Access Algebra *Staff Facilitation*
A Formative Evaluation Report

Prepared for

OMSI
OREGON MUSEUM OF SCIENCE AND INDUSTRY

by
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EXECUTIVE SUMMARY

This report describes the formative evaluation study conducted at the Oregon Museum of Science and Industry (OMSI) to inform the development of the *Access Algebra* professional development programs and materials. *Access Algebra* is a five-year, NSF-funded project led by OMSI. The project will create a 5000 ft.² traveling exhibition designed to engage visitors and, in particular, 10- to 14-year-olds and their families with the topic of algebra.

The overall goal of the evaluation was to help the project team identify promising strategies for staff to facilitate visitor learning in the exhibition. To this end, the study focused on three evaluation questions:

1. Which staff facilitation strategies successfully promote prolonged, mathematical, visitor-driven engagement?
2. Are specific strategies more or less successful with different types of visitor groups?
3. What are examples of successful facilitation strategies?

Key Evaluation Findings

- Staff members having a positive impact on visitor experiences, including engagement times, levels of math talk, and visitor satisfaction.

- All four facilitation strategy types (orienting, posing challenges, promoting math talk, and supporting visitor interactions) were related to increased visitor engagement times and levels of math talk. The team identified strategies from each category that worked well across the majority of prototypes.

- Visitors indicated that they appreciated the balance between staff guidance and providing visitors space to explore the exhibits on their own.

- Facilitation at the "Balancing Art" and "Downhill Race" prototypes was particularly successful at fostering long engagement times and high levels of math talk.

- General and specific relationship talk were the least common categories of math talk exhibited by visitor groups. The team may want to consider developing more strategies for promoting specific and general relationship talk. One promising approach is for staff to use a broader range of facilitation strategy types.

- Promoting math talk was the most challenging of the four strategy categories for staff. This strategy category could be reserved for more advanced facilitators.

ACKNOWLEDGMENTS

THIS IS A FORMATIVE EVALUATION REPORT
Formative evaluation studies like this one often:
- **are conducted quickly**, which may mean
  - small sample sizes
  - expedited analyses
  - brief reports

- **look at an earlier version** of the exhibit/program, which may mean
  - a focus on problems and solutions, rather than successes
  - a change in form or title of the final exhibit/program

INTRODUCTION

This report describes the formative evaluation study conducted at the Oregon Museum of Science and Industry (OMSI) to inform the development of the *Access Algebra* professional development programs and materials. *Access Algebra* is a five-year, NSF-funded project led by OMSI. The project will create a 5000 square foot traveling exhibition designed to engage visitors and, in particular, 10- to 14-year-olds and their families with the topic of algebra. The exhibition will use creative design challenges in the context of music, art, and engineering to foster algebraic thinking—a type of mathematical inquiry.

The project also includes a substantial professional development component to support museum educators and volunteers facilitating informal math learning experiences for visitors in the exhibition. OMSI will provide training to staff members as the exhibition tours museums across the country. The overarching goal of these trainings will be to prepare museum educators and volunteers to facilitate informal learning experiences for visitors within the exhibition and support the overall learning goals of the exhibit activities. At the time this evaluation study was conducted, the project team had outlined three goals for staff facilitation: (1) staff will facilitate a deeper level of visitor engagement with the exhibits (prolonged engagement), (2) staff will promote algebraic thinking at the exhibits (mathematical engagement), and (3) staff will support visitor agendas and roles (visitor-driven engagement).

Evaluation Focus

The overall purpose of the evaluation was to help the project team identify staff facilitation strategies that support the goals outlined above. To this end, the study focused on three evaluation questions:

1. Which staff facilitation strategies successfully promote prolonged, mathematical, visitor-driven engagement?
2. Are specific strategies more or less successful with different types of visitor groups?
3. What are examples of successful facilitation strategies?

The evaluation study built on prior project evaluations, including prototype testing with visitors and prototype testing with museum education staff and visitors. In previous evaluations with museum education staff, the primary focus was to determine how well the design of the exhibits supported interactions between staff and visitors. In contrast, the focus of this study was to understand the types of strategies staff could use to facilitate visitor learning.

In addition to answering the questions outlined above, the study was also an opportunity for the team to further refine its framework for describing algebraic thinking and math talk at exhibits and to explore methods for assessing math learning. At the end of the report, we discuss the benefits and limitations of the study methods for assessing math learning at exhibits.

Theoretical Perspective

The project team's approach to staff facilitation has built on a sociocultural perspective of learning in free-choice environments (e.g., Ellenbogen, Luke, & Dierking, 2007; Falk & Dierking, 2000). This perspective emphasizes the social processes of learning, the learning strategies that groups bring with them to these environments, and the roles, identities, and agendas that influence the outcomes of the experiences. An important assumption underlying the teams approach to facilitation and professional development has been that supporting visitor learning strategies and being responsive to visitor roles and agendas will lead to richer, more satisfying visitor learning experiences in the exhibition.

METHODS

We evaluated staff facilitation at four different prototypes: "Balancing Art," "Drawing in Motion," "Downhill Race," and "Digital Strings." Each prototype was tested on two separate days. The first day with the "Balancing Art" prototype was used to pilot test the instruments and study protocol. Significant changes to both the protocol and instruments were made following this test, therefore only data from the second day were used in the final analysis. The evaluation included observation of staff-visitor interactions, debriefs with staff after each interaction, post-interaction interviews with families, and a group debrief at the end of each day of prototyping. Each of these methods is described in more detail below.

Two educators were present whenever possible during the prototyping and traded off facilitating visitor interactions. Throughout the day, educators often suggested new strategies and participated in the staff debriefs (see below). Both educators were paid staff with considerable experience facilitating visitor learning at OMSI. Both had also received training from the project team on facilitating visitor learning at the exhibit prototypes. The goal of using highly experienced educators was to focus on testing the facilitation strategies, rather than the experience level of the staff members. We made an effort to balance the number of interactions observed for each educator. However, this was not always possible. For example, with the "Downhill Race" prototype, one of the educators represented 70% of the observed interactions with visitors.

Observation
During the prototyping, at least one evaluator observed interactions between staff and visitors and took open-ended notes, paying particular attention to the strategies that staff members used, family dynamics, and visitor and staff math talk. The evaluator also tracked the length of the interactions, from the moment that one group member touched the exhibit or paid attention for at least five seconds to when the last group member left the exhibit. At the end of the interactions, the evaluator also noted the level of group engagement, the degree of visitor versus staff talk, and the degree of visitor versus staff facilitation. On days when a second evaluator was present to conduct family interviews, this individual also rated interactions along these three measures. Only visitor groups with which a staff member interacted were included in the analysis. A sample observation form is attached in Appendix A.

Staff debriefs
At the end of each interaction, the educator and evaluator filled out the staff debrief form. Staff noted whether or not they had heard any instances of each of the four math talk categories (features, strategies, specific relationships, and general relationships) and documented specific examples and visitor quotes. They also discussed which facilitation strategies the educator had used during the interaction (orienting, posing challenges, promoting math talk, and supporting visitor interactions) and whether or not those strategies had been successful at promoting prolonged, mathematical, visitor-driven engagement. Other evaluators or educators present during the prototyping were welcome to participate in the staff debriefs. The second educator was asked not to begin a new interaction with visitors until the debrief had finished, although interactions did occasionally overlap. The debrief instrument is included in Appendix B.

Family interviews
During one day for each of the four prototypes, a second evaluator also observed the staff-visitor interactions and interviewed visitor groups immediately after the interaction had ended. The evaluator spoke with the visitor who had been most involved with facilitating group learning during the interaction, based on his or her own observations. The interviews consisted of several open-ended questions prompting visitors to discuss their perceptions of the staff facilitation and talk about which strategies they had found more or less helpful. The interview instrument is included in Appendix C.

Group debriefs
At the end of each day, educators and evaluators, as well as any program development staff that were present during the day, debriefed about the prototyping overall. This was an informal discussion facilitated by the lead evaluator. The group discussed successful and unsuccessful examples for each strategy category. After the first day of testing with each prototype, the program development team summarized the group debrief notes in the form of an exhibit-specific strategies matrix. During the debrief at the end of the second day of testing, the group focused on revising and finalizing this matrix. Educators and evaluators used the observation and staff debrief notes to inform these discussions.

The final strategies matrix for each prototype is included in Appendix D. These represent an important product of the evaluation process but were not a part of the data analysis discussed below. Instead, we focused on analyzing the notes from the group debrief discussions and identifying facilitation strategies that the team felt had been successful across the majority of prototypes.

Data analysis

Quantitative data from the observations and staff debriefs were entered into SPSS and used to generate descriptive statistics. Because the study was not designed to produce generalizable results or show causal connections, findings from the quantitative analysis should be viewed as preliminary and used to suggest potential avenues for future investigation.

Data from the family interviews and the group debriefs were analyzed qualitatively. Interview data was coded inductively (Charmaz, 2006) to identify important themes that emerged from visitor responses. Because there was considerable overlap in the types of responses visitors gave to each question, responses to all the questions were analyzed as a group, rather than separately. In the findings reported below, the frequency that themes appeared across the interviews is provided to show the relative importance of the themes, rather than to suggest that these findings can be generalized to a larger population (Morgan, 1993). We reviewed notes from the group debriefs to identify strategies that the team felt had been successful for at least three out of the four prototypes.

FINDINGS

Observations

We observed 83 visitor groups at four prototypes over the course of seven days. Table 1 describes the visitor groups that were observed at each prototype. The average group size was 3.3. The target age range (10- to 14-year-olds) was well represented in the sample. Evaluators estimated visitor ages by category (see observation instrument, Appendix A). Approximately 75% of observed groups included individuals estimated to be between 8 and 14 years old. Over a third of groups (35%) included visitors in the 12 to 14 age category. In general, visitor groups were similar across the four prototypes. "Downhill Race" included the most visitor groups with 12- to 14-year-olds (44%), while "Drawing in Motion" included the least (22%).

