REVEAL

Emergent Activity Frames in Facilitated Family Interactions at Math Exhibits

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Executive Summary

With support from the National Science Foundation (NSF), the Oregon Museum of Science and Industry (OMSI), in partnership with the Institute for Learning Innovation (ILI), TERC, and Adelante Mujeres, completed a fifth and final study as part of REVEAL—Researching the Value of Educator Actions on Learning (DRL-1321666, REVEAL.TERC.edu).

The purpose of this study was to explore whether the notion of activity frames might be a useful alternative to sociomathematical norms to help describe the behaviors of family members at interactive math exhibits. In this study, activity frames are defined as context-specific, emergent understandings or expectations, either implicit or explicit, about the nature and goals of family and staff interactions at math exhibits (Pattison et al., in review; Pattison, Gontan, & Ramos-Montañez, in review). Researchers questioned not only whether activity frames could describe family behaviors, but also if they might influence the mathematical reasoning with which families engage at the exhibits. The motivation for studying activity frames stemmed from researchers' objective to help exhibit facilitators adopt strategies for fostering deeper and more extended family interactions at math exhibits (Pattison et al., in review; Pattison et al., 2017). Earlier attempts by the team to use the construct of sociomathematical norms to describe family behaviors at math exhibits were not successful and activity frames emerged as an alternative.

This research was founded in a qualitative, inductive, culturally-responsive approach to identify possible activity frames that might influence math reasoning behaviors at two math exhibits and inform future research in service of practice. This research was guided by two questions related to visitors' approaches to the mathematical challenge(s) posed by an exhibit or staff facilitator:

1. What activity frames are at play during families' interactions with the math exhibits?
2. How might different activity frames influence the nature and outcomes of families' experiences at the math exhibits?

These questions were addressed by REVEAL partners, researchers and educators working in collaboration to review a sample of video data collected during a prior REVEAL study. For each of 20 videos, researchers produced high-level summaries of visitors' mathematical approaches to the exhibit challenges, including shifts in approaches, as the basis for identifying emergent and relevant group behaviors among family members. Research team members followed a series of steps to describe specific behaviors in family members' approaches to the completion of the mathematical challenge, and developed video summaries that included mathematical reasoning behaviors relevant to each exhibit as outlined in a rubric created in the prior REVEAL quasi-experimental study (Pattison et al., 2017; Pattison et al., in review). The rubrics capture the essence and intentions of the unique challenges posed by the two exhibits used in this study, “Balancing Art” and “Drawing in Motion.”

The first priority of this study was to identify and describe emergent and prevalent activity frames at play during families’ interactions at math exhibits. This report presents and illustrates six activity frames presented as contrasting pairs (a) Completing and Refining, regarding how families perceive the completion of a challenge; (b) Teaching and Exploring, related to the families’ perception of the activity as a didactic activity and/or as exploration; and (c) Competing and Collaborating, involving how a family perceives they have to work together at the exhibit. In most of the 20 videos, more than one of these activity frames was apparent at any given time.

As a second priority, the REVEAL team speculated on these frames’ influence on the intended nature and outcomes of the math challenges posed by the exhibits. This study was not designed to capture correlation or causation between activity frames and mathematical outcomes, but utilizing the mathematical rubrics to view the activity frames begins to suggest relationships among activity frames and how exhibit designers and educators might intend for visitors to approach the exhibit. For instance, the mathematical reasoning rubrics for the two exhibits studied here prioritize iteration, accuracy (balance or intended line slope), exploration (multiple strategies) and collaboration (the family is the unit of analysis), among others. Identification of possible relationships between activity frames and mathematical reasoning behaviors could provide a basis for additional research to further understand this connection. As a service to practice for exhibit facilitators, these research findings are presented in a REVEAL professional development module https://reveal.terc.edu/Educator+Resources; Andanen et al., 2017) that encourages awareness of activity frames and how they might impact families’ experiences at museums.

