speech or gestures, that they are making the tube longer or shorter by moving to specific numbers indicated on the sheet music. At "Drawing in Motion," visitors might follow the directions about which numbered point to move to, but when challenged to move diagonally, do so in two steps—first the X direction, then the Y, rather than using an understanding of slope to coordinate their actions.
Generalize the Relationship	Through their actions, visitors set up challenges involving unknowns, but do not talk about or seem to think about equations as such. Their actions are similar to the solving of equations, but their discourse and thinking are not. For example, at "Balancing Art," a visitor might pick up a weight and ask where to put the weight to achieve balance—the position on the beam would be an unknown—but he or she does not talk about this as solving an equation. In other words, we have no evidence that they are aware of the abstract (or algebraic) nature of what they are doing.
Generalize the Relationship and Articulate It	As visitors undertake a goal or challenge, they discover or apply a general understanding of a relationship (a rule) using numbers and unknowns (like an equation or graph) and talk about what they are doing using abstract ideas such as slope, having multiple solutions to a single problem, and other concepts associated with algebra. We know visitors are aware that they are using abstract ideas (i.e., algebra) because of the ways they talk about what they are doing.

Algebraic Thinking, cont'd.

Most visitors we observed built their exhibit experiences around challenges, either those presented explicitly in the exhibits or those they set for themselves. Visitors wanted to build a specific structure, score the most points, name that tune, achieve a perfect balance, put the ball in the hole, avoid losing a marble in a gaping mouth, connect all the dots, or win the race. If, at first, visitors failed to meet a challenge, they looked for ways to improve and tried again. When they met the exhibit's challenge or achieved their own challenges, many visitors celebrated (some exhibits even celebrated along with them). There were cries of "Yes!" with arms raised above their heads, fist pumps, high and low fives, sometimes a little victory dance, and perhaps even a bit of taunting of the vanquished sibling.

Visitors applied algebraic thinking in different ways and did so within the context of the challenges they attempted and the goals they sought to achieve. Completing challenges was easier when visitors discovered the key functional relationships embedded within the exhibits. Respondents had an even easier time if they discovered and used the mathematical tools provided by the exhibits. For instance, most visitors at "Fast Tracks" discovered they could make the ball roll faster if they made the track steeper, and some found that they could measure the ball's speed using the digital readouts on the speed gates. At "Drawing in Motion," many visitors discovered that they had to move both sliders at the same time to draw a diagonal line and that they had to pay close attention to the relative rates of motion of the two sliders to precisely connect the dots on screen. Respondents showed and told us they were thinking about and using these relationships in a range of ways—some were felt or experienced kinesthetically (like "Testing Gears" or "Bike Race"), some were expressed as words or gestures in qualitative form, some included measurements and counts, and some used the kinds of generalized and symbolic approaches associated with the subject of algebra.

As visitors wrestled with completing a challenge, they tried different approaches—or modes of engagement—and often shifted between them. For example, as visitors attempted a challenge, they might start with trial and error and then, gaining some insight from this exploration, might find a relationship and apply a generalized understanding of that relationship to the challenge. Visitors also moved back and forth between modes. For instance, a group might apply a generalized understanding of a relationship in meeting one challenge but then when faced with a more complex challenge, might shift to a trial and error approach.

Here's one scenario. Visitors might start by observing a phenomenon at the exhibit. Once visitors discovered a challenge or set a goal, their efforts generally became more focused. They started applying strategies to solve whatever problems they encountered. The simplest strategy was trial and error: just try something—whatever comes to mind—and see if it works. Thinking about the results of their informal experiments often led visitors to discover a key relationship—the thing they had to change and the way they had to change it to achieve their goal. When this relationship was expressed through visitors' actions and words, we termed it finding a relationship.

Algebraic Thinking, cont'd.

If visitors discovered that they could apply numbers—measurements and counts—to describe the functional relationship, they began to engage in applying numbers to a relationship. Visitors moved to generalizing the relationship when they started to approach the challenge using more abstract ways of thinking generally associated with school algebra. This mode of engagement involved using graphs, data tables, and equations that expressed the key relationship in ways that allowed visitors to meet a range of challenges presented by the exhibit.

What we call generalizing the relationship overlaps considerably with what might traditionally be considered doing algebra (sometimes defined as "abstract arithmetic"). We do not, however, restrict the term "algebraic thinking" to this mode of engagement. Algebraic thinking, as defined for this study, begins as soon as visitors recognize a relationship between two things that change (i.e., variables) at the exhibit. In informal settings like *Design Zone*, therefore, even children too young to have heard the word "algebra" can, at a basic level, practice algebraic thinking. As visitors shift to other modes, their thinking might become quantified and then generalized so that their understanding of a relationship applies to a range of challenges.

The scenario described above presents a generalized, rather linear description of visitors' engagement. In our video study, however, we found that visitor engagement with algebra in the exhibition was complex and did not follow a prescribed path. Engagement was fluid, with visitors moving back and forth across modes as they approached the challenges.

Algebraic Thinking in Three Exhibits in Depth

The following section discusses respondents' algebraic thinking in depth during their engagement at three exhibits. By focusing on each exhibit, we can identify important patterns that emerge at a single exhibit and note exceptions that reveal interesting aspects of algebraic thinking across these exhibits.

At "Balancing Art," visitors might observe phenomena, find a relationship, and state it in several different ways, such as, "When you add a weight to one side of the balanced scale, that side goes down," or "When you take away a weight from one side of a balanced scale, that side goes up." A statement relating variables of weight and distance with balance might be, "You can balance the scale if you place two weights symmetrically on either side of the pivot"—implying that visitors noticed a relationship involving two variables. Putting this in natural language, one might say something like, "A heavy weight that is closer to the pivot can be balanced by a lighter weight farther from the pivot." One also might state the general relationship as, "When trying to balance the scale, both weight and position matter."

At "Drawing in Motion," the core relationships were between the positions of the two sliders (along number lines) and the position of the pointer drawing on the screen. The "X" slider controlled horizontal position. The "Y" slider controlled vertical position. When the "X" slider was moved to the right, the pointer moved to the right, drawing a horizontal line along the path it followed; when "X" moved to the left, the pointer moved to the left. When the "Y" slider was moved to the right, the pointer moved down, leaving a vertical line behind it; when "Y" moved to the left, the pointer moved up. With coordinated exploration at this exhibit, visitors could discover relationships like this: "When you move X and Y to the right at the same time, the line on the screen slopes upwards to the right."