Table 1. *Characteristics of visitor groups observed at prototypes*

Characteristic	Balancing Art (n = 11)	Drawing (n = 23)	Downhill Race (n = 23)	Digital Strings (n = 26)	Total (n = 83)
Avg. group size	3.4	3.3	3.4	3.4	3.3
Groups with children 8–14	91%	65%	78%	73%	75%
Groups with children 12–14	36%	22%	44%	39%	35%

Note. Drawing = Drawing in Motion.
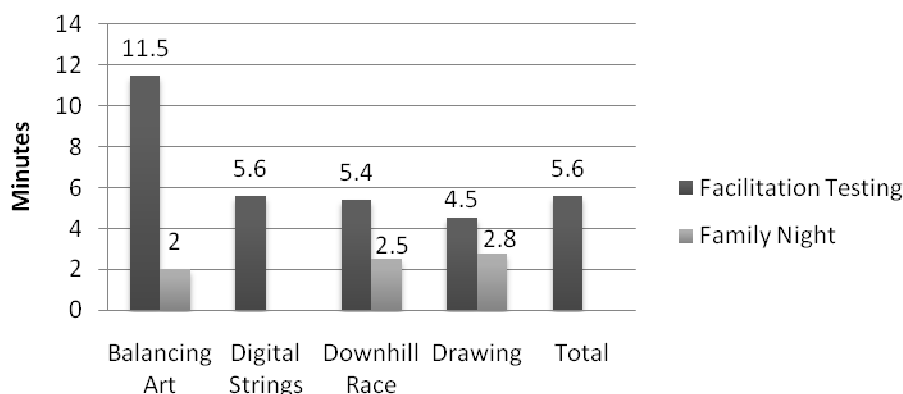
Engagement time
Evaluators tracked the length of each observed interaction. Timing began when the first visitor in a group touched the exhibit or paid attention to it for more than five seconds and ended when the last group member walked away from the prototype. Engagement times were not recorded for those groups that left the exhibit before staff had a chance to interact with them. Figure 1 shows the median engagement times for each prototype and all four prototypes combined. The median engagement time for the exhibits combined was 5.6 minutes. "Balancing Art" had by far the highest median engagement time (11.5 minutes), while "Drawing in Motion" had the lowest (4.5 minutes). The data did not suggest that testing date or time of week influenced engagement times. The "Balancing Art" exhibit is one of the most open ended of all the activities and may provide staff with a greater variety of opportunities and challenges to keep visitors engaged. The engagement times for all of the prototypes are long compared to other studies of interactive exhibits. For example, Humphrey and Gutwill (2005) reported average hold times of 3.3 minutes for "active, prolonged engagement" exhibits and 1.1 minutes for "planned discovery" exhibits.

Median Engagement Time
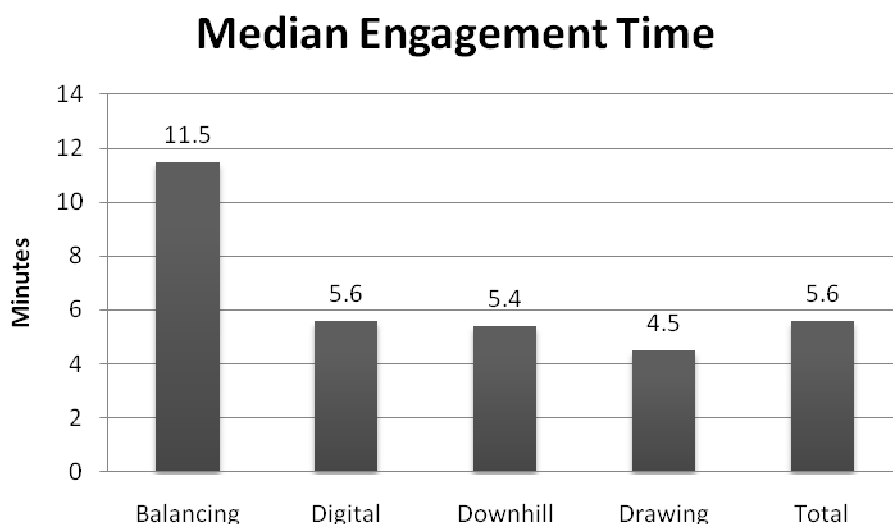
Figure 1. *Median visitor engagement times by prototype and for all four prototypes combined. Balancing* = Balancing Art. *Digital* = Digital Strings. *Downhill* = Downhill Race. *Drawing* = Drawing in Motion.

Figure 2 compares the median engagement times from this evaluation study to those recorded during the Family Night formative testing (Garibay Group, 2009). The prototypes were not facilitated by staff during Family Night. The "Digital Strings" exhibit was not built in time for Family Night, so no comparison could be made. Overall, engagement times were much higher for staff facilitated versus non-staff-facilitated prototyping. The difference was particularly pronounced with the "Balancing Art" prototype, indicating that this exhibit may benefit more from staff facilitation. As the Family Night report noted, longer engagement times may not always mean more learning or higher visitor satisfaction. However, the long engagement times at the facilitated prototypes do suggest the staff facilitation has the potential to foster deeper engagement with the exhibits.

Comparison of Median Engagement Times

Figure 2. Engagement times for facilitated prototypes compared to engagement times for non-staff-facilitated prototypes during the Family Night formative evaluation (Garibay Group, 2009).

Staff-visitor interactions

In order to capture the nature of interactions between visitors and staff, evaluators rated level of group engagement, visitor versus staff talk, and visitor versus staff facilitation, each on a seven-point scale. For level of group engagement, a higher number corresponded to a greater proportion of the group being actively engaged with the activity. For visitor versus staff talk, a higher number corresponded to visitors engaging in most of the talking. For visitor versus staff facilitation, a higher number corresponded to staff primarily leading the interaction. Each of these measures was then converted to a dichotomous variable, with scores of 4 to 7 coded as "high" and scores of 1 to 3 coded as "low." Because these measures were highly subjective, whenever a second evaluator was present during the prototyping, he or she also rated group engagement, talk, and facilitation. We were then able to calculate level of agreement based on 36, 33, and 35 instances of each of the three measures, respectively.

Table 2. *Visitor group engagement during staff-visitor interactions*

Engagement type	Evaluator 1	Evaluator 2	Agreement rate
High group engagement	90%	92%	95%
Primarily visitor talk	66%	71%	73%
Primarily visitor facilitation	41%	38%	72%

Note. All three measures of staff-visitor interactions were rated by evaluators on a seven-point scale and then converted to dichotomous variables. Agreement rate indicates the proportion of interactions rated the same by two evaluators for each measure.

Table 2 shows the percentage of groups that were rated as "high" for each measure by evaluator 1 and evaluator 2, as well as the agreement rate between the two evaluators. The agreement rate was calculated as the total number of groups for which the ratings by both evaluators matched (either both high or both low) divided by the total number of groups for which two observations were made. The agreement rate was high for all three measures and especially for group engagement (95%). Data from both evaluators also showed similar patterns for the three measures. For almost every group, group engagement was rated as high, indicating that staff members were successful at engaging the majority of visitors in most groups. Over two-thirds of groups were also rated as high in terms of visitor versus staff talk. In these interactions, the majority of talking was done by visitors, rather than by staff. Less than half of the interactions were rated as high in terms of visitor versus staff facilitation. In other words, in more than half of the interactions, staff played the primary facilitation role. Depending on whether or not these measures become an important part of the project team's goals for a successful staff-visitor interaction, the data indicate that staff can explore more ways to encourage visitor conversations and promote facilitation within visitor groups.

Median Hold Time and Staff-Visitor Interactions
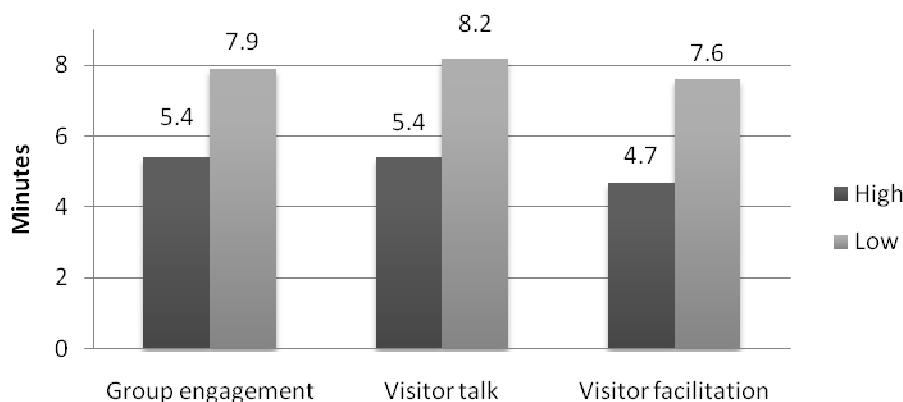
Figure 3. *Comparison of median engagement times by level of group engagement, visitor versus staff talk, and visitor versus staff facilitation.*

To explore how the nature of staff-visitor interactions related to hold times, we compared median hold times for low and high engagement groups, primarily visitor talk versus primarily staff talk groups, and primarily visitor facilitation versus primarily staff facilitation groups (Figure 3). The results were surprising and may indicate a need to think about the trade-offs of the current staff facilitation approach (however, see discussion of math talk below). Groups where the majority of group members engaged with the activity actually had a lower median hold time (5.4 minutes) compared to groups where less than half of group members were actively engaged (7.9 minutes). Interactions were visitors did the majority of the talking had lower median hold times (5.4 minutes) compared to interactions where staff did the majority of the talking (8.2 minutes). Finally, the median hold time was higher for groups when staff members were the primary facilitator (7.6 minutes) compared to when visitors were the primary facilitators (4.7 minutes).

Staff Debriefs

Math talk
As part of the staff debrief, evaluators and educators discussed whether or not they had heard any of the following four types of visitor math talk: features, strategies, specific relationships, or general relationships (see Appendix E for a detailed description of math talk categories). If either an evaluator or an educator noticed at least one instance of one of the math talk categories, that category was coded as being present in the interaction. The math talk categories evolved throughout the prototyping process, so results from this portion of the data collection should be seen as preliminary. "Prediction" was initially included as a separate category but was later dropped because of how rarely visitors verbalized their predictions. We did not include this category in the data analysis.

After several rounds of data collection, it was decided by the project team that strategy, specific relationship, and general relationship talk always included feature talk, since each of these three math talk categories necessarily involved mathematical features of the exhibit. For this reason, data from previous prototyping that was coded as having one of these three math talk categories but not feature talk was re-coded to include feature talk.

Table 3 shows the percentage of staff-facilitated interactions that included at least one of the four categories of math talk for each prototype and for all four prototypes combined. Because the evaluator was not always able to conduct staff debriefs after each interaction, the sample size for this analysis is slightly lower (n = 74). Overall, most of the facilitated interactions (85%) included at least one category of math talk. Math talk was most common at the "Downhill Race" prototype and least common and "Digital Strings." It is interesting to note that "Digital Strings" was not prototyped and was not initially selected as one of the facilitation-friendly exhibits.

Table 3. Frequency of visitor math talk

| Math talk	Balancing Art (n = 9)	Drawing (n = 25)	Downhill Race (n = 19)	Digital Strings (n = 21)	Total (n = 74)
Any	89%	91%	95%	72%	85%
Features	89%	91%	95%	72%	85%
Strategies	67%	81%	90%	56%	73%
Sp. relationship	67%	52%	74%	32%	53%
Gen. relationship	44%	0%	74%	32%	35%

Note. Drawing = Drawing in Motion; sp. relationship = specific relationships; gen. relationship = general relationships.