Introduction

Context within the REVEAL Project

This is the fifth and final study in REVEAL—*Researching the Value of Educator Actions for Learning*, a National Science Foundation (NSF)-funded research project (DRL-1321666) to study factors that influence museum facilitators' roles in deep and extended family engagement and learning at interactive math exhibits. The project produced five research studies, a model of staff-facilitated family learning, and a professional development series available through the REVEAL website (https://reveal.terc.edu/Educator+Resources).

In study one, a design-based research (DBR) study, a cross-disciplinary team of educators and researchers collected and analyzed data from hundreds of staff-family interactions to produce a model of staff-facilitated family learning at exhibits (Figure 1), including facilitation strategies for supporting mathematical reasoning and adapting to the needs and interests of different family groups (Pattison et al., 2017). During study two, the team trained four new educators and conducted a quasi-experimental study to test the REVEAL responsive facilitation model and assess the impact of the model on the exhibit experience, measuring five distinct outcomes: engagement time, intergenerational communication, visitor satisfaction, mathematical reasoning, and math awareness (Pattison et al., in review). During the third study the team tested the transferability of the REVEAL facilitation model (Figure 1) to a different museum, reflecting on the importance of context and educational approach of an institution (Gontan, Pattison, Brandon, Rubin, Andanen, & Benne, 2016). The fourth study was a pilot study designed to describe and explore types of influencing factors present when families shifted to deeper engagement as measured by visitor satisfaction, mathematical reasoning and intergenerational communication. The fifth study was designed to describe one type of influencing factor identified in the pilot study, activity frames. Activity frames are defined as context-specific, emergent understandings or expectations, either implicit or explicit, about the nature and goals of family and staff interactions at math exhibits (Pattison et al., 2018; Pattison, Gontan, & Ramos-Montañez, in review), and are elaborated upon below.

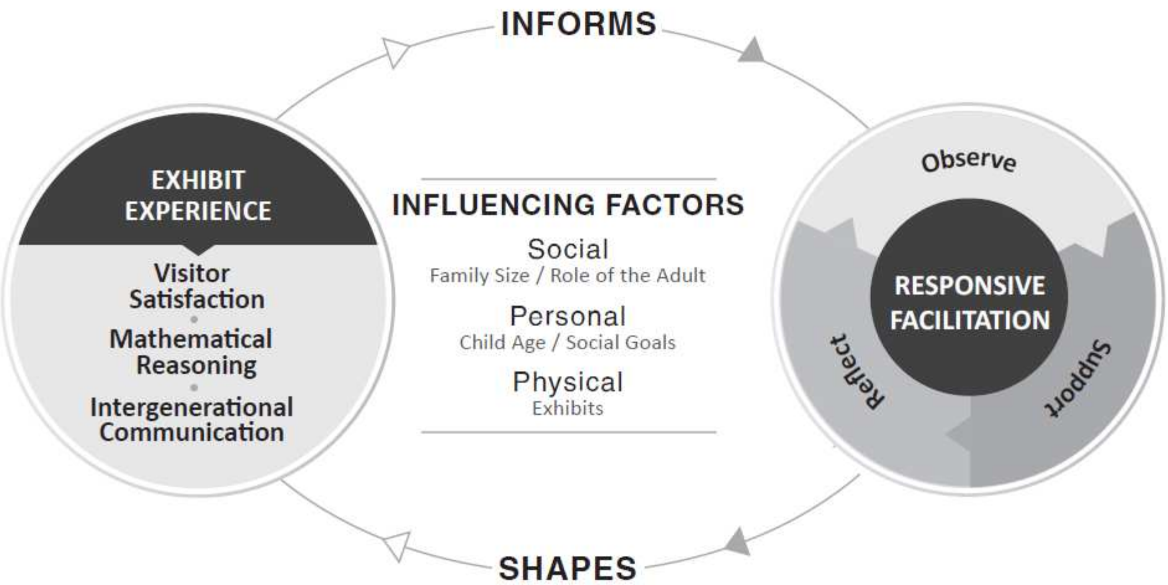

Figure 1. REVEAL facilitation model.