The core relationship at "Slide-a-Phone" was between the length of the sliding tube and the pitch of the sound produced when a visitor hit the drum-like surface at one end of the tube. At its simplest expression, visitors noticed that when they moved the slider, the pitch changed. With a bit more exploration, they often noticed that moving the slider to the left made the tube longer, and when the tube got longer, the pitch got lower. Moving the slider to the right made the tube shorter and the pitch higher. In other words, "A longer tube makes a lower note and a shorter tube a higher note."

At all three exhibits, visitors could discover the core functional relationships through exploration. They could, in a sense, *feel* the relationships as they discovered them, because of the physical feedback to their body motions; they encountered physical resistance as they lengthened the sound tube, moved the sliders, and positioned the weights. Some respondents seemed to develop a kind of kinesthetic understanding of the relationship before they were able to verbalize their understanding. They might express their ideas about this relationship through gestures when they had trouble finding words or use gestures as part of a verbal description.

When visitors expressed these functional relationships through words and gestures, they were often expressing qualitative relationships. For example, as they talked about balancing the scale at "Balancing Art," respondents sometimes held their arms out and tilted them side to side. At

Algebraic Thinking in Three Exhibits in Depth, cont'd.

"Slide-a-Phone" they moved their hands apart to show a longer tube and lower note and moved them closer together to show a shorter tube and higher note. Each exhibit, however, also allowed visitors to think about the relationships using numbers, expressing at least some aspects of the relationship quantitatively. These numbers included measurements of tube length at "Slide-a-Phone," position markers on the sliders and the resulting coordinate grid for "Drawing in Motion," and the weights of the hanging shapes and their positions on the balancing rod at "Balancing Art."

Visitors often found and used these numbers while engaging with the exhibits. When they did, they were moving from a qualitative understanding of the relationships and engaging in *quantitative* ways. Note that for "Drawing in Motion" and "Balancing Art," visitors could use numbers to describe both sides of the core relationship; the important variables could be measured (or counted, as one could approach relative rates of motion in "Drawing in Motion"). At "Slide-a-Phone," however, only the length of the tube was quantified on the graph-like "Name that tune!" challenge cards. The pitch of the resulting sound was not measured.

Once visitors recognized and used the quantitative tools available at an exhibit, they were ready to move on in their mathematical understanding of the relationship to a mode that expressed that relationship in more abstract terms, a mode more traditionally identified as algebra. At two exhibits, the abstraction was made concrete using a graph: the coordinate system in "Drawing in Motion" and the graph-like "Name that Tune" challenge cards in "Slide-a-Phone." At "Drawing in Motion," the variables were labeled classically as "X" and "Y." To make drawings on the screen, visitors had to work collaboratively to move a point that drew lines, with one shifting the point to designated numbers in the horizontal or X direction and the other to numbers in the vertical or Y direction. Their movements were combined into a real-time drawing on the on-screen coordinate grid.

The "Slide-a-Phone" challenge cards charted tube length (vertical axis) against order of notes (non-numeric horizontal axis of "time") and showed the notes as colored dots labeled with the exact length of the tube required to hit that note. Each "Slide-a-Phone" card displayed a different series of tube lengths arrayed from left to right—which, when struck on the drum head in order, played a familiar song. "Balancing Art" took another approach to presenting an algebraic relationship, a physical manifestation of balancing an equation. As the parent panel stated, "Solving these challenges involves balancing two sides of an equation. You have to think about both weight and distance."

"Balancing Art"

The four video cases at "Balancing Art" illustrate the roles that attentive caregivers can play in advancing their children's algebraic thinking and the important role that the parent panel played in helping respondents advance their algebraic thinking.

Algebraic Thinking in Three Exhibits in Depth, cont'd.

The encounter of the mother and 12-year-old girl in the "Balancing Art" video nicely illustrates some recurring engagement patterns at this exhibit (Figure 31). Respondents often began their engagement at "Balancing Art" using a qualitative approach; the child in this dyad started to figure things out quickly, using a qualitative relationship almost immediately as she attempted to balance the scale. Since engagements often began before respondents had viewed the accompanying labels, this could be seen as evidence that the exhibit's design helped respondents recall the concept of a balance-beam scale, which is already familiar to most children of this age. It was also typical for caregivers to engage with the exhibit experience from the very beginning, even if they mostly stood, watched, and looked at labels for the first 30 to 60 seconds. Because many caregivers did not do or say much at first, though, they could not always be assigned a code immediately (it took 26 seconds in this example). The child in this dyad took the lead at first, noticing the numbers on the weights but not doing much with them. As parent and child stood back, however, the parent would read labels—sometimes aloud—and apply what she found. The mother and daughter noticed the challenge label early on and a minute into the interaction the mother noticed the parent panel and apparently understood its significance. The mother made increasingly sophisticated suggestions to her child based on what she had read, reflecting increasingly quantitative and more abstract ways of thinking as time passed. These suggestions helped the child shift her approach.

Figure 31. "Balancing Art": Algebraic thinking trajectory (mother and her 12-year-old daughter). P = parent, C = child

Mode of Engagement								
Generalize the relationship and articulate it								
Generalize the relationship						P	P C	P C
Apply numbers to a relationship (quantitative)					P			
Notice numbers			C	C P	C	C		
Find a relationship (qualitative)	C	C P	P					
Trial and error								
Observe phenomena								
Time (min):	0:26	0:53	1:24	1:30	1:54	3:30	4:06	6:26 end

Algebraic Thinking in Three Exhibits in Depth, cont'd.

Although the parent's thoughts doubtless included abstract ideas about equations from about a minute in, she did not reveal that understanding in her questions and suggestions to the child until about 3:30 into the interaction. At that point she started posing problems for her child, many of which could be solved as if they were equations with unknowns. For instance, the mother put a 4 weight at position 4 on one side, and asked, "How much do you think you'll have to put at 2 to make it balance?" When the child solved that problem, the mother said, "Let's make it harder." She made up a new problem and asked, "What would you have to put on 3 to make it balance?" Then after realizing her problem might not have a solution, she said, "Or can you do it?" The child solved the problem, but with one weight on three and one on another position. At that point the mother asked the child to set a problem that she, the parent, could solve. Using this approach, both mother and daughter began to generalize the relationship.