We also compared the frequency of each of the four math talk categories for each prototype and all four prototypes combined (Table 3). For all four prototypes combined, feature talk was the most common type of math talk (85%), followed by strategies (73%), specific relationships (53%), and general relationships (35%). The findings support other studies showing that concrete visitor talk related to features of the exhibit and how to use the exhibit is much more common than more abstract, conceptual talk (e.g., Allen, 2002). However, because specific and general relationships are an important part of the algebraic thinking goals of the exhibition, the project team might consider additional strategies that staff can use to promote these types of math talk.

Comparing across exhibits, the "Downhill Race" prototype had the highest percentage of groups coded for each of the four math talk categories. "Digital Strings" had the fewest number of groups with examples of feature, strategy, and specific relationship talk, while "Drawing in Motion" had the fewest examples of general relationship talk. It is notable that not a single group at the "Drawing in Motion" exhibit was coded as using general relationship math talk. This may indicate that the activity and staff facilitation strategies used at the exhibit are not optimal for promoting this type of talk or the current math talk rubric is not capturing general relationship talk specific to the exhibit.

To examine visitor math talk in more detail, we analyzed the number of math talk categories coded for each visitor group. Figure 4 shows the proportion of groups that exhibited none, one, two, three, or all four math talk categories. About 15% of groups were not coded for any of the math talk categories, while just over a quarter of groups (26%) engaged in all four types of math talk. Almost none of the groups were coded as only engaging in feature talk, calling into the question the utility of this math talk category. Analysis of average number of math talk categories by exhibit prototype confirmed the results discussed above. "Downhill Race" had the highest average number of coded math talk categories per group (3.3), followed by "Balancing Art" (2.7), "Drawing in Motion" (2.2), and "Digital Strings" (1.9).

Because the method for tracking and categorizing math talk in this study was different from the Family Night formative evaluation, comparisons were not possible.

Level of Math Talk
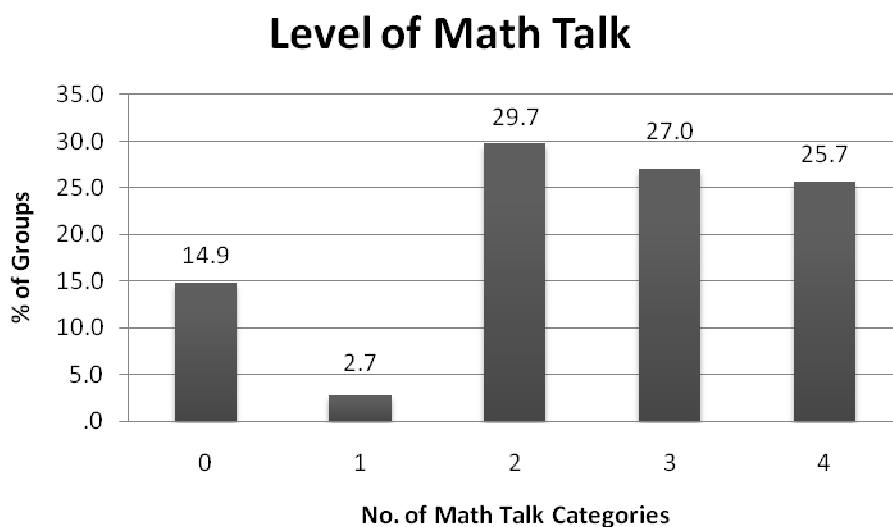
Figure 4. *Frequency of visitor groups coded for zero, one, two, three, or all four math talk categories. N = 74.*

We also compared median engagement times for groups that did and did not engage in math talk (Figure 5). Median hold times were higher for groups that engaged in at least one of the math talk categories (7 minutes) compared to groups that engaged in no math talk (2.9 minutes). This may be due to a variety of factors. Visitors that spend more time at exhibits may have more opportunities to engage in math talk. On the other hand, highly engaged visitor groups may be more likely to both spend longer at the exhibits and to engage in math talk.

Median Engagement Time and Math Talk
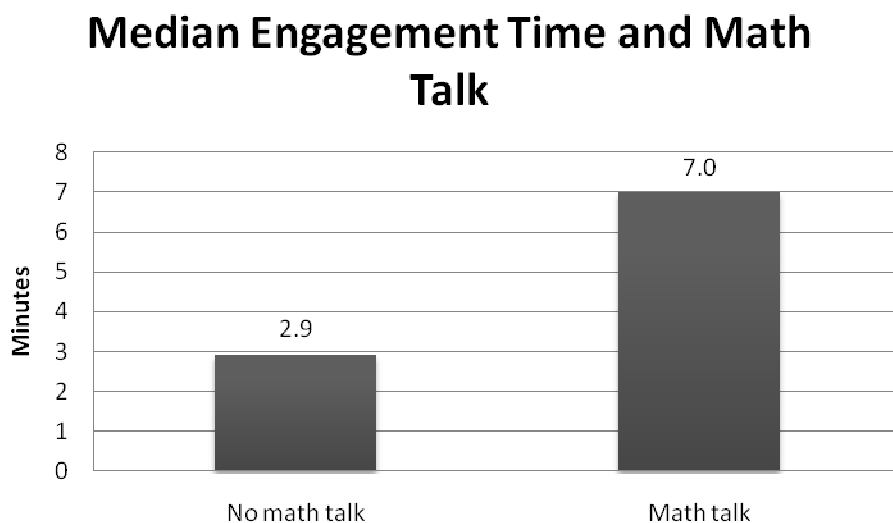
Figure 5. *Comparison of median engagement times for groups that did and did not engage in math talk.*

These results were confirmed by a finer grained analysis of engagement time and level of math talk (see Table 4). Groups that were coded for more math talk categories had higher average and median engagement times.

Table 4. *Average and median engagement times for visitor groups, by level of math talk*

| No. math talk categories | Engagement time (min) | | Sample size |
	Mean	Median	
0	5.4	2.9	11
1–2	6.6	4.7	24
3	8.0	7.1	19
4	11.1	10.3	19
Total	8.0	6.1	73

Note. Because only two visitor groups were coded for only one math talk category, this group was combined with the two math talk category.

There were almost no differences in levels of math talk by type of staff-visitor interaction, including group engagement level, visitor versus staff talk, and visitor versus staff facilitation. These results conflict with the findings that math talk was related to hold times (see Figure 5) and that group engagement time differed by type of staff-visitor interaction (see Figure 3). The data suggest that the link between staff-visitor dynamics and hold times is much weaker than the link between hold times and math talk. This is not surprising, since the measure of staff-visitor dynamics was exploratory and highly subjective. The team may want to explore the relationships between these variables more closely in the future and look for more precise measurements of group engagement, visitor versus staff talk, and visitor versus staff facilitation.

Facilitation strategies
During the staff debrief, evaluators and educators also discussed the strategies that staff had used to facilitate visitor interactions. The evaluator noted whether the staff had used strategies from any of the following four categories: orienting, posing challenges, promoting math talk, or supporting visitor interactions (see Appendix F for a description of facilitation strategies). These categories had been developed by the project team prior to the evaluation study and were intended to help the team develop exhibit-specific strategies that promoted prolonged, mathematical, visitor-driven engagement. During the debrief, the evaluator made note of specific strategies that educators had used, which categories the strategies represented, and whether or not the team felt the strategies had been successful. This portion of the debrief was used during the group debrief to identify strategies that had been successful across a variety of groups and, if possible, in what contexts those strategies had been successful.

Table 5. *Frequency that staff used facilitation strategy types*

Facilitation strategies	Balancing Art (n = 9)	Drawing (n = 26)	Downhill Race (n = 19)	Digital Strings (n = 22)	Total (n = 74)
Orienting	78%	82%	95%	77%	83%
Challenging	78%	59%	63%	54%	61%
Math talk	11%	50%	79%	58%	55%
Supporting	67%	46%	37%	46%	46%

Note. *Drawing = Drawing in Motion; challenging = posing challenges; math talk = promoting math talk; supporting = supporting visitor interactions.*

Table 5 shows the relative frequency with which educators used each of the four types of strategies. Across all prototypes, orienting was the most common (83% of interactions), followed by posing challenges (61%), promoting math talk (55%), and supporting visitor interactions (46%). A variety of factors could influence how frequently each of these types of strategies was used. For example, staff may not have felt that certain types of strategies were not always appropriate or the team may not have developed as many exhibit-specific strategies for each category. The team may want to consider how important promoting math talk and supporting visitor interactions are as staff facilitation strategies and whether or not staff should be encouraged to use these strategies more frequently.

Staff also used some types of strategies more frequently at certain prototypes (Table 5). Orienting was relatively consistent across the prototypes but was most common at the "Downhill Race" exhibit (95%). Posing challenges and supporting visitor interactions were both more common at "Balancing Art" (78% and 67% respectively) compared to the other prototypes. Promoting math talk was most common at the "Downhill Race" prototype (79%) and was relatively rare at the "Balancing Art" exhibit (11%). This may partly reflect the project team's increasing emphasis on this strategy category, since "Balancing Art" was the first of the four prototypes tested.

Level of Staff Facilitation

Figure 6. *Percentage of interactions during which staff used zero, one, two, three, or all four types of facilitation strategies. N = 76.*

Staff often used several of the strategies during a single interaction. Figure 6 shows the relative frequency that staff used none, one, two, three, or all four types of facilitation strategies. Staff used at least three different strategies with about half of visitor groups (51%).

Median Hold Time and Level of Facilitation
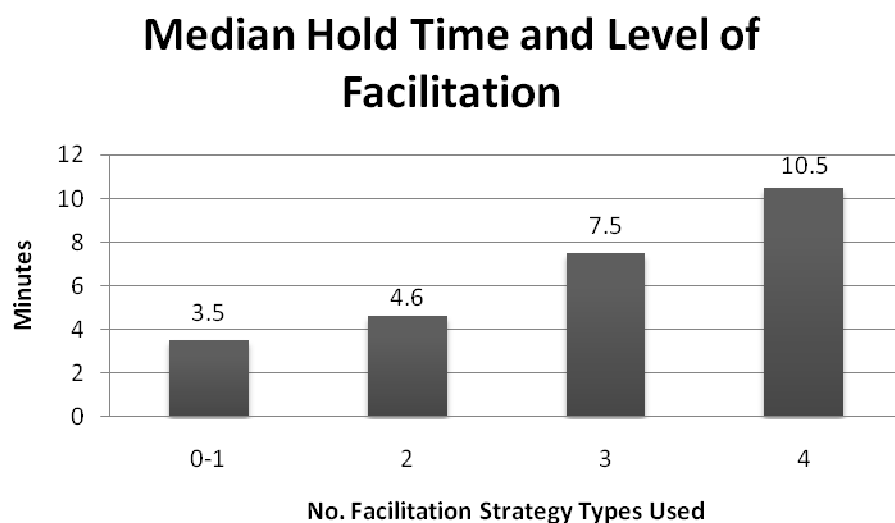
Figure 7. *Comparison of group median hold time by the number of types of facilitation strategies used by staff. N = 75.*

There was a clear relationship between visitor hold times and the number of types of facilitation strategies used by staff (Figure 7). Interactions during which staff used no more than one strategy type had the lowest median hold times (3.5 minutes), while interactions during which staff used all four strategy types had the highest (10.5 minutes). The number of facilitation strategies used

was also related to the level of visitor math talk (Figure 8). The use of more facilitation strategies was associated with more math talk categories. The mean number of math talk categories was highest when staff used all four facilitation strategy types (3.3) and lowest when staff used no more than one strategy type (1.4). Again, this does not necessarily imply a causal relationship. Longer engagement times may simply provide more opportunities for visitors to engage in math talk and for staff to use different strategy types. However, it does suggest that staff members are having a positive impact on visitor engagement and algebraic thinking and that the facilitation strategies that the team has developed are effective, particularly when more than one type of strategy is used. In the least, staff facilitation is not preventing visitors from staying at the exhibits and engaging in math talk.