Rationale for the Current Study

REVEAL researchers initially intended to study how sociomathematical norms shaped the nature and outcomes of staff-family interactions at exhibits as inspired by the seminal work of Cobb and Yackel (1996). Cobb and Yackel asserted that sociomathematical norms are shared understandings of the criteria on which mathematic activities are evaluated, and the discourse, explanations and analysis related to these activities. Sociomathematical norms develop over time through interactions between learners and educators and constrain and afford math discourse and learning within the classroom.

The REVEAL research team expected that the notion of sociomathematical norms would shed light on the impact of staff facilitation, positing the norms as critical factors shaping the discourse of families at interactive math exhibits and moderating the impact of staff facilitation on family learning. Despite what seemed to be a promising approach and framework, the team discovered that sociomathematical norms were difficult to conceptualize and measure during relatively brief interactions with families at exhibits. In the classroom, norms can be thought of as well-established expectations and assumptions about learning and thinking that develop over the course of months among students and teachers. In contrast, an exhibit experience happens in a matter of minutes with staff and families rapidly negotiating expectations they bring with them, such that the notion of norms is elusive, if even relevant. From a measurement perspective, the concept presented many challenges. Measuring sociomathematical norms requires the identification of a consistency of patterns within interactions and often involves analyzing the problems, solutions, explanations and justifications of mathematical activities (Cobb, Wood, Yackel, & McNeal, 1992). The team struggled to identify indicators of previously held, negotiated, or emergent norms that multiple team members could assess reliably. Given these challenges, and after extensive consultation with the research oversight committee and advisors, including experts on sociomathematical norms, the team set the notion aside and continued to answer other research questions.

The basis for this study was to explore an approach other than sociomathematical norms to learn how situated understandings of facilitated interactive math exhibits might emerge among families and how these understandings, in turn, might shape the families' experiences at interactive math exhibits. The lens of activity frames (Goffman, 1986; Norris, 2011; Norris & Jones, 2005; Rowe, 2005; Scollon, 1998) was selected as it seemed relevant to understanding brief experiences and it provided a method to look at expectations and understandings of the situation as these emerged through discourse among participants. This study presents an activity frame approach to video analysis resulting in descriptions of six emergent activity frames with illustrations of these frames through the use of video transcripts, and discussion of possible implications of these frames on math reasoning behaviors for families at exhibits. The potential of this approach and these results for future research will be discussed, as well as how practitioners might recognize these frames in their work to support family learning.

Building on Prior Work Related to Activity Frames

Fundamental to the research in this study is the theoretical construct of activity frames that builds on the concept of "situation definitions" from the field of sociolinguistics (e.g. Norris & Jones, 2005; Scollon, 1998) and refers to the implicit expectations and assumptions about the meanings, goals, and ways of behaving that underlie a particular experience. Goffman (1986) described activity frames as certain situational characteristics (e.g. understandings, expectations, goals) within individual interactions that become salient, determining how participants perceive that particular situation and the roles and the identities that they assume while in it (Greeno, 2009; Hand, Penuel, & Gutiérrez, 2012; Hegedus et al., 2014; Norris, 2011; Norris & Jones, 2005; Scollon, 1998). According to Rowe (2005), activity frames are central to social interactions because they determine which behaviors are expected and acceptable, including the roles available and the interpretation of behaviors. Activity frames are a fundamental part of human social interactions, affording and constraining the roles participants can adopt within a specific interaction, behaviors that are expected or sanctioned, and ways that actions and talk are interpreted (Rowe, 2005, (Pattison et al., 2018, in review). In several studies, the negotiation of activity frames has been used within the context of STEM classroom learning (Greeno, 2009; Hutchison & Hammer, 2009; Jimenez- Aleixandre, Rodriguez, & Duschl, 2000; Shim & Kim, 2018).

A particular example highlighted in the work of Shim and Kim (2018) talks about “productive” or “unproductive” framings during science inquiry and group discourse. This type of framing can have a powerful influence on student participation in peer group work. Other studies suggest that students may frame a science activity as being about “making sense of the phenomenon” versus “playing the classroom game” (Hutchison & Hammer, 2010) or “doing science” versus “doing school” (Jimenez-Aleixandre et al., 2000), each of which has different implications for peer group dynamics and the types of discourse and participation that are expected and valued (Jimenez-Aleixandre et al., 2000).