Examining the chart for the group consisting of a mother and her 10-year-old daughter (Figure 32) reveals additional complexities. In this group, the mother and daughter's problem solving moves more or less in concert for more than 14 minutes. They quickly worked their way up to the simplest form of quantitative thinking by placing equal weights at equal distances on the scale. Then, however, they shifted again as the challenges they set for themselves became more complex, relying on

Figure 32. "Balancing Art": Algebraic thinking trajectory (mother and 10-year-old daughter). P = parent, C = child

Mode of Engagement	Time (min):	0:03	0:23	0:31	0:57	1:39	4:40	4:50	13:04	14:10	15:14	15:20	16:37	17:33 end
	Generalize the relationship and articulate it											P	P	P C
	Generalize the relationship										P		C	
	Apply numbers to a relationship (quantitative)			C P	C				P	P C	C	C		
	Notice numbers				P	C P		C P	C					
	Find a relationship (qualitative)	C	C P				C P							
	Trial and error													
	Observe phenomena													

Algebraic Thinking in Three Exhibits in Depth, cont'd.

qualitative rules to solve them (the simplest being "add another weight to the side of the scale that's higher"). At about 13:20, the mother decided she wanted to move beyond this very basic approach, saying "If we put it on the 5 then it should balance, because they're the same [position]. But we want to know what it would take to balance them when they're not on the same [position]." At about 13:40, the mother noticed the parent panel and read it to her daughter. The mother said, "Here's the equation. I knew there was an equation, look! 3 times 4 is the same as 4 times 3!" First they tried out the examples on the parent panel, then came up with their own equations—sometimes getting the math a bit wrong (such as adding when they should have multiplied), but generally understanding the abstract ideas about taking both weight and distance into account when solving the equations. As they began to apply what they had learned from the parent panel, they began to generalize the relationship, with the mother arriving at that mode first. The mother even connected the exhibit to the girl's school math (at 18:40), asking, "When we start doing balancing equations in math, are you going to remember this?" Gesturing at the giant mobile and then stretching her arms out straight like the beam, the mother said, "This is what I mean when I say balance your equation. Your equation is a balance beam and you gotta have the same thing on both sides. And it doesn't matter if it looks the same, as long as it equals the same." Her daughter said, "Huh," and then resumed her attempt to balance the mobile using every available weight.

Another group (Figure 33) consisted of a grandmother and her 11-year-old grandson, who had a different experience with algebraic thinking, primarily because the grandmother quickly found both the

Figure 33. "Balancing Art": Algebraic thinking trajectory (grandmother and 11-year-old grandson). P = grandparent, C = child

Mode of Engagement										
Generalize the relationship and articulate it				P	P	P				
Generalize the relationship		P					P			
Apply numbers to a relationship (quantitative)								P	P C	P C
Notice numbers		C	C	C						
Find a relationship (qualitative)			P		C			C		
Trial and error	C					C	C			
Observe phenomena										
Time (min):	0:20	1:53	3:18	4:33	4:57	5:26	5:43	6:10	8:26	8:31 end

Algebraic Thinking in Three Exhibits in Depth, cont'd.

challenge label and parent panel. After they both looked at the parent panel, the grandmother asked, "Have you had any algebra in school?" Her grandson said "Yeah," and she continued, "But you understand the principle that both sides have to balance," and she pointed out the challenges. Although the labels got her thinking and talking very quickly, the grandmother struggled to adjust her approach to meet the needs of her grandson, who struggled a bit. As the boy continued to use trial and error to balance the mobile, she said, "See, you can do this by guess, or you can do this by the numbers, the algebra problem," pointing at the parent panel and talking about how "1 times 6 is equal, the same as 2 times 3." In this case the parent panel succeeded with the caregiver but, for uncertain reasons, the child was not ready or able to follow her. The grandmother worked through several more challenges with her grandson. For his final challenge, the grandmother totaled the weight on one side of the beam. "You have 3, 3, and 3. 9 times 4 is…" The boy took over the other side of the beam, swapping out weights until there were three 3 weights at the 4 position on that side. He said, "There, 9 and 9." Grandma said, "Good, you got it, that's great!" and they put the weights back in the bin.

Another "Balancing Art" group included a mother and her 10-year-old son (Figure 34). In some ways, they had a similar experience to the third group. The boy immediately started hanging weights on the beam, seemingly without much thought, saying, "This looks like it will be fun! I like this." The mother tried to get him

Figure 34. "Balancing Art": Algebraic thinking trajectory (mother and her 10-year-old son). P = parent, C = child

Mode of Engagement															
Generalize the relationship and articulate it							P			P	P		P	P	P
Generalize the relationship											C				
Apply numbers to a relationship (quantitative)								P	P C	C		P C	C		
Notice numbers					C		C	C						C	
Find a relationship (qualitative)		C		C		C P									C
Trial and error	C		C												
Observe phenomena															
Time (min):	0:11	0:18	0:32	0:41	1:05	1:18	1:42	2:09	2:18	2:25	5:25	6:12	8:10	10:10	12:20 end

Algebraic Thinking in Three Exhibits in Depth, cont'd.

to try some exhibit challenges, saying, "Do you see that there are little signs right here?" but having little impact on his actions at first. The mother discovered the parent panel early (at about 1:40), pointing it out to her son and reading part of it aloud. She exclaimed, "Oh, so it's like algebra! Balancing two sides of an equation. You have to think about weight and distance." She then spent the rest of the interaction subtly encouraging her independent-minded son to try some higher-level approaches to balancing the scale. She gradually helped him to use a quantitative approach as he tried a few exhibit challenges and balanced with a 3 weight at the 4 position on one side and a 4 weight at the 3 position on the other. But then the boy spent much of his time setting his own challenges, trying to balance weights in various combinations using simple quantitative rules about equal weights at equal distances from the pivot. At one point his mom asked, "Is it cheating when you're using the same side?" Then she stated, "If you match them on each side it's not as challenging." Toward the end of the engagement, the boy decided to balance the scale using every available weight. At that point, he shifted back to a qualitative approach.

Overall, at "Balancing Art," children took the lead at balancing the scale, but caregivers—because they stood back and read the parent panel—led or tried to lead their children through teaching behaviors. Based on the follow-up interviews, there were indications that the parent panels stimulated adults' *memories* of algebra, either from their own school days or from helping their children with their homework. Caregivers used a range of teaching strategies to help their children, but it sometimes took a while to help children try other approaches. In one case, the child clearly preferred to find his own ways to engage with the exhibit. It's also possible that the kinds of thinking required at this exhibit were beyond what some 10-year-olds could accomplish.

Algebraic Thinking in Three Exhibits in Depth, cont'd.