Faciliation Strategies and Math Talk
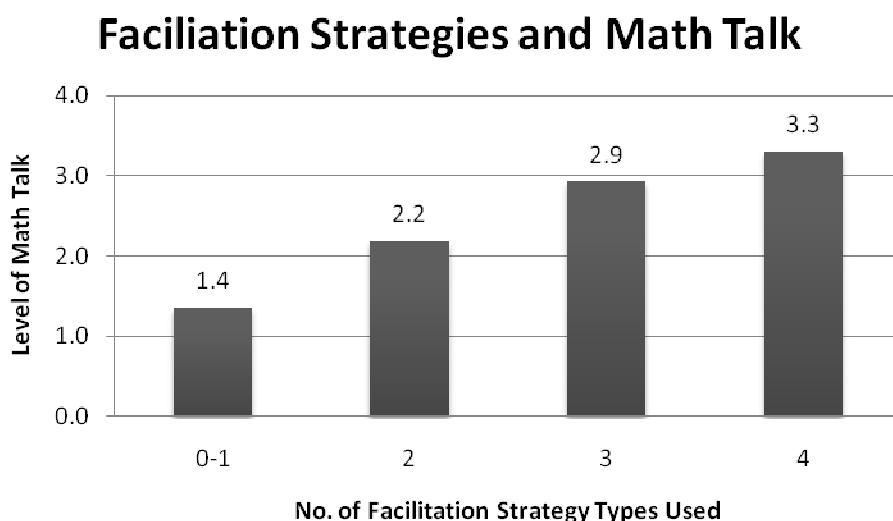
Figure 8. Comparison of levels of visitor math talk by the number of facilitation strategy types used by staff. Level of math talk was equivalent to the mean number of coded math talk categories. N = 74.

The use of specific types of staff facilitation strategies was related to both hold times and visitor math talk (see Figure 9 and 10). Figure 9 shows median visitor hold times when staff did and did not use each strategy type. Hold times were higher when staff posed challenges, fostered math talk, and supported visitor interactions. There was almost no difference in hold times when staff used orienting strategies (6.6 minutes) compared to when they did not (6.7 minutes). The use of challenges was associated with the greatest difference in hold times (9.6 minutes compared to 3.5 minutes). Similarly, Figure 10 compares the mean number of math talk categories when staff did and did not use each strategy type. The use of each facilitation strategy type was associated with a higher number of math talk categories. These results also provide support for the importance of facilitation in the *Design Zone* exhibition and suggest that all four of the strategies are potentially important for fostering algebraic thinking.

Median Engagment Time and Facilitation Strategies
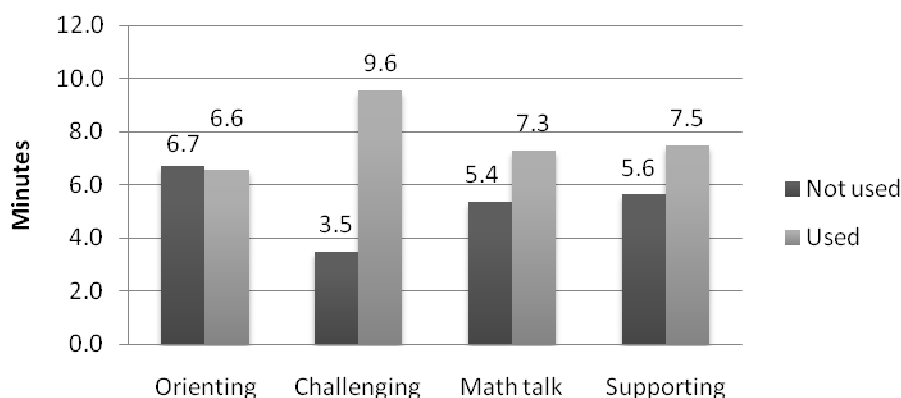
Figure 9. *Comparison of median engagement times for interactions during which staff did and did not use each facilitation strategy type. N = 75.*

Math Talk and Facilitation Strategies
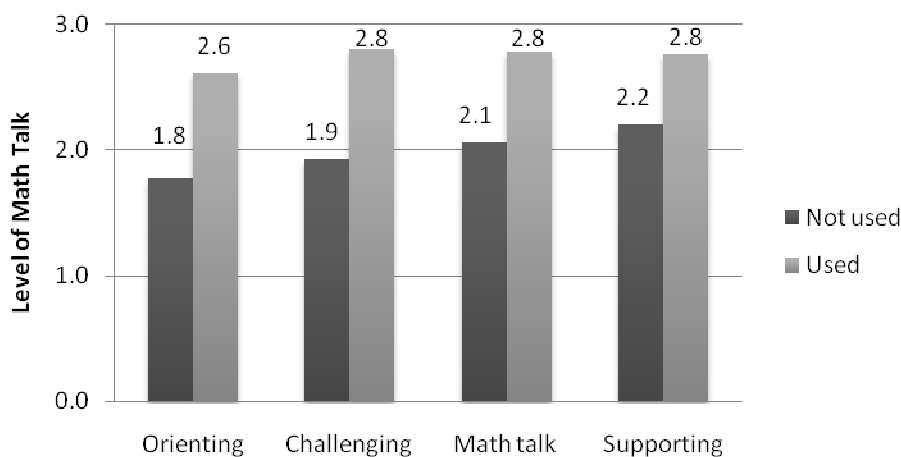
Figure 10. *Comparison of the mean number of math talk categories coded for interactions during which staff did and did not use each facilitation strategy type. Level of math talk was equivalent to the mean number of coded math talk categories. N = 74.*

Visitor Interviews

We conducted interviews with visitor groups during one day for each of the four prototypes. In each case, the evaluator conducting interviews also observed the interactions between staff and visitors and selected the individual who seemed the strongest facilitator within the visitor group to be interviewed after the interaction. A total of 44 interviews were conducted, including 10 at "Balancing Art," 18 at "Drawing in Motion," nine at "Downhill Race," and seven at "Digital Strings." The majority of these interviews (73%) were with female visitors.

In general, visitors were very positive about their experiences and the support strategies used by staff. When explicitly told what approach that staff members were trying to take with visitors and asked whether or not they felt this had worked, 93% of those interviewed implied that the approach had been successful. Representative quotes included:

> *It worked beautifully. [The educator] explained how it worked and then stood back.*

> *Yes, that worked. [The educator] checked out the situation and looked for ways to help but treaded lightly.*

> *It was good. [The educator] was prompting but not ahead of it, letting my daughter decide, showing her the options.*

Visitors mentioned a variety of specific staff facilitation strategies that they felt helped their groups be successful at the exhibit. Important themes from these responses are described in more detail below. Table 6 shows the frequency of each theme. Because one of these interview questions explicitly described the staff facilitation approach, interview codes were analyzed for responses to questions before this approach was described ("uncued") and for all responses ("all").

Table 6. *Themes from visitor responses to questions about successful staff facilitation strategies*

Theme	"Un-cued"	All
Guiding	86%	89%
Giving space	30%	70%
Asking questions	9%	9%
Explaining	7%	11%
Encouraging	5%	5%
Helping (general)	2%	5%

Note. "Un-cued" themes represent coded responses before visitors were explicitly told about the staff facilitation approach. N = 44.

Guiding
Almost every visitor group appreciated the way staff members guided visitors in using the exhibit. Visitors specifically mentioned how staff members provided a goal or a challenge, oriented visitors on how to use the exhibit, gave hints, tips, or suggestions, highlighted the important features, including mathematical features, or made suggestions about how to simplify the activities. Representative quotes included:

[The educator] gave us a goal.

[The educator] gave [us] the music sheet guessing game. Making a song activity was more fun than not having anything to do at the exhibit.

Showing us how to use it, pushed reset, guided us to the next stages.

[The educator] gave hints to steer them [kids] in the right direction. Gave suggestions about what to do.

She explained how it worked, the sensors for the timers, how the weights were distributed, encouraged us to try different weight distributions, and challenged us to try to get specific times.

[The educator] was encouraging with suggestions of what they should do next, let them [kids] come to a conclusion on their own but guided them how to get there.

Giving space

Visitors also found it helpful when staff members gave them the time and space to explore the exhibit on their own and attempt the challenges without too much staff support. Visitors specifically mentioned letting them figure out the challenges, providing options, rather than dictating specific goals or challenges, allowing time for exploration, being available as needed, and not interfering too much. One visitor particularly liked how staff members introduced themselves: "because people get nervous and walk away if they are being watched and don't know why." Almost a third of visitors (30%) alluded to this theme in their responses to the first two questions. This number jumped to 70% after the interviewer described the facilitation approach, which included the phrases "visitors are always in charge" and "staff are there to help without telling you what to do." Representative quotes included:

Yes, [the educator] was there to give ideas but not tell us how to do it.

Let them try it out first before directing them to the challenges.

[The educator] was good. [The educator] showed us and then stepped back and let us do it.

Definitely left room for them to do the tasks themselves, encouraged them.

[The educator] was there when we needed her.

These types of responses provide support for the facilitation approach as outlined by the project team. Currently, one of the primary goals of the facilitators is to support the facilitation and learning that is already going on within families, rather than creating a purely staff-led experience. The interviews indicate that many visitors value a balance between staff guidance and visitor group autonomy.

Explaining and asking questions

A small number of visitors said that they appreciated or would have liked more direct staff facilitation, including providing explanations and asking questions. Responses were coded as "explaining" if they went beyond general comments, such as "explained it," and mentioned

explaining the science behind the exhibit or explaining why the activity worked. These responses are a good reminder that different groups have different expectations for their experience and that some visitors may be disappointed if staff do not adopt a more hands-on approach. Representative quotes included:

> *[The educator] was great, asking questions to make them think.*
>
> *They got that the smaller number the faster, but not that it was the location of the weights. They got that it wasn't which got there faster but what the times are. They didn't know why, if he explained the idea that the closer to the center of the weights is faster. Some explanation [would have been good] of how the speed is affected, show why the numbers are different.*
>
> *Maybe explain the physics, why mass in the center is faster.*

Other
A few visitors (9%) also mentioned appreciating general encouragement or help from staff.