The activity frame lens was used in the NSF-funded project Designing Our World (DOW) (Pattison et al, in review). An important goal of the project was to understand how activity frames influence identity negotiation and how they provide a useful perspective for educators to better understand ways in which participants’ identity work can be supported. By applying activity frames to an informal learning environment, DOW researchers developed the Identity-Frame Model, a descriptive model of engineering learning identity negotiation (Pattison et al., in review). In the Identity-Frame Model, an activity frame is an emergent and negotiated understanding of what activities are about, the primary activity goals, and how engineering is regarded during the experience. Both activity frames and engineering learning identity are negotiated by participants. Within the context of the DOW informal engineering education program, researchers asserted that regardless of the development and delivery of programs, youth interpreted activities on a collaboration/competition spectrum. At one end of the spectrum, youth focused on individual work and success, establishing a competitive activity frame by competing to get the right answer the fastest and engaging in conflict regarding activity materials and goals. On the other end of the spectrum, youth worked together with minimal conflict, shared material and ideas, and claimed success as a group, creating a collaborative activity frame.

Drawing on prior work, researchers on the present study defined activity frames as continuously negotiated context-specific emergent understandings or expectations, either implicit or explicit, about the nature and goals of the family and staff interaction at math exhibits.

Methods

This study built on the findings of the REVEAL pilot study and the theoretical model developed in DOW. We used a qualitative video analysis approach intended to answer the research questions. Using inductive analysis methods, we analyzed a total of 20 videos previously collected during the second REVEAL study to identify emerging activity frames. Details on these methods are included below.

Partnerships

The work presented in this report was a collaboration between the Oregon Museum of Science and Industry (OMSI), the Institute for Learning Innovation (ILI), TERC, and Adelante Mujeres. Scott Pattison from ILI and Andee Rubin from TERC met regularly with the OMSI team to co-develop an analysis plan and protocol, provide feedback on video analysis and co-lead the interpretations of results, and provide essential feedback on this research report. Adelante Mujeres, an organization that educates and empowers Latina women and their families in the state of Oregon, continued their partnership with OMSI and REVEAL to ensure that a family math learning perspective was included in the project. Adelante Mujeres staff shared their perspective through video observations and co-organized a dissemination event where the REVEAL team shared resources with Latino family advocates of the Hillsboro School District.

Culturally Responsive Research Approach

The research team continued to apply the Culturally Responsive Research Framework (Garibay, C., & Huerta-Migus, L., 2017) developed during the project. This framework is organized around the five types of validity Kirkhart and Hopson (2010) identified as crucial to culturally responsive evaluation, which include methodological, interpersonal, theoretical, experimental, and consequential. This particular study included bilingual researchers (Spanish and English) and involved Adelante Mujeres staff in video analysis and interpretation of results.

Exhibit Context

The videos selected for analysis included families (groups that consisted of one adult visitor over the age of 18 and at least one child between the ages of four and 17) engaging in an unstructured interaction with an OMSI educator (facilitated experience) at one of two interactive math exhibits. One exhibit was “Balancing Art” and the other was “Drawing in Motion.” In “Balancing Art,” visitors hang pieces of different weights on either side of a pivoting rod to create a balanced mobile; in “Drawing in Motion,” visitors draw different designs using sliders that represent X and Y coordinates. Detailed information on each exhibit can be found in Appendix A in this report.

Mathematical Content Focus

The analysis of activity frames using the REVEAL videos was situated in the mathematical content focus of the project, focusing particularly on family interactions at math exhibits designed to encourage *algebraic thinking*—a type of mathematical reasoning, similar to scientific inquiry, involving the exploration of mathematical relationships and the use of these relationships to understand and create in the world around us (Kaput, Carraher, & Blanton, 2008; National Council of Teachers of Mathematics, 2000). Algebraic thinking includes a range of strategies for reasoning with relationships between quantities, using a variety of formal and informal representations (e.g., verbal, graphic, tabular). These reasoning strategies are applicable to a broad age range, including elementary school children (e.g., Kaput et al., 2008).