"Drawing in Motion"

At "Drawing in Motion," caregivers and children each controlled a slider and acted cooperatively to complete the challenges, so there was little opportunity for a parent to stand back and watch or read labels. A father and 12-year-old daughter (Figure 35) moved up through different modes in concert as they worked through the exhibit challenges—at least until they had to draw a diagonal line (at 2:40). At that point, the father explained, "Oh, OK, now we're both going to 9 at the same speed." Then, when it didn't work out, "You moved faster than I did, and you went farther." They completed the challenge anyway, and were rewarded as the computer program completed and colored the drawing of the hippo. Although this indicated that the father was engaged in generalizing the relationship, it took a bit more explanation before his daughter understood. With the father's supervision, they successfully drew several diagonal lines, including one where they had to move at different speeds. Continuing to lead, the father said, "I'm Y, and it says I have to move twice as fast as you…How about 1, 2, and I'll go 2 for every beat, OK? 1, 2, go, 3, 4, 5. How'd we do? Pretty good!" After the exhibit challenges were completed, the group switched to Free Draw mode (at 7:24 minutes) and drew a square spiral, which had no diagonal lines and shifted to applying numbers to the relationship. (For this dyad to have moved to "generalizing the relationships," they would have had to move beyond the practical aspects of drawing a particular diagonal line and talk about diagonals using more abstract terms such as slope and ratio.)

Figure 35. "Drawing in Motion": Algebraic thinking trajectory (father and his 12-year-old daughter). P = parent, C = child

Mode of Engagement						
Generalize the relationship and articulate it						
Generalize the relationship				P	P C	
Apply numbers to a relationship (quantitative)			P C	C		C P
Notice numbers						
Find a relationship (qualitative)		P C				
Trial and error	P C					
Observe phenomena						
Time (min):	0:33	1:45	2:02	2:40	3:40	7:24 end

Algebraic Thinking in Three Exhibits in Depth, cont'd.

Another group included a mother and a 10-year-old girl (Figure 36). Both contributed as they worked to figure out this exhibit. The girl first discovered the numbers (at 0:12), but did not figure out how to use them. The mom pushed some buttons until she reached a screen that showed the X and Y axis. Then she said, "Oh, I see, you get it? Like if you're going to draw that, you have to use the coordinates….'Cause you're the X, and I'm the Y." It took another minute or so for the mother to figure out how to draw cooperatively using "the numbers on the sliders," and with her help, the girl came to understand and at this point she shifted to applying numbers to the relationship (at 2:20 minutes). By taking turns moving from point to point they completed four exhibit challenges, though they never figured out that they were supposed to draw diagonal lines between some points (the computer program rewarded their efforts regardless of how they connected the points).

Figure 36. Drawing in Motion: Algebraic thinking trajectory (mother and her 10-year-old daughter). P = parent, C = child

Mode of Engagement						
Generalize the relationship and articulate it						
Generalize the relationship						
Apply numbers to a relationship (quantitative)				P	P C	P C
Notice numbers		C				
Find a relationship (qualitative)						
Trial and error	P	P	P C	C		
Observe phenomena						
Time (min):	0:08	0:12	0:40	1:03	2:20	5:10 end

Algebraic Thinking in Three Exhibits in Depth, cont'd.

Another group (Figure 37), a mother and her 10-year-old son, had a similar experience to that of the previous group, moving to and continuing to use a qualitative approach. The mother took the lead, and the child mostly followed along as told (correcting the parent once when she made a mistake). There was minimal conversation, and while the mother directed the interaction, she did not engage in any teaching/coaching behavior. For the first couple of minutes they did not refer to the numbers on the sliders or coordinates.

The mom mostly said things like, "OK, try to go this way. Yeah, over towards this way," waving with her hands. When they started challenge 2, the mom started pointing out the numbers and used them to direct their actions. "So you're going to go over 5 and up 5 is what you want to do." Thus the mother shifted to a quantitative approach, and with her help the child began to notice the numbers. Like the previous group, this group never figured out that they should move their sliders at the same time to draw diagonal lines.

Figure 37. "Drawing in Motion": Algebraic thinking trajectory (mother and her 10-year-old son). P = parent, C = child

Mode of Engagement	Generalize the relationship and articulate it							
	Generalize the relationship							
	Apply numbers to a relationship (quantitative)				P	P		
	Notice numbers			P		C	P C	P C
	Find a relationship (qualitative)	P	P C	C	C			
	Trial and error	C						
	Observe phenomena							
	Time (min):	0:13	1:55	2:48	3:00	3:07	4:02	4:45 (end)

Algebraic Thinking in Three Exhibits in Depth, cont'd.

In the following group (Figure 38), a grandfather guided his 11-year-old grandson. The grandfather read both the text on the screen and the parent panel as they worked to figure out the exhibit. The boy, on the Y slider, asked "What's straight up and down?" Then he moved his slider. "Oh, I'm sideways." At about 2:00, they had figured out how to use the sliders for the exhibit challenges they undertook. They first tried to draw a star, with the grandfather calling out numbers they should try to reach (but without drawing diagonal lines at first). Taking on challenge 1, the grandfather figured out, "This is one where you have to work together." They worked their way through the four challenges, using hints on the screen to draw diagonal lines. Then they completed a series of free draw challenges including the heart. At this point the group shifted back and forth between applying numbers to the relationship and generalizing the relationship several times as they tried the simpler challenges, even coming up with their own (this group did not discuss their slope-drawing activities in abstract terms).

Overall, the dyads using "Drawing in Motion" were somewhat less successful in shifting into generalizing and articulating relationships. We noted two interesting factors that likely played a role.

First, only one of the four "Drawing in Motion" adults noticed and read the parent panel, which introduced the concept of slope and hinted at how to draw lines with different slopes. The parent who did read the panel led his child in a fairly successful engagement. The two parents who never figured out

Figure 38. "Drawing in Motion": Algebraic thinking trajectory (grandfather and his 11-year-old grandson). P = grandparent, C = child

Mode of Engagement													
Generalize the relationship and articulate it													
Generalize the relationship					P	P C		P	P C		P	P C	P C
Apply numbers to a relationship (quantitative)			P	P C	C		P C	C		P C	C		
Notice numbers													
Find a relationship (qualitative)			C										
Trial and error		C P											
Observe phenomena	C												
Time (min):	0:57	1:30	2:00	3:08	4:07	4:23	4:48	5:18	5:49	7:32	10:53	13:01	14:52 end

Algebraic Thinking in Three Exhibits in Depth, cont'd.

how to draw diagonal lines did not appear to notice or read the parent panel during their engagement. Generally, caregivers were as engaged with the physical experience as their children, never getting a chance to stand back and contemplate what their children were doing, as parents did at "Balancing Art."