Very few visitors suggested things that staff could have done better to facilitate interactions. It is important to note, however, that both the educators involved in the testing were very experienced. Also, the evaluation may not have been well designed to elicit negative comments from visitors. Staff facilitation is probably not something that visitors have thought about before and they may feel particularly uncomfortable criticizing OMSI staff.

Group Debriefs

Before prototyping, the program development team created a framework for categorizing successful facilitation strategies at the exhibits. Although this framework evolved throughout the evaluation process, the categories have remained useful as a way of understanding the types of facilitation strategies that are successful across exhibits. Before prototyping, the project team developed four categories of staff facilitation strategies: *orienting*, *posing challenges*, *supporting visitor interactions*, and *promoting math talk*. Appendix F describes these facilitation strategies in more detail. Exhibit-specific strategies that were considered successful by the team are included in Appendix D.

In reviewing the group debriefs notes, we looked for strategies that had been mentioned as successful for at least three out of the four prototypes. Strategies that fit these criteria are described below for each of the four strategy categories. We also discuss a few strategies that the team mentioned as being very important but that were not present in the debrief notes for at least three prototypes.

Orienting
During "orienting," members show visitors how to use the exhibit, highlight the primary goal of the activity, or point out important features. Discussion notes highlighted how orienting can happen at any time and that the facilitator should respond to visitor cues to decide if and when orienting is appropriate (and which orienting strategies to use). Particularly successful orienting strategies, from the team's perspective, included:

- Showing visitors how to use the exhibit,
- Modeling vocabulary and highlighting math features, and
- Defining the goal of the activity (or initial challenges).

Other potentially important strategies that were mentioned included giving visitors time to explore and connecting to visitors' prior knowledge and experience.

Posing challenges
Challenges have emerged as a successful, nonthreatening approach to guiding visitor interactions. The project team developed a number of challenges for staff to pose to visitors beyond those built into each prototype. Having a variety of challenges of different types and difficulties allowed facilitators to adapt to different groups. Sometimes it was worthwhile to have visitor groups choose from a selection of challenges in order to promote buy in, while other times it was better for staff to choose a challenge. This latter option allowed staff to determine an appropriate level of difficulty or to engage visitors who were not sure they wanted to stay. Particularly successful strategies included:

- Simplifying challenges for visitor groups who were struggling with the exhibit or for younger visitors;
- Extending challenges, including those requiring facilitator-only props and extensions, for visitors who were ready to engage more deeply with the exhibit; and

- Scaffolding strategies to help families complete challenges.

During the group debriefs, staff also mentioned the potential for encouraging and supporting visitors who come up with their own challenges.

Supporting visitor interactions
Research shows that visitors are often effective at facilitating their own learning. Individual visitors in a group often take on leadership roles during a museum visit, helping to guide and direct the learning of other group members. In order to promote "visitor driven" engagement, the project team encouraged educators to support, rather than supersede, the facilitation that was already going on within visitor groups. Staff discussed the importance of observing groups to determine who was playing a facilitator role within the family and to look for opportunities to support those individuals. Educators also looked for transition points when visitors could begin taking more leadership in the interaction. The group observed that staff may need to take a stronger role with school groups because chaperones have less experience with the students and may not have the same motivation to facilitate learning as parents or other visitors in family groups. Particularly successful strategies included:

- Providing space, standing back, or walking away;
- Handing props to visitor facilitators (e.g., a parent) and giving suggestions about how to use those props; and
- Explicitly prompting visitor facilitation (e.g., suggesting that visitors work together or that a visitor explain the activity to a newly arrived group member).

The team also discussed other potentially promising strategies, such as using a different facilitation style with some group members (e.g., providing the "inside scoop" to parents), working with one child when a parent is helping another child, or modeling facilitation for the group and then stepping back. Visitor responses to the interviews support the importance of this strategy category.

Promoting math talk
Discussion with the team indicated that this was one of the most challenging strategy categories. The project team was also conflicted about whether promoting math talk was specific to talk or also included a broader range of non-verbal indicators of math learning and thinking. Specifically with questions, staff struggled to determine when it was appropriate to ask more abstract or more explanatory questions, such as "why" questions, or more close-ended questions where it was implied that the facilitator knew the correct answer. The project team indicated that these types of questions could be threatening to visitors or lead to uncomfortable interactions unless there was a strong rapport or trust established with visitor groups. The use of these types of questions might also depend on the level of competence and knowledge of visitors. Strategies that were mentioned as successful for at least three of the prototypes included:

- Posing challenges designed to promote math talk;
- Asking open-ended questions (e.g., "tell me about your wheel") or past tense questions that prompted visitors to explain their thinking related to a challenge they had successfully completed;

- Explicitly encouraging communication among visitors (e.g., encouraging visitors to plan, suggesting that one visitor explain the activity to a newly arrived group member, or asking visitors to direct the actions of the staff member); and
- Asking questions that prompted visitors to make predictions (although, these may be threatening, as discussed above).

In many cases, staff indicated that posing well designed challenges was a more effective way of promoting math talk than asking questions. Other promising strategies that the team mentioned included using mathematical representations to prompt math talk, which was particularly successful with the "Downhill Race" activity, and watching for visitor cues and opportunities to ask questions, such as when visitors seem surprised by a result. This strategy category may need more attention from the development team.

DISCUSSION

In the discussion below, we outline how the study findings address each of the three primary evaluation questions. At the end of the report, we also discuss the strengths and limitations of the evaluation methods for assessing math learning at exhibits.

1. Which strategies successfully promote prolonged, mathematical, visitor driven engagement?

This study provided evidence that staff are having a positive impact on visitor experiences and that the overall facilitation approach is promising. Median engagement times were substantially higher compared to Family Night formative testing with non-staff-facilitated prototypes. Furthermore, over 80% of visitor groups were coded as engaging in at least two categories of math talk. During interviews, visitors were also very positive about the approach to staff facilitation and indicated that they recognized and appreciated the balance between staff guidance and providing visitors space to explore the exhibits on their own.

Facilitation at the "Balancing Art" and "Downhill Race" prototypes was particularly successful at fostering long engagement times and high levels of math talk. This is likely a combination of exhibit design, visitor engagement with the activities, and the exhibit-specific facilitation strategies that the team has developed. Notably, both exhibits included strong facilitator-only extensions (mystery weights for "Balancing Art" and adjustable wheels for "Downhill Race"). "Balancing Art" also had the advantage of being extremely open ended, while "Downhill Race" benefited from a very accessible mathematical relationship. These features may have influenced staff facilitation strategies. For example, posing challenges and supporting visitor interactions were more common at "Balancing Art" compared to the other prototypes, while orienting and promoting math talk were most common at "Downhill Race."

The evaluation also showed that all four facilitation strategy types (orienting, posing challenges, promoting math talk, and supporting visitor interactions) were related to increased visitor engagement times and levels of math talk. Visitor responses about which strategies they felt had been successful included examples that aligned well with all four facilitation strategy types. Furthermore, the data suggest that the use of multiple facilitation strategies was related to an increase in engagement times and levels of math talk. During the group debriefs, the team identified a variety of strategies that worked well across the majority of the prototypes. These included strategies from each of the four strategy categories. Although all four facilitation strategy categories are promising, the use of challenges had a particularly strong relationship with engagement times. Visitors spent relatively little time on average at exhibits when staff did not pose challenges (3.5 minutes) compared to when they did (9.6 minutes).

The team may want to consider developing more strategies for promoting specific and general relationship talk. Across all four prototypes, less than half of visitor groups engaged in either specific or general relationship talk. These two math talk categories seem particularly relevant to the overall algebraic thinking goals of the exhibition. One challenge is that these types of math

talk may be highly dependent on the nature and design of the exhibit activity. For example, the high frequency of specific and general relationship talk at "Downhill Race" may be because the mathematical relationship in this exhibit is particularly accessible to visitor groups. Regardless of the prototype, however, the more facilitation strategy types staff members used, the more likely it was that visitor groups engaged in more math talk categories. When facilitators used all four strategy categories, groups on average engaged in at least three of the math talk categories. (However, see discussion of study limitations below.)

Although the team worked to develop specific facilitation strategies to promote math talk, this strategy category proved to be the most challenging for staff. This will be important to consider when training staff and volunteers with less experience than the educators involved in this study. There is also the danger with this facilitation strategy of becoming too didactic or asking visitors questions that feel inappropriate to the free-choice learning setting. Because the use of each of the four facilitation strategy types was associated with increased levels of visitor math talk, it may be appropriate to emphasize more accessible strategies with new staff, such as orienting and posing challenges. Promoting math talk then becomes the focus for more advanced facilitators.

Finally, the team should think about the importance of promoting visitor talk rather than staff talk and encouraging visitor facilitation rather than staff facilitation. Evaluators rated a third of interactions as involving primarily staff talk and less than half of the interactions as primarily visitor facilitated. Despite this, most visitors indicated that they were very satisfied with their interactions and recognized and appreciated the balance between staff guidance and providing visitors space to explore the exhibits on their own. Furthermore, the data was inconclusive on how the level of visitor talk and visitor facilitation influenced engagement times and math talk. Future evaluation studies could explore these factors further to help the team determine the appropriate level of staff involvement when facilitating visitor groups.

2. Are specific strategies more or less successful with different types of visitor groups?

During the group debriefs, the team identified a number of visitor factors that influenced staff members' approaches to facilitation and how successful facilitation strategies were with different groups. These included how successful visitors were at using the exhibit on their own, visitor age, level of visitor interest and engagement with the activity, presence of a strong facilitator within the group, whether or not visitors were part of the family or school group, relevant background knowledge, and staff-visitor rapport. Some examples from the group discussion included:

- When visitors are already successfully using an exhibit, staff orienting may not be necessary.
- "Simplifying" challenges are especially appropriate when visitors are struggling with an exhibit activity or when visitor groups include young children.
- "Extension" challenges are more appropriate when groups have successfully engaged with the exhibit and seem interested in going deeper.

- When visitor groups include individuals who are taking a strong facilitator role, staff should look for opportunities to use supporting visitor interactions strategies.
- Because school group chaperones may be less prepared to take a leadership role, staff may have to play a stronger facilitation role with school groups.
- After staff members have developed trust and a rapport with a visitor group, there may be more of an opportunity to ask questions that probe visitor thinking.

Although these observations are based primarily on the group debriefs, they can be used to provide guidance to staff and volunteers during training about when specific strategies are appropriate. They also provide hypotheses for future research and evaluation studies
.

3. What are examples of successful facilitation strategies?

As part of the group debriefs, the team captured a list of exhibit-specific facilitation strategies that the team felt were successful for each prototype. These are included in Appendix D. Results from the observations and staff debriefs support the approach of developing exhibit-specific strategies for each of the facilitation strategy categories.