For the experimental study, the REVEAL team defined and identified indicators of mathematical reasoning that (a) were relevant to the focus of the exhibits, (b) varied across groups, and (c) were readily visible through observations of staff-family interactions. Figure 2 below summarizes the dimensions identified through the project: (a) identifying mathematical quantities, (b) describing mathematical relationships, (c) exploring mathematical relationships, and (d) achieving mathematical goals. The description of mathematical reasoning relies heavily on verbal indicators from family groups (e.g., naming mathematical quantities and verbally describing relationships among them), since this is an important way that staff facilitators assess how visitors are understanding the mathematics in the exhibits. However, the definition also recognizes the importance of behavioral aspects of mathematical reasoning, including nonverbal ways that visitors organize and track their actions to explore the relationships and how visitors are able to accomplish the mathematical tasks and goals posed by the exhibits or the facilitators. During the REVEAL experimental study, this conceptualization of algebraic reasoning was further refined into a video coding framework (Figure 2) that assessed level of reasoning for each of the four dimensions across all family members (using the family as the unit of analysis).

Dimension	Dimension description	Example exhibit-specific indicators BA: "Balancing Art" exhibit DiM: "Drawing in Motion" exhibit
Identifying mathematical quantities	Visitors verbally identify the mathematical quantities (variables that change in relation to other variables) embodied by the exhibit.	BA: Commenting about the weight of the piece, distance of pieces from the fulcrum, or "heaviness" of piece (torque).
Describing mathematical relationships	Visitors verbalize the relationships among the mathematical quantities in the exhibit, especially the effects of changing one quantity on the other quantities.	DiM: Discussing how participants at both sliders have to move simultaneously to create a diagonal line.
Exploring mathematical relationships	Visitors organize and track their actions to determine the relationships among quantities.	BA: Systematically moving or placing weights on the rod based on the relative torque on each side of the fulcrum.
Achieving mathematical goals	Visitors are successful in accomplishing the mathematical challenge(s) posed by the exhibit or by staff facilitators.	BA: Balancing the rod with weight configurations of different levels of complexity (e.g., symmetric, asymmetric). DiM: Successfully drawing challenge shapes of different levels of complexity (e.g., shapes with or without diagonal lines).

Figure 2. REVEAL video coding framework used in the quasi-experimental study.

Appropriate to the museum setting, and aligned with concepts of "early algebra" (Kaput et al., 2008), the framework and related coding scheme were designed to capture multigenerational algebraic reasoning as it occurred within groups for both adults and children. Similar to other research on mathematical reasoning outside the classroom (Pattison, Rubin, & Wright, 2017), families in the REVEAL studies were often quite flexible in the ways they used multiple mathematical reasoning strategies during the interactions, adapting to the needs and interests of different group members and the demands of the creative design challenges presented in the exhibits.

For the study presented in this report, we started with (and focused on) identifying emerging activity frames that related to the video coding framework's fourth dimension about how visitors accomplish the mathematical challenges posed by the exhibit or by a staff member. This dimension seemed relevant to activity frames because explicit and implicit understanding of what the activity was about seemed to relate to how families approached and completed the challenges set forth by the experience.

Video Selection

Data included in this study were video recordings of family groups interacting with math-related exhibits at OMSI. The original video was collected during the REVEAL quasi-experimental study where researchers tested the REVEAL facilitation model with four educators at three different exhibits and compared a variety of outcomes between facilitated and unfacilitated interactions (Pattison et al., 2017).

From the 392 video recordings collected during the REVEAL quasi-experimental study, a total of 20 videos were selected and analyzed for this study, with equal representation from families interacting at two exhibits ("Drawing in Motion" and "Balancing Art"). These two exhibits were selected because math reasoning behaviors tend to be more evident than in "Designing for Speed," which is the third exhibit that is part of the REVEAL exhibit (Appendix B). Only videos that included a facilitator interacting with the family were selected. Informed by work on DOW, researchers determined that 20 videos could be analyzed within the scope of this study and would provide sufficient data to answer the research questions outlined above. To provide a breadth of videos that encompasses the diversity of the OMSI audience, researchers utilized two criteria for selection: math awareness and language spoken at home. This information was collected from visitors during the quasi-experimental study through post-interaction surveys. Out of the 20 videos, 10 videos were from families that reported speaking more than one language at home, while the other 10 families reported only speaking one language at home. From each of those sets, half of the families reported being aware of the math content in the exhibit while the other half did not report being aware of the math on the exhibit. Is important to note that the post-interaction survey was completed by one adult in the family group and math awareness was coded as being present if the adult referred to math in a question asking about the content in the exhibit. This measure potentially increased the likelihood that the videos represented a variety of math-related activity frames potentially at play during these interactions, including interactions in which activities were explicitly framed by families as mathematical and those in which the math remained implicit. However, it is important to mention that this measure only captures the math awareness of a single adult member of the family.