Second, visitors were rewarded with the animation no matter how they connected the coordinate points. They did not even have to attempt drawing a diagonal line for the higher-level challenges to get the reward. It appears that the exhibit's feedback did not help support visitors in generalizing relationships.

Algebraic Thinking in Three Exhibits in Depth, cont'd.

"Slide-a-Phone"

"Slide-a-Phone" provided an interesting contrast to the other two exhibits. Some groups used the same problem-solving mode for nearly their entire engagement, and one group never engaged in a quantitative mode. Only one group generalized the relationship and only did so during the final minute of their engagement. We examine these groups' engagements below to try to understand why.

In a group consisting of a mother and son (Figure 39), the 12-year-old child started with a trial and error approach. Then at 0:41, the mother read the parent panel and subsequently shifted to qualitative modes of engagement. She read the panel aloud to her son, "It says, the longer the tube the lower the pitch, the shorter the tube the higher the pitch. But you already know that." This helped him to approach the challenge qualitatively. They looked at the sheet music graph (challenge card), and the mother said, "So this is what they have set up, is the length of the tube, and the…," pointing at the axes on the graph. Then she realized, "You can play a song, that's what it's supposed to be." So they played one song together, positioning the tube using numbers but not saying them out loud. The boy recognized the song as "Twinkle, Twinkle, Little Star" before they even played it, which the mother questioned. Once they played the song the mother agreed it was "Twinkle, Twinkle," and they were ready to move on, as the child commented that the exhibit was "kinda boring."

Figure 39. "Slide-a-Phone": Algebraic thinking trajectory (mother and her 12-year-old son). P = parent, C = child

Mode of Engagement	Generalize the relationship and articulate it					
	Generalize the relationship					
	Apply numbers to a relationship (quantitative)					
	Notice numbers					
	Find a relationship (qualitative)			P	P C	P C
	Trial and error		C	C		
	Observe phenomena					
	Time (min):	0:17	0:26	0:41	1:12	2:00 end

Algebraic Thinking in Three Exhibits in Depth, cont'd.

The following "Slide-a-Phone" group consisted of a father and his 10-year-old son (Figure 40). The child indicated he was familiar with the length-pitch relationship and almost immediately recognized that it applied here. He slid the tube far to the right, shortening the tube, and said, "I'm thinking we should move this to the lowest pitch we can get. 'Cause I'm a fan of low pitches." So, the boy started his engagement qualitatively and, once they figured out the sheet music graph, quickly shifted to a more quantitative approach, positioning the tube based on the lengths marked on the notes, and for the last song, hitting the drum once for each note. Because he positioned notes based on color, the father continued to use a more qualitative approach for most of the group's engagement. Around 5:00, the father noticed the parent panel, which described the sheet music as a graph. He read the label out loud, asking his son, "You do graphs in school, right?" This gave both parent and child a new way of thinking and talking about what they had been doing, and they consequently shifted to generalizing the relationship right at the end of their engagement. As they finished up, the dad asked, "So what do you think?" The son said "I think it's pretty clever," but he did not want a "Slide-a-Phone" for his room.

Two other groups at "Slide-a-Phone," on the other hand, engaged with the exhibit at the initial mode in which they began their interactions:

- A father and 10-year-old daughter began the engagement using a qualitative approach and used that for the duration of their engagement. The parent read the directions label as they began their interactions.

Figure 40. "Slide-a-Phone": Algebraic thinking trajectory (father and his 10-year-old son). P = parent, C = child

Mode of Engagement							
Generalize the relationship and articulate it							
Generalize the relationship						P C	P C
Apply numbers to a relationship (quantitative)		C	C	C	C		
Notice numbers				P			
Find a relationship (qualitative)	C		P		P		
Trial and error							
Observe phenomena							
Time (min):	0:20	1:14	1:40	3:21	3:33	5:40	6:11 end

Algebraic Thinking in Three Exhibits in Depth, cont'd.

The father and daughter played the sheet music using the *colors* of the notes to find the matching tube position.

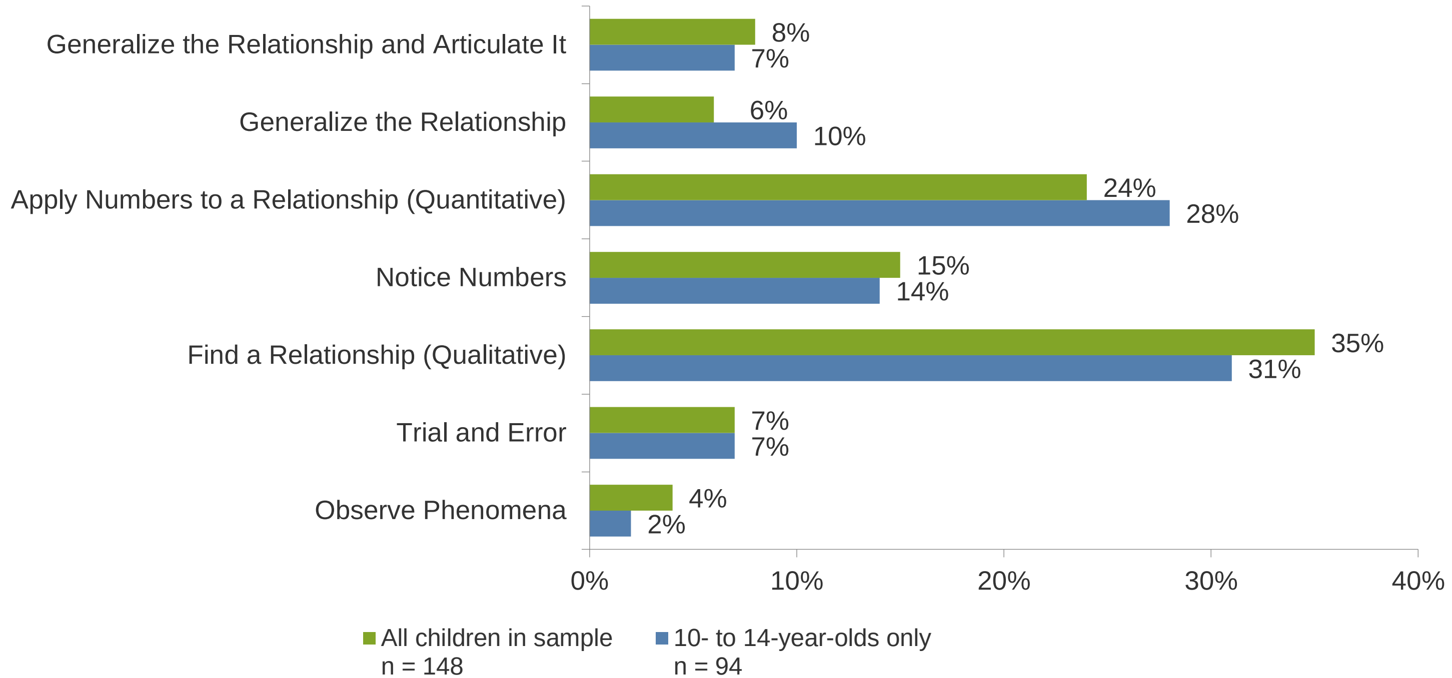
- In another group, a mother and her 10-year-old daughter read the parent panel together as they began their engagement. The parent matched the numbers on the notes to the numbers on the tube, but did not pay much attention to the meaning of the numbers. She and the child used this mode of engagement for the entire time.