Assessing math learning

In addition to answering the questions outlined above, the study was also an opportunity for the team to further refine its framework for describing algebraic thinking and math talk at exhibits and to explore methods for assessing math learning. An important outcome of the evaluation process was a refined framework for describing visitor math talk (see Appendix E). During the staff debriefs, evaluators and educators discussed the type of math talk they heard from visitors and noted specific quotes and examples. We used these examples to test our current math talk categories, clarify and provide more detailed definitions of each category, and develop exhibit-specific examples for each category. For example, based on data from the first few prototypes, we determined almost no visitors were making explicit predictions and decided to collapse this category into "specific relationship" talk. We also made the decision that strategy, specific relationship, and general relationship talk must always reference the mathematical feature of the exhibit. Therefore, feature talk was a necessary prerequisite of the other three math talk categories. The final framework developed through the study provides a starting point for the summative evaluation.

Although the study proved to be an effective process for refining the math talk framework, it was less clear that the staff debriefs were a reliable method for assessing visitor algebraic thinking at the exhibits. During the staff debriefs, educators and evaluators discussed what examples of math talk they had heard from each visitor group and which math category each example represented. Each interaction, therefore, was coded for the presence or absence of at least one example of each category. Although this was a very rough measure of visitor math talk, it was clear that more precision was not possible. Educators were primarily focused on facilitating visitor experiences and often had trouble remembering examples of math talk from the interactions. For

the evaluators, it was often difficult to hear conversations between staff and visitors. During the debriefs, it was sometimes challenging to place visitor quotes into specific categories. Because the math talk framework continued to evolve, coding was not always consistent across the prototypes and it was difficult to compare how the codes had been applied. Overall, the method was a successful formative evaluation technique but we would not recommend it as an approach to assessing math learning in the summative evaluation.

Finally, the process brought up a number of issues related to how algebraic thinking should be assessed and how important math talk is as a goal of the facilitation and the exhibition in general. Although math talk was the only indicator of algebraic thinking used in the evaluation study, staff often noticed a variety of visitor nonverbal behaviors that suggested algebraic thinking and math learning. The team pointed out examples of visitor groups that seemed to be engaging in deep algebraic thinking, even though there was very little conversation among the group or with staff members. For staff, nonverbal behaviors often provided important clues that influenced their facilitation approach. It would be valuable for the team to continue to discuss the importance of math talk and to look for other valid and reliable measures of visitor algebraic thinking. One approach suggested by the team would be to develop a list of exhibit-specific behaviors to complement measures of math talk.

Study limitations
Because the study was not designed to show causal connections, it is difficult to determine the relationship between such variables as engagement times, level of math talk, and use of facilitation strategies. The data suggest that staff facilitation strategies are related to an increase in engagement times and math talk. However, some types of visitor groups may simply be more likely to spend longer at the activities, providing staff more opportunities to use different facilitation strategies. The interview data, however, does show that the majority of visitor groups are highly appreciative of the role staff played at the exhibits.

REFERENCES

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. Thousand Oaks, CA: Sage Publications.

Ellenbogen, K., Luke, J., & Dierking, L. (2007). Family learning in museums: Perspectives on a decade of research. In J. Falk, L. Dierking, & S. Foutz, *In principle, in practice* (pp. 17-30). Lanham, MD: AltaMira Press.

Falk, J., & Dierking, L. (2000*). Learning from museums: Visitor experiences and the making of meaning*. New York: AltaMira Press.

Garibay Group. (2009). *Design Studios family night report*. Unpublished evaluation study.

Humphrey, T., & Gutwill, J. (Eds.). (2005). *Fostering active prolonged engagement: The art of creating APE exhibits*. San Francisco: The Exploratorium.

Morgan, D. (1993). Qualitative content analysis: A guide to paths not taken. *Qualitative Health Research, 3*(1), 112-121.

APPENDICES

Appendix A: Observation Form
Appendix B: Staff Debriefs Form
Appendix C: Visitor Interview Guide
Appendix D: Strategy Matrices
Appendix E: Math Talk Categories
Appendix F: Facilitation Strategies

APPENDIX A. Observation Form

Access Algebra Facilitation Prototyping Observation Instrument (Digital Strings)
Observations begin when the first group member touches the exhibit or pays attention for more than 5 seconds.

Group #:   Date: Data collector: Staff facilitator: Group
size:_____

Age/Gender: 2-4____   5-7____   8-11____   12-14 ____   15-18____   19-25 ____   26-35____   36-49____   50-
65____   66+____

Descriptions & conversations	Evaluator comments

Engagement	Visitor-Staff Dynamics
Time:____minutes ____seconds Challenges completed: □ 1 increasing pitch □ 2 twice as long Group engagement None 1 / 2 / 3 / 4 / 5 / 6 / 7 Entire group NOTES:	Visitor/staff talk All staff 1 / 2 / 3 / 4 / 5 / 6 / 7 All visitor Facilitation All staff 1 / 2 / 3 / 4 / 5 / 6 / 7 All visitor NOTES:

APPENDIX B. Staff Debrief Form

Access Algebra Facilitation Prototyping Staff Debrief Guide (Digital Strings)
To be completed after each visitor interaction. Staff and evaluator discuss and answer questions together.

Group #:   Date: Data collector: Staff facilitator:

Questions

1. What kinds of math talk did you hear?

✔	Math talk	Description & examples (including quotes)
	Features	□ String length □ Pitch, musical note □ Tempo, speed □ Note length, note duration, song length □ Other:
	Strategies	*Comments related to using the exhibit or solving exhibit challenges that refer to at least one mathematical feature (includes suggestions, planning, leading questions, goals, and evaluative comments)*
	Specific relationships	*Explicitly mention two or more quantities/variables AND describe a specific comparison or cause-and-effect relationship between those quantities/variables.* □ String length □ Pitch, musical note □ Tempo, speed □ Note length, note duration, song length
	General relationships	*Explicitly mention two or more quantities/variables AND describe a generalized cause-and-effect relationship between those quantity/variables.* □ String length □ Pitch, musical note □ Tempo, speed □ Note length, note duration, song length
	OTHER	

2. What strategies did you use? (Note any strategies that were particularly successful or unsuccessful.)

✔	Strategy	Description & examples (including vocabulary and phrases)
	Orienting	
	Posing challenges (simplify / extend / visitor)	
	Promoting math talk	
	Supporting visitor interactions	
	OTHER	

3. Other notes (including things to try next time, specifics about interaction, etc.)?

APPENDIX C. Visitor Interview Guide

Access Algebra Facilitation Prototyping Visitor Interview Guide (Digital Strings)
Questions to be asked at end of interaction. Questions directed to primary group facilitator (e.g., parent). Evaluator can probe for depth and clarity.

Group #:   Date: Data collector: Staff facilitator: Group size:_____

Age/Gender: 2-4____   5-7____   8-11____   12-14 ____   15-18____   19-25 ____   26-35____   36-49____   50-65____   66+____

Interviewee age:____   Gender: M / F

Agreed to be interviewed: Y / N   Reason for refusal:_____

Interview questions

What would you tell someone this exhibit is about?

Today a museum educator was also working at this exhibit.
What kinds of things did the educator do that helped you and your family be successful?
        [Probe to exhaustion: Anything else?]
        [Optional probe for clarity: Can you remember a specific example of that?]

When this exhibit is finished, it will travel to museums around the country. One of the reasons we are testing it today is to find out how we can better train educators and volunteers at different museums as the exhibit travels. To help us do this, your honest opinion is very important.
What are some things you can think of that the educator could have done differently to help you and your family be successful at this exhibit?
        [Probe to exhaustion: Anything else?]
        [Optional probe for clarity: What would be an example of that?]

One thing we want to emphasize when training museum educators and volunteers is to make sure the visitors are always in charge. This isn't school, obviously. Staff are there to help without telling you what to do.
Do you think this worked in this case? Why or why not?
        [Probe for depth: Why / why not?]
        [Optional probe for clarity: Can you remember any examples of things that helped / didn't work?]

Do you have any other suggestions for how we can better train our educators and volunteers?

Observations	
Group engagement None 1 / 2 / 3 / 4 / 5 / 6 / 7 Entire group Visitor/staff talk All staff 1 / 2 / 3 / 4 / 5 / 6 / 7 All visitor	Facilitation All staff 1 / 2 / 3 / 4 / 5 / 6 / 7 All visitor NOTES:

APPENDIX D. Strategy Matrices

Balancing Art

SUPPORT STRATEGY	DESCRIPTION
ORIENTING AND FOSTERING SAFE LEARNING ENVIRONMENT	• Some people self-orient—need to observe and determine appropriate point of entry • Giving physical space to explore (before and after orienting) fosters safe environment • "There are lots of ways to use different blocks to make this bar balance—try it out" • Common goal for group to work on together = "getting bar to balance" • Raise awareness of "tools" to be successful—bar, weights, values, goal of balancing, "position matters" • Offer guidance to participants/kids and visitor lead (or onlookers) separately to support visitor roles and encourage involvement • Give visitors physical space to explore—move away from exhibit when appropriate "I'm going to give you time to think and test your ideas—let me know if you need me"
ENCOURAGING MATHEMATICAL EXPLORATION AND "MATH TALK"	FEATURES • Have them point out the numbers and values found in the exhibit on bar and on weights/blocks • Using "on the" language (e.g.; 6 on the 5 is the same as 5 on the 6) RELATIONSHIPS: • "If you have 2 and 3 here, then you can do a 3 and 2 there (just reverse numbers)" • Helping visitor to focus on each side of the "equation"—"what do you have on this side" • Use parent panel (to explain an example or the relationship) PREDICTIONS: • "Are you ready to check? I'm going to let go now, what do you think will happen?" • Prompt them to make their predictions explicit. "Where do you think that block will go?" "Any reasons you decided to try that?" "You seem surprised." • Once rapport established with visitor, "Tell me more about what you want to test so I can help you out." • If they get it right "How did you know that was going to work?" • Use of mystery weights good for this—less threatening because they don't have all the information STRATEGY: • Facilitator can model how visitors can devise a strategy
POSING CHALLENGES	**"Simplifying"** • "Let's start by trying to make it balance with '1s' on each side" (working with 1s, 2s and 5s as they're easier than other numbers, etc.) • Point out first challenge on parent panel • Posing symmetrical balance (same weight on same # for each side) • Posing inversely symmetrical balance (similar to challenge 1–3 and 4 on the 4 and 3) • Isolate a section - when visitor frustrated with a situation, help them to look at a side (you have 25 here, how can you get the same over there?)
	"Extending" • "Let's look at why this one worked before we start another challenge." • "Is there another way to solve this?" • "How can you check your answer?"