Video Analysis

Once videos were selected, the research team piloted several approaches for coding videos for activity frames. While previous work and extant literature suggested several potential activity frames and coding approaches, the team found that coding videos from a deductive perspective with an *a priori* list of frames left too much risk of missing frames important to exhibit interactions that may not have been identified by earlier research. Therefore, an exploratory inductive approach was adopted to identify key activity frames and definitions, but video clips of the family interactions at exhibits are very rich in social and behavioral activity and this richness made it difficult to identify specific actions that suggest activity frames and see overall patterns of emergent frames. Ultimately, a three-step process was developed to code the video data and identify activity frames. The process included (a) writing a summary, (b) parsing the summary, and (c) writing a qualitative description.

During the first step of the process, researchers viewed a video clip in its entirety while taking notes regarding the perceived goal of the family at the exhibit, indicators of math reasoning behaviors, and social dynamics. Once they finished viewing the clip, the researcher wrote a 2–3 sentence summary of the interaction capturing the overall narrative of the clip. Limiting the length of the summaries provided constraints, allowing researchers to distill the essential qualities and events from the interactions. During the second step, researchers parsed the summary into segments based on the perceived dominant activity frame of the family at the exhibit. For example, at “Balancing Art,” a section might have been parsed when a family moved from balancing the bar to determining the value of the mystery weight. Parsing was done based on the dominant activity frame. In cases where extensive negotiation of the goal occurred, that negotiation was parsed as a separate segment. Parsing the summaries helped to identify significant shifts in the interaction suggesting potential changes in activity frame. All twenty videos were summarized and parsed by at least two researchers. Consensus on the number and content of parsed segments was reached through discussion among the researchers with the number of parsed segments ranging from one to four for a single exhibit interaction.

In the final step, researchers wrote a qualitative description for each of the parsed segments. The qualitative descriptions detailed specific actions, behaviors, and observations from the clip, including what the dominant activity frames appeared to be, what different individuals were doing, the social dynamics and power structures at play, what mathematics reasoning behaviors were observed, how the facilitator contributed to the interaction, and negotiations individuals made to change the activity frame. The qualitative descriptions provided a deeper look into each of the video segments and provided details regarding the social, mathematical, and behavioral dynamics in the summaries. Qualitative descriptions were presented in a table form with narrative entries (Appendix B).

Qualitative descriptions and summaries of the twenty clips were generated, reviewed, and discussed by the research team with input from practitioners (including an OMSI educator and Adelante Mujeres staff) to identify aspects of the interaction that appeared most consequential to the quality of the exhibit experience and richness of the mathematical behaviors observed (Charmaz, 2006; Creswell, 2013; Patton, 2015). Guided by the research questions and the qualitative and inductive approach used in this study, qualitative descriptions were used to identify and describe overall patterns of emergent and prevalent activity frames at play during families' interactions with the exhibits.

Results

The analysis described above resulted in the identification and illustration of six activity frames related to how families accomplish the mathematical challenge(s) posed by the exhibit or by staff facilitators. These six frames are presented as contrasting pairs to facilitate interpretation and illustration and include (a) Completing and Refining, (b) Teaching and Exploring, and (c) Collaborating and Competing. Common indicators of these activity frames are summarized in Tables 1–3, and each pair of activity frames is explained in detail using descriptive examples in the following sections.