In general, the dyads at "Slide-a-Phone" used primarily a qualitative approach. The use of colored notes and tube positions gave visitors a chance to discover a qualitative rule, but it was a sort of dead end; this rule did not inspire further thinking about either the length-pitch relationship or the graph-like nature of the sheet music. The colored notes did allow younger visitors to play the music even if they couldn't read the numbers, but that came at a cost in terms of the potential for algebraic thinking by older children.

Algebraic Thinking among General Visitors

To determine the general patterns of engagement with algebraic reasoning in a larger visitor sample, we coded structured observation data (triangulated with follow-up interviews), using the same modes of engagement developed for the video case studies. We found that 90% of children in the target age range at the exhibits (and 88% of children in the entire sample) engaged in algebraic reasoning. Some 42% engaged quantitatively and another 17% moved to abstract thinking (Figure 41). Notice that nearly a third (28%) of children in the target age range approached the challenges quantitatively.

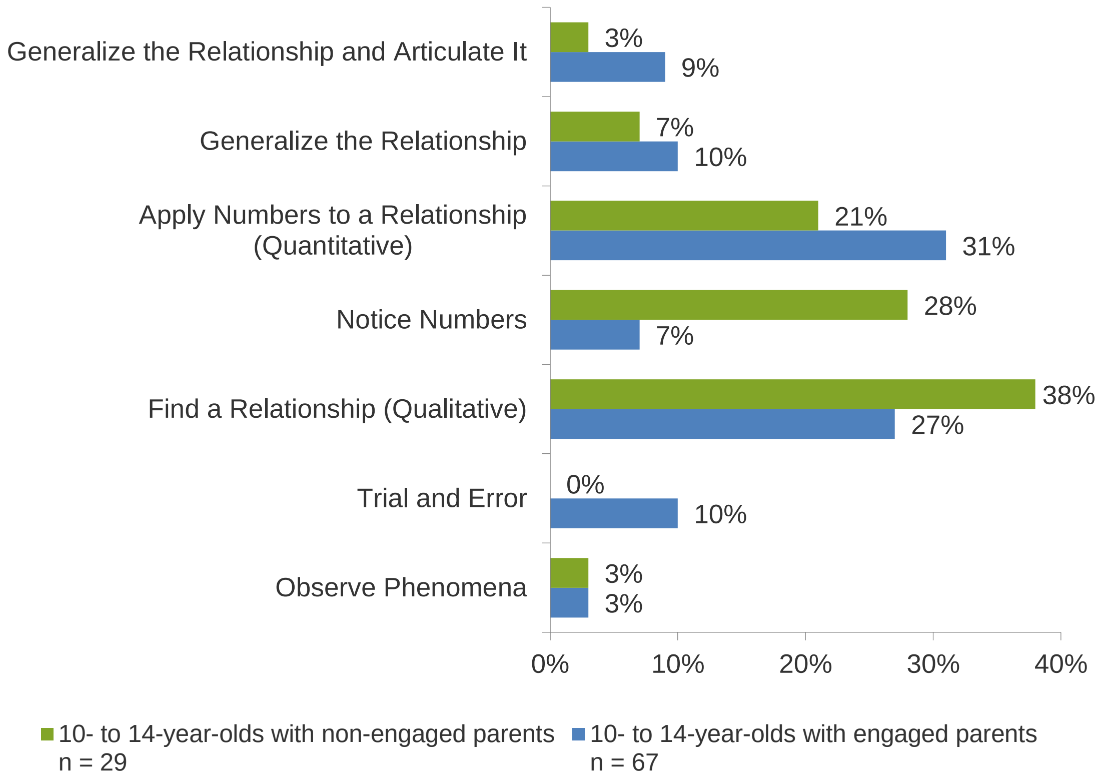
Figure 41. Algebraic thinking: Modes of engagement



Parent Role in Algebraic Thinking

Structured observations revealed that about one-third of parents were unengaged during their interactions at the exhibit at which we observed them. (Keep in mind, of course, that how engaged a parent can be will vary based on the age of their children and from exhibit to exhibit.) Given that the video case studies indicated that adults played a role in helping children move toward more sophisticated modes of engagement, we also examined how this dynamic played out in the larger visitor sample. We disaggregated data for groups with children in the target age range by comparing those with “engaged parents” to those where the parent was not engaged at the time we observed them. Although the sample sizes are small, the data suggest that parental involvement did make a difference (Figure 42). When parents were engaged, 50% of children engaged in algebraic thinking using a quantitative approach or even generalizing relationships. When parents were not engaged, only 31% of children used those modes of algebraic thinking.

Figure 42. Algebraic thinking: Modes of engagement comparison of children with engaged and non-engaged parents.



Additional Factors Affecting Algebraic Thinking

Although parental engagement was clearly important, we also identified certain aspects of the exhibits themselves that contributed to how children engaged in algebraic thinking. First, some exhibits seemed to support more abstract levels of thinking than others. “Fast Tracks,” for instance, provided wonderful opportunities for visitors to discover a basic relationship—steeper slope results in greater ball speed—and allowed visitors to measure one side of the relationship: ball speed. The labels, however, did not support taking this relationship to more abstract levels by, for example, graphing the results.