	• Mystery weights (When a group has already oriented to the normal challenges or for people who know math really well) • Referring back to simpler challenges to solve more complex problems. "Do you remember what you did here?"
	"Visitor-generated" • Encourage visitors to challenge each other—put weight on one side and then see how many different ways to balance with different blocks on other side • Encourage visitor to challenge you/facilitator if they are alone (facilitator can model problem solving and math talk)
FOSTERING VISITOR INTERACTION	• Give everyone a role to ensure their involvement (e.g.; ask someone to hold the bar until the group is ready to test their ideas) • Once someone has been identified as lead and given inside information about how it works, announce to group that you are going to give them space to work on it together—walk away • Hand visitor or less involved onlooker mystery weight with prompt, "they might need your help testing this one out" but give them value of weight • Work with younger child at the box with mini balance bar while older kid works on challenge • Stand beside or behind group (and onlookers) to encourage their involvement

Drawing in Motion

SUPPORT STRATEGY	DESCRIPTION *Summarize the most successful strategies for each category, in terms of promoting prolonged, mathematical, visitor-driven engagement. Give specific examples, including quotes, for each strategy.*	COMMENTS *Capture any specific notes about the strategies, including in which contexts they were successful or not so successful.*
ORIENTING AND FOSTERING SAFE LEARNING ENVIRONMENT	• Give visitors space to explore—possibly in free draw?—duplicate challenges here • Orienting can happen at any point • "At this exhibit you are going to work together to make shapes—but it helps to take a minute and take turns getting familiar with how moving each of your bars independently impacts the white box on the screen." "Who controls left/right movement? Up and down?" • Roles of x-axis and y-axis stations and numbers and how to relate that to screen • First slope challenge (challenge 2) then, not too much orienting needed • "When you are working together to make an angle/slope, speed matters." • Try pointing out button console as "origin" and emphasize numbers/coordinates • Pointing out goal of challenges "get to the blue target by following/tracing the line"	• Consider playing a stronger role with school groups because chaperone not as aware of dynamics, individuals, etc. • Consider who best can navigate y-axis, particularly tricky to translate between controls and screen
PROMOTING MATHEMATICAL EXPLORATION, ACTIONS AND "MATH TALK" Features Relationships (specific and general) Predictions Strategy	• Encourage group to have **planning conversations** about how they are going to move • Prompt visitors to be more explicit in giving each other directions **Good Prompts/Questions:** • "Ok, talk it out, what are you going to do here?" • "When you are working together, be sure to give each other clear instructions for how you are going to move together." • When a staff member is at one station give visitor directive, "You tell me what to do." • "How are you going to get an angled line?" Use words like steep, slope • "What did you have to do differently for this challenge?" after the second attempt • After they make a curve/sloped line, "How did you make that slope (or curve)? Did it feel easier or harder to you? Tell me more about that" or "What makes you say that?" • With the new image challenges, "What if you wanted to match the other side?"	• Visitors sometimes read hints directly • May need more support for this strategy category (for example, a list of prompts) • Getting visitors to look away from screen may be key to getting them to talk mathematically. (e.g., using counting strategy and the number line) • Some people don't talk, but are behaving in a clearly mathematical way (e.g., gesturing, how they move the X and Y lines, etc.

| POSING CHALLENGES | **"Simplifying"**
• Start with free draw just to get sense of how each person moves
• Help visitors to start challenges by working on vertical/horizontal lines, even if slope involved
• Encourage them to take any curved lines in a challenge and make them straight

"Extending"
• "Do you want to try that again?" This worked well to help visitors follow the line better "Do you think you can do it better/more accurately?"
• Do challenges without looking at the screen. Help visitors avoid just hand/eye coordination
• Have visitors switch positions/axis

"Visitor-generated"
• Visitors pick challenge cards to draw. Seemed to be more effective if visitors chose. More buy in. Sometimes visitors gave up if they hadn't picked the image.
• Challenge cards: most effective pictures are forgiving—house, stick figure, zig zag, straight spiral)
• One visitor has the challenge card and verbally has to instruct the other how to move
• Drawing on dry-erase board (how would you make house with a wider roof?) | • Help avoid the challenges simply becoming a hand-eye coordination activity
• "How would you do that differently?" when getting visitors to try to challenge a second time
• Opportunity to think more critically about challenge image choices—e.g., symmetrical images may be good—to match sides, may need more prediction and planning
• Helpful to have smaller pack of challenge cards to hand to visitor to make their own selection (rather than large cards) |
| **FOSTERING VISITOR INTERACTION** | • Giving visitors space, especially around buttons
• Give visitor control of the buttons—ask them for "help" controlling them and step to side or back
• Helping the visitor on one side when an adult is helping the visitor on the other side
• Letting visitors free play at the beginning could work if facilitator there to explain controls, otherwise, not as helpful. Free play could help give context to activity.
• Staff facilitate through challenges, then step back to let adult takeover in free draw | • Not as clear a way to give visitors the "inside scoop" for this activity. Staff did try with one group, but not as effective.
• Harder to engage adults as facilitators unless they are helping or in control of one of the axis |

Downhill Race

SUPPORT STRATEGY	DESCRIPTION *Summarize the most successful strategies for each category, in terms of promoting prolonged, mathematical, visitor-driven engagement. Give specific examples, including quotes, for each strategy.*	COMMENTS *Capture any specific notes about the strategies, including in which contexts they were successful or not so successful*
ORIENTING AND FOSTERING SAFE LEARNING ENVIRONMENT	**How to Get Started:** **INVITATION:** • "These wheels all roll at different speeds—your challenge is to find the fastest (and then we'll make some predictions about why)" INSTRUCTIONAL: • **Telling people how to get good data is important** (e.g., "the challenge is seeing how fast the wheel goes without giving it a push, just let it go, keep it straight to prevent wobbling") • Explain how to use the **timer mechanism** • Point out the scale • Explore the **differences between the wheels** ○ compare extremes first—wheel 1 & 4	• Tips for getting good data may not be an issue with the final exhibit • Age of visitor may dictate how well they're able to observe differences between the wheels • Scale may prompt visitors to talk even if they actually don't weigh the wheels • *Consider playing a stronger role with school groups because chaperone not as aware of dynamics, individuals, etc.* • How will differences in wheels be accentuated in the final exhibit?

	- o have visitors weigh the wheels - o adjust mystery wheels (eventually, not at outset) • Orient/demonstrate how to use **graphs or charts** (e.g.; plot one point for group and hand over)	
PROMOTING MATHEMATICAL EXPLORATION, ACTIONS, AND "MATH TALK" Features Relationships (specific and general) Predictions Strategy	**Good Prompts/Questions:** (determine which ones based on confidence/knowledge of visitor) "What did you do, I didn't get a chance to see it?" "Tell me about your wheel." "How are you going to change it?" <or> "What might you do differently to make it faster/slower?" "What did you change?" "Do you think it will go faster or slower than... (last one, first one, etc.)" "Why do you think it went faster?" "Now that you see how each wheel is different, how might that impact their speed?" "If you had adjustable wheel, how would you beat it?" "What might happen if you move half weights in and half out?" - o Specific generalizations were made by some people averaging that number = 2.5 - o "If #1 is fastest and #4 slowest, then this will be somewhere in the middle of all of them" **Things to watch for:** **Testing of wheel speed** combined with **observations** of wheels **Record/graphing of data.** Demonstrate plotting point and remind visitors to record data throughout interaction. **Incremental moving of weights on adjustable wheel** - Comparing of wheels - Visitors making switches with wheels based on what had happened before **Things to listen for:** - Feature talk will most likely be prevalent (and important) at outset of interaction - There will be lots of generalization about relationships at this exhibit! - Predictions can occur before each release - Challenges offer opportunity to encourage strategy talk (planning conversations) about how they are going to move	- The type of questions that facilitators can ask depends on confidence and knowledge of visitor "Observing" visitors and confidence levels will help dictate facilitator questions *Some people don't talk, but are behaving in a clearly mathematical way* - Adjusting race talk to math talk? - Graph-based prediction—worked well - Props—blank graph and completed graph

POSING CHALLENGES	**"Simplifying"** • Choose two wheels (e.g., 2 and 4) for visitors to compare. "Which wheel do you think is faster?" • Have visitor adjust wheel to get within a certain range of time (rather than an exact time) • Invite/challenge visitors to race their wheels • "I am going to make an adjustable wheel (facilitator), see if you can make one that goes slower" • Fun trick to engage—set all 4 wheels up to see if you can get them to progressively roll down the hill one at a time with a single release **"Extending"** • Place a dot on the graph and have visitors predict and test which wheel it represents • After visitor articulates generalization, have visitor use the adjustable wheels to verify their prediction. • *"Do you want to try that again?" Allow visitors to make adjustments based on what they learned* "How do you think you can get it closer to X seconds?" • If they have adjustable wheel—"What do you think the wheel is closest to? Test it!" • Give the clipboard—"Do you want to keep track of your numbers and see which is fastest?" • "How would you change your wheel if you wanted it to move faster?" • Have graph for 1, 2, 3, 4—then space to add adjustable weights • Have them "average" weights on adjustable wheel and make predictions about time ○ Test the adjustable wheel against a fixed wheel that is closest to their prediction so they can make adjustments based on 2 points of data **"Visitor-generated"** • Design your own wheel and have another visitor predict which fixed wheel it was the closest to—then test it • Forget about clock and use all 4 wheels on same track and look at spreading • Watch all 4 be lined up and watch them spread. Then hand them to visitor and see if they can recreate it.	• "How might you do that differently?" when visitors trying adjustable wheels challenge a second time • Comparing two wheels and making predictions/testing was good for younger groups • Overall time range for all the wheels is small, making it harder to work with
FOSTERING VISITOR INTERACTION	• **Tell people how to get good data (inside scoop?)** (e.g., "don't push the wheel, just let it go, keep it straight to prevent wobbling") helps facilitation, since adults/facilitator then stress tips with group • Less about inside scoop, more about giving them roles than "secret" information • *Stepping back, giving visitors space* • Invite adults/facilitator to help group figure out differences between wheels • Hand the adult/facilitator a wheel and encourage them to "try it out" • When new visitor joins (especially another member of group/family) have someone who has been there already explain what they are doing and get them involved • "Maybe you can fill others in on what is going on here" or "would you share what you have done so far?" • When there is a group with a chaperone, facilitator will need to take a stronger lead • With school groups, try to focus on helping one of the kids to be facilitator—they know the kids better than the chaperone • Give adjustable weights to adult/group lead to guide changes and give them a role • Hand small graph to someone and have them be in charge of graphing results	• Consider if there are age group tips for this exhibit

Digital Strings

SUPPORT STRATEGY	DESCRIPTION *Summarize the most successful strategies for each category, in terms of promoting prolonged, mathematical, visitor-driven engagement. Give specific examples, including quotes, for each strategy.*	COMMENTS *Capture any specific notes about the strategies, including in which contexts they were successful or not so successful*

ORIENTING AND FOSTERING SAFE LEARNING ENVIRONMENT	**How to Get Started:**
	HOOK/INVITATION:
	• "Want to try to make some music?"
	• "We're making music, these represent strings, you can change the note by making them longer or shorter (so get longer/lower)"
	• "Do you play music?" (if observe some understanding of music)
	
	INSTRUCTIONAL:
	• Press play to hear the sounds—it will play 3 times through and stop
	• The knobs make the lines shorter and longer
	• Make aware they can only make changes when the exhibit is not playing
	• Orienting to the possibility of changing instrument sounds
	• Direct visitors to the note chart (parent panel), when ready
	• Bridge to talk about note chart. For example, listen for visitor talk that references notes or some sign from visitors that they are ready to talk about note names.
	