Second, some exhibits provided visitors with a qualitative “shortcut” that meant they did not have to use the quantitative tools provided. For example, three exhibits allowed visitors to use colors instead of numbers to meet their challenges (colored dots on the sheet music and tubes at “Slide-a-Phone” and “Whack-a-Phone” and the colored dots on the ramp at “Roller Coaster Hills”). The use of colored notes at “Slide-a-Phone,” for instance, gave visitors a chance to discover a qualitative rule about the relationship between color and pitch but did not get visitors thinking more about either the length-pitch relationship or the graph-like nature of the sheet music.

Third, one exhibit, “Drawing in Motion,” rewarded visitors with an animation even if they did not attempt to draw a diagonal line. In those cases, the exhibit’s feedback did not seem to support visitors’ movement towards generalizing the relationship (slope).

Fourth, despite the important role that the parent panel could play in guiding visitors’ algebraic thinking, the placement of that panel sometimes made it harder for parents and children to notice them. It may have been more effective to embed some of the key algebraic ideas and phrases more explicitly in the challenge labels, directions, and on-screen hints. In a traveling exhibition where configurations may shift and panels may be placed in different locations from those originally intended, this may become even more important.

Impacts Summary

All four impacts were met. Twelve indicators were met, three were not met (two came close), and one indicator (1-3) seemed to apply only to some types of exhibits, making it difficult to obtain large enough sample sizes to measure this indicator (Tables 8–11).

Table 8. Impact 1: The target audience of youth 10–14 and their families will use algebraic thinking skills

Indicators	Evidence of Indicator
1. During the visit, 70% of the target audience will discover various functional relationships/rules at exhibits as demonstrated by their use of the relationship/rule (to make a prediction, explore relationships, etc.).	90% of youth in the target age range (and 88% of children in the entire sample) engaged in algebraic thinking. All forms of reasoning beginning at the qualitative level in visitors' modes of engagement are based on using relationships/rules.
2. During the visit, 60% of the target audience will be able to describe the relationships/rules encountered (words, images, models, tables, graphics, equations, etc.).	83% of children in the 10−14 age range described or used a relationship/rule or pattern during their engagement (often qualitatively).
3. During the visit, 50% of the target audience will be able to create a rule of their own that they can use to extend or create a pattern or other transformations with objects and/or numbers.	This indicator applies to certain types of exhibits, such as "Build-a-Wall" (extending patterns with blocks) where visitors have leeway to create in ways that are not possible at many other exhibits. As the exhibit concept evolved from the early stages to final design this indicator seems to be less important for assessing Impact 1 and is, perhaps, more of a holdover from earlier stages of the process. While we noted examples of visitors extending patterns at the blocks exhibits, the sample size for children in the target age range at those exhibits was too small to provide a reliable quantitative measure.
4. During the visit, the average dwell time of the target audience at a component will be 2 minutes.	The mean dwell time of 4:33 exceeded the NSF indicator target of 2 minutes. Children in the 10−14 age range spent more time at the exhibits than the overall sample (mean of 6:30), which, depending on the group's configuration, could also include children younger than the target age range.
5. Demographic use of the exhibit will mirror general museum demographics.	Demographics vary from museum to museum, meaning that this indicator can only be broadly generalized. The randomized sample obtained via exit surveys indicated visitors to *Design Zone* reflected the general science museum-going population. 84% of visitors surveyed came in family groups. There was a broad distribution of age ranges: more than half (58%) the families reported having children 6–9 years old in their group and more than a third (37%) reported having children in the target 10–14 age range in their group. One third (33%) of visitors indicated they had been to the museum before. 81% identified as Caucasian.

Impacts Summary, cont'd.

Table 9. Impact 2: The target audience of youth 10–14 and their families will have enjoyable and memorable experiences with algebra/math

Indicators	Evidence of Indicator
1. During the visit, a majority of the target audience (51%) will report they found their experience at the exhibit enjoyable.	95% of groups rated their enjoyment at the exhibit as a 3 or 4 on a 1–4 scale. Those groups with children 10–14 years old provided slightly higher ratings (97%).
2. During the visit, a majority of the target audience (51% or more) will feel challenged, but successful.	74% of groups with children 10–14 years old agreed or agreed strongly (ratings of 3 or 4 on a 1–4 scale) that the exhibits were challenging, but they successfully figured them out. 68% of all groups provided 3 or 4 ratings.
3. During the visit, 60% of the target audience will use math tools provided.	On average, at individual exhibits, 57% of groups in the total sample used the math tools provided. When data were disaggregated for groups with children in the 10–14 age range, 51% of children and 33% of adults used one or more of the math tools.
4. During the visit, 50% of the target audience will self-report awareness of the math/algebra involved in at least one of the activities they did.	51% of groups with children in the target age range agreed (providing 3 or 4 ratings on a 1–4 scale) that their group had used algebra in the exhibit. A larger percentage of groups with children ages 10–14 recognized doing math; 81% of groups agreed (providing 3 or 4 ratings on a 1–4 scale) that their group had used math in the exhibit.

Table 10. Impact 3: The target audience of youth 10−14 and their families will be aware that algebra is more than solving equations

Indicators	Evidence of Indicator
1. During the visit, 40% of the target audience will self-report awareness of doing algebra despite not solving equations.	43% of groups agreed (providing 3 or 4 ratings on a 1–4 scale) that their group had used algebra in the exhibit. Agreement ratings were higher (51%) for groups with children in the 10–14 age range. A larger percentage of visitors recognized doing math; 68% of groups agreed (providing 3 or 4 ratings on a 1–4 scale) that their group had used math in the exhibit.

Impacts Summary, cont'd.

Table 11. Impact 4: Groups of target audience members will feel comfortable engaging in algebra activities together

Indicators	Evidence of Indicator
1. During the visit, 70% of the target audience will ask questions.	43% of groups asked questions as part of their engagement at an exhibit. Adults tended to ask more questions than children.
2. During the visit, 50% of the target audience will answer questions.	43% of groups answered questions as part of their engagement at the exhibit. Children tended to answer more questions than adults (largely because adults did more of the asking).
3. During the visit, a majority of the target audience (51% or more) will talk to others in their group.	78% of children and 70% of adults talked with other members of their group. The conversation was not always between adults and children; children often engaged in conversations with other children in their group.
4. During the visit, a majority of the target audience (51% or more) will work cooperatively (sharing strategies, helping each other, etc.).	Cooperative behaviors, such as taking turns and working together, predominated the types of interactions among groups. 61% of children in target age groups (and 41% of the adults) engaged in cooperative behaviors.
5. During the visit, 60% of the target audience will report feeling comfortable in their overall experience at the exhibit.	81% of groups rated their comfort 3 or 4 on a 1–4 scale. Comfort ratings were higher (94%) for groups with children in the 10–14 age range.

Conclusions and Recommendations

Conclusions

It's clear that *Design Zone* provided a challenging, yet successful, comfortable, and enjoyable experience for a cross-section of visitors (not just those included in the target audience). Most of them remembered doing math in the exhibit, and about half remembered encountering algebra—but this recognition did not diminish their enjoyment of the experience. Enjoyment ratings were high (95%).

Visitors spent significant time at *Design Zone* and actively engaged with the exhibits and with others in their group. Children took an active role, engaging directly with exhibits, and parents often took on the role of guide/teacher. Groups enthusiastically tried out challenges, with the majority (89%) attempting at least one challenge. We observed a range of behaviors, but cooperative ones predominated with those in the group working together to try to successfully complete a challenge.

Video data illustrated the rich interactions that can take place when parents and children engage together. The range of teaching and leadership demonstrated by these parents was particularly impressive.

In the larger sample, 40% of parents also took on the guide/teacher role for at least part of the engagement. The data suggest that parents' teaching can lead their children towards more sophisticated levels of algebraic thinking.

Design Zone successfully engaged visitors in algebraic thinking. Using the modes of engagement coding developed to map ways visitors engaged in algebraic thinking, most (90%) successfully engaged at least through qualitative approaches, with a healthy percentage (42%) of those in the target range engaging quantitatively and another 17% beginning to generalize relationships. While few explicitly articulated these relationships, the exhibition nonetheless successfully induced children to engage in thinking about key relationships—what they had to change to meet a challenge and the way they had to change it.

Visitors recognized connections to both their everyday worlds and to school-based learning. Interestingly, the connections to the everyday world were often physical analogies to the exhibits, whereas the connections to schools were more often about math and algebra.

Design Zone, overall, provided successful and enjoyable experiences for visitors and met the goals for the project. Perhaps the major challenge remaining for the project and the informal math education field is to find more effective ways to guide visitors toward more quantitative and, ultimately, more abstract ways of engaging in algebraic thinking on the exhibition floor.

Recommendations

- Recognize the complexity even of qualitative relationships, and make sure the ones that most visitors discover and use are going to be functional relationships that can be quantified. That may mean avoiding situations like the colored notes at “Slide-a-Phone,” which let visitors complete the challenge by simple matching without thinking much about the relationship between length and pitch.

- Provide visitors with the tools to measure both sides of a simple relationship between variables. “Fast Tracks,” for instance, provided wonderful opportunities for visitors to discover a basic relationship—steeper slope results in greater ball speed—but allowed visitors to measure only one side of the relationship (ball speed). Is there some way to allow visitors to measure and graph ramp steepness as well as ball speed?

- Continue to refine the mathematical tools that show relationships to make them even more integral to visitors’ success and to make sure visitors are rewarded when they use them. For instance, the sticky pivot at “Balancing Art” sometimes threw respondents off course as they tried to balance the equations shown on the labels; visitors got it right, but the scale still looked off balance. In another example, “Drawing in Motion” rewarded visitors even when they did not try to draw a diagonal line.

- Although parent panels effectively guided many visitors toward higher levels of algebraic thinking, the placement of these panels sometimes made them harder to notice them. Ideally the panels should be placed where parents standing a bit behind their children can notice and read them without moving (which did not happen with some of the recent installations of “Balancing Art”). When parents are going to deeply engage with the exhibit challenges alongside their children, it may be more effective to embed key algebraic ideas and phrases more explicitly in the challenge labels, directions, and on-screen hints.

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Appendices

Appendix A: Exit Survey Respondent Profile

Respondents by Gender

	Pacific Science Center	Franklin Institute
Male	47%	49%
Female	53%	51%

Respondents with Children in Group

	Pacific Science Center	Franklin Institute
Groups with children	**85%**	**76%**
5 or younger	38%	47%
6 to 9 years	62%	55%
10 to 14 years	40%	35%
15 to 17 years	12%	5%
18 or older	6%	3%

Respondents' Prior Visitation

	Pacific Science Center	Franklin Institute
Visited museum before	75%	62%
Were museum members	58%	37%
Visited with family	89%	82%

Respondents by Race/Ethnicity (self-identified)

	Pacific Science Center	Franklin Institute
African-American	3%	9%
Caucasian	80%	81%
Asian/Pacific Islander	17%	8%
Hispanic/Latino	3%	5%
Native American	1%	0%
Other	11%	5%

Appendix B: Video Study Respondents

Exhibit	Adult Gender	Adult Age (years)	Adult Race/ Ethnicity	Adult Highest Education	Child Gender	Child Age (years)	Child Grade	Child Race/ Ethnicity (as identified by adult)
Balancing Art	Female	Declined	Caucasian	Some college education	Female	10	4th	Caucasian
	Female	49	Caucasian	College graduate	Female	12	5th	Caucasian
	Female	Declined	Caucasian	College graduate	Male	11	5th	Declined
	Female	47	Caucasian	Postgraduate degree	Male	10	4th	Caucasian
Drawing in Motion	Female	33	African-American	College graduate	Male	10	4th	African-American/ Hispanic-Latino
	Male	54	Caucasian	Postgraduate degree	Female	12	7th	Caucasian
	Female	19	Hispanic/ Latino	Some college education	Female	10	5th	Hispanic/Latino
	Male	60	Caucasian	Some college education	Male	11	5th	Caucasian
Slide-a-Phone	Male	34	Caucasian	College graduate	Female	10	4th	Caucasian
	Female	40	Hispanic/ Latino	College graduate	Female	11	5th	Hispanic/Latino
	Female	36	Caucasian	Some college education	Male	12	7th	Caucasian
	Male	51	Caucasian	Some postgraduate education	Male	10	4th	Caucasian

Appendix C: Observations—Child Respondent Profile

Gender of Designated Child

	OMSI	Pacific Science Center	Franklin Institute
Male	54%	52%	58%
Female	46%	48%	42%

Age of Designated Child

	OMSI	Pacific Science Center	Franklin Institute
5 to 9 years	50%	33%	25%
10 to 14 years	47%	59%	71%
15 to 18 years	3%	7%	4%