	VOCABULARY
	• Use of terms strings, longer, shorter, (lower, higher),pitch, and octave are key here
	  • Visitors and parents respond to this by shifting their vocabulary
	  • "It's like frets, you touch it here to get a shorter string"
	• "Double or half of that length"
		• Orientation seemed to be the focus of the exhibit!
		• Most visitors approach and hit "play," so when interaction ends, leave board with various notes on it for next visitor to approach—and "piano" seems to be good instrument to start on
		
		•
		
		Shakedown issues:
		• Sometimes instrument selection screen doesn't match the sound. (Too much play with the knob? Issue with not having detents?)
		• Sometimes knobs would work but the play button (and instrument selection) would stop working
		• Occasionally, all the buttons stopped working, or weird variations of different knobs and buttons would not work
		• Occasionally, visitors could adjust some knobs during playback
		• Problem with lights lining up with the y-axis scale

PROMOTING MATHEMATICAL EXPLORATION, ACTIONS, AND "MATH TALK" Features Relationships (specific and general) Predictions Strategy	• Need to work more to develop strategies for promoting math talk with this exhibit • How does planning talk play a role? **Good Prompts/Questions:** (determine which ones based on confidence/knowledge of visitor) • "Let's hear how the sound changes as you change the lines." This didn't seem to work well. • "What happens if we 'double' that one" • "What kind of song are you making?" • Encourage visitors to sing or hum their idea • Visitors may be shy about this • Facilitators can help by modeling • "What have you tried so far?" • "Tell me about your song/choice of string lengths." • "How are you going to change it?" <or> "What might you (or did you) do differently?" • "Tell me what you did here" VS. is that higher or lower? • "What do you think that is going to sound like?" (Sample response: "It's going to sound higher with each string.")	• This worked so much better because of the Mystery Note challenges • Name that Tune—not really promoting desired activities/talk with group • Inverse relationships prevalent • Math talk felt difficult with this exhibit—more like Downhill Racer • The type of questions that facilitators can ask depends on confidence and knowledge of visitor • "Observing" visitors and confidence levels will help dictate facilitator questions • *Some people don't talk, but are behaving in a clearly mathematical way*

	• "Which strings are flashing when the note is lowest?"
	• "What do you think needs to happen next?"
	• "How does this relate to the frets of a guitar?"—this works if they have some experience with music or specifically playing guitar
	
	Things to watch for: Consider non-verbal cues and hand gestures when evaluating math learning.
	
	• Where and how they make changes
	   o "I can see you want to make a change, what are you going to do?"
	   o Once they have explored all the variables (sound, speed, dials) then introduce the songs/challenges
	• Hands pointing up or down
	• Counting lines
	• Looking at scale on sign and referring back to board may be indicator of previous math knowledge
	
	Things to listen for:
	• Predictions are happening if they are humming song?
	• "Oh, they're getting lower, longer, higher, etc."
	• Challenges are likely place for math talk to happen
	• Feature talk will most likely be prevalent (and important) at outset of interaction
	• There will be lots of generalization about relationships at this exhibit!
	• Predictions can occur before each hitting of play button
	• Challenges offer opportunity to encourage strategy talk (planning conversations) about how they are going to set string lengths	

POSING CHALLENGES	**"Simplifying"**
	• Highlight low and high notes by setting strings to the extremes and putting the same notes together (e.g., 100, 100, 25, 25)—isolate variable
	   o Slowing tempo down helps visitors hear differences between notes.
	   o Changing instruments may be helpful
	• "When do you hear high notes?" Followed by "let's listen."
	   o If it's too fast, slow the tempo down
	   o Make differences between notes extreme so that it's easier for visitors to hear
	• "Let's make something that looks like a mountain." "Start and end at the same note." This challenge worked well!
	   o Group seemed to notice relationship with pitch
	   o Other options: make a valley, make a "v"
	• Using the piano as the instrument because it is the cleanest sound
	• If it is too fast, slow it down
	• How to distinguish between high and low notes
	• High/low PITCH orientation may be something more necessary for younger kids
	• Set half of strings short and half of strings long to help isolate pitch
	• Parent panel "make a song that increases in pitch"
	• "Which one is flashing when you hear the high notes?"
	• With Mystery Note challenges, have them play song through without guessing/replacing missing note—will give them a better sense for song
	• Have them record the different guesses they made on which was the mystery string note/number—use dry erase on mystery dry erase card
		• **Challenge cards with missing notes on dry erase board—try this!**
		• Many visitors just wanted to compose their own songs
		   • This may not involve predicting
		   • Haven't found a way to focus this back to the math
		   • Idea: "how about you make a song that's all above or below 50?" "Then move it down or up an octave"
		   • What language to use with this type of challenge that involves changing octaves? "Raise an octave"? "Cut all the strings in half"?
		• Playing song by ear will be best for groups demonstrating understanding of music and familiarity with a specific song
		• Playing by ear still mathematical because selecting "higher/lower"
		• MOST SUCCESSFUL SONGS:
		   • Mary had a little lamb

	"Extending"
	• "If you wanted to make a song that had low notes, what would you do?"
	• "What do you want to do next?"
	• *"Do you want to try that again?" allows visitors to make adjustments based on what they learned"*
	• **Challenging visitors to figure out a song without music** to promote math talk (planning talk)
	  ○ Have them hum tune if they don't know actual notes (is it higher or lower?)
	• **Challenge cards with missing notes**
	  ○ Figuring out missing notes forces them to deal with the relationship between pitch and string length
	• Challenge visitors familiar with music to set up a scale
	
	"Visitor-generated"
	• Visitors come up with their own song to play
	• Visitors pick a song "Do you want to try playing a song, we have some over here?" hand selection of options to them
		• Twinkle, Twinkle—but hard w/ dropped notes
		• When the Saints go Marching In
		• Hot Cross Buns
		• The missing note challenge seemed most successful
		• Variety of challenge levels needed or would help
		• Starting at shortest length and moving it up
		• Consider deeper challenges with one, two, and three notes missing
		• Handing over the challenge card was useful for engaging the "unsure" visitors

FOSTERING VISITOR INTERACTION	• *Step back and give visitors space* • Talk with other child/children if adult working with other child/children • Give parents song sheets to engage the whole family • Assign specific strings to specific visitors • "Do you want to show them what you've done so far?" (when someone new joins the group) • Try having different people control different notes. Divide larger group in half (teams?). • "You are going to work together to…." (make a song, figure out the mystery note, etc.) • **Give group lead inside scoop:** "the longer the string, the lower the note," "octave is 2x longer/shorter" • Useful to hand them the collection of challenges with the understanding that answers were on the back (inside scoop) • "Here's some things you can try together" • Make challenge cards available for them to pick up • With big group/extreme situation, everyone had their own string/knob, but then facilitator needs to take stronger role of directing exploration	May end up acting as security to stop random visitors from jumping in the middle of a song • The problem is not that the exhibit is so wide, but that the interface is so wide (looks like individual workstations) • Facilitator may need to protect the play button when there is a large group • Useful to have small box to place over play button as facilitator affordance

APPENDIX E. Math Talk Framework

MATH TALK	Description
Features	Visitors explicitly identify mathematical features of the exhibit, including quantities and variables.
Strategies	Visitors explicitly discuss how to use the exhibit or complete the activity AND refer to at least one of the mathematical features of the exhibit. Strategy talk includes suggestions, leading questions, goals, and evaluative comments. Strategy talk always includes feature talk.
Specific relationships	Visitors explicitly mention two or more quantities or variables in the exhibit AND describe a specific comparison or cause-and-effect relationship between those quantities or variables. These relationships could be stated as predictions. Relationship talk always includes feature talk.
General relationships	Visitors explicitly identify two or more quantities or variables in the exhibit AND describe generalized cause-and-effect relationships between those quantities or variables. Visitors answer the question, "Does this always work?" Relationship talk always includes feature talk.

APPENDIX F. Facilitation Strategies

Museum educators and volunteers have an important role to play in the *Design Zone* exhibition. Staff can help achieve the visitor learning goals by facilitating a deeper level of visitor engagement, promoting algebraic thinking, and supporting visitor agendas and roles. This emphasis on visitor agendas and roles acknowledges that museum staff can support mathematical inquiry and algebraic thinking while still honoring the individual interests and motivations of visitors. Four promising categories of staff facilitation strategies were identified during formative evaluation: orienting, posing challenges, promoting math talk, and supporting visitor interactions. Evaluation results also emphasized the importance of observing visitor groups before initiating a staff-visitor interaction. By noticing how visitors are using the exhibit, who is taking a leadership role within a visitor group, and the math talk that is already going on, staff can tailor their support strategies to the interests, goals, and prior knowledge of each group.

Orienting
During "orienting," staff can describe for visitors how to use the exhibit, highlight the primary goal of the activity, and point out important features. Orienting also includes modeling phrases and vocabulary that visitors can use to talk about their experiences at the exhibit. Orienting can happen at any time, depending on the needs of visitor groups.

Posing challenges
Challenges have proven to be a successful, nonthreatening way to guide visitor engagement at exhibits. Providing visitors with challenges gives them a common goal and creates the potential for an exciting, memorable experience. By developing a variety of challenges, staff can tailor this strategy to individual groups. For example, "simplifying" challenges are helpful for groups that are struggling with the activity, or for younger visitors, while "extending" challenges offer visitors opportunities to extend their experiences. Staff can also encourage and support visitors in developing their own challenges.

Supporting visitor interactions
Research shows that visitors are often effective at facilitating their own learning. Individual visitors in a group often take on leadership roles during a visit to a museum, helping to guide and direct the learning of other group members. In order to promote "visitor driven" engagement, staff can use a variety of strategies to support, rather than supersede, the facilitation that is already going on within visitor groups. The degree to which groups will be prepared to guide their own learning will vary. For example, school groups often require more direct facilitation from staff.

Promoting math talk
To deepen visitor algebraic thinking at exhibits, staff can use strategies to promote math talk among visitor groups. Unlike classrooms, informal educators rarely have the opportunity to establish a "culture" of math talk. However, staff can capitalize on the experience and comfort visitor groups often have learning together. Although asking questions is one strategy for promoting math talk, staff should take care to avoid violating participants' expectations for the free-choice learning experience. For example, asking visitors to explain or justify their thinking may feel threatening or inappropriate (NRC, 2009).