Table 1: Description and Possible Indicators of Completing and Refining

Completing and Refining: Involves the way that families approach engaging with challenges provided by the exhibit, facilitators, or other members of the group. Families can perceive the activity as a task that they want to finish in order to get it done or to move onto another activity (Completing). Families can also perceive the activity as a task that they want to engage with thoroughly and accurately by refining their approach and strategy iteratively (Refining).	
Completing	Refining
Working quickly	Responsive to feedback
Less responsive to feedback	More "standards," repeating or fixing mistakes
"Good enough" attitude/language	Conversation around goals
Stop after one completed challenge	Coordination
	Talk of strategies
	Repeat activities or accomplish multiple challenges

Table 2: Description and Possible Indicators of Teaching and Exploring

Teaching and Exploring: Involves the way that families approach the learning goals underlying the activity. Families can perceive the activity as a didactic activity wherein a member of the group takes on a role of authority, teaching or facilitating others in the group (Teaching). Families can also perceive the activity as an inquiry activity wherein they will all engage with the exhibit, exploring and determining what they need to do together with or without specific goals (Exploring).	
Teaching	Exploring
One-way communication	Two-way dialog
Conversation includes instructions, explanations, questions, suggestions, and statements	Statements and questions from participants
One individual in a position of authority	Participants on "equal ground"
Imbalance in verbal and physical activity between individuals	No individual taking a leadership or supervisory position
	Shared participation at exhibit

Table 3: Description and Possible Indicators of Collaborating and Competing

Collaborating and Competing: Involves families' negotiation of group member roles while engaging with the challenges provided by the exhibit, facilitators, or other members of the group. Families can perceive the activity as an activity wherein they need to work together (Collaborating). Families can also perceive the activity as a competition wherein some members attempt to "outperform" others doing something better or faster than others (Competing).	
Collaborating	Competing
"We" language—Let's work together	"I" language
Conversation around goals, what to do and how to do it	Less responsive to feedback
Helping each other	Individual focus on the exhibit and/or other individuals
Taking turns	Disagreement about what to do or how to do it
Individual focus on the group	

Completing and Refining

This contrasting pair of activity frames refers to the way in which families approach engaging with the challenges provided by the exhibit, facilitators, or other members of the group. For the purposes of this study, a challenge is defined as a call to take part in an activity and can be built into an exhibit, such as the drawing challenges at the "Drawing in Motion exhibit," or issued by a facilitator or family member, such as a balancing challenge at the "Balancing Art" exhibit. Groups coded as working under the Completing Activity Frame seemed to perceive the exhibit as a task that they wanted to finish, sometimes to simply get it done and move onto some other activity within the museum or to meet a goal.

In this activity frame, families appear focused on working through the challenges as quickly as possible. Conversations among group members usually revolved around the speed or process of engaging with the challenge and there was not as much room for iteration.

Groups coded as working under the Refining Activity Frame generally perceived the activity as a task that they wanted to finish accurately or thoroughly by refining their approach and strategy. These groups usually engaged in iteration until they met a “standard” that was set by the group. In these cases, families were often observed trying a challenge multiple times when the outcome was not as they had anticipated, such as fixing a "mistake" by erasing a diagonal line in at the DiM exhibit because it looked "messy" or finding alternative solutions to a challenge that satisfies the members of the group. Often families working in this activity frame discussed their approaches to the challenge and were vocal about their goals or strategies, such as coordinating movements at the DiM exhibit (e.g. "Let's go slow," "On the count of three").

Tables 4 and 5 contain two transcripts from a video in which a family is working on the “Drawing in Motion exhibit.” A Refining Activity Frame is dominant in the first transcript (Table 4) where two children work on the exhibit challenges. In the second transcript (Table 5), there is an ongoing negotiation between the same two children and an adult, with the adult trying to shift the dominant Refining Activity Frame to a Completing Activity Frame.

At the time that the first transcript starts, two children have been watching a group playing with the “Drawing in Motion” activity and are waiting for their turn to interact with the exhibit. They spend around 10 minutes observing while an adult that was accompanying them plays at nearby exhibits. The children work through the first challenges, which only have vertical and horizontal lines. They then move to a challenge with diagonal lines where they are trying to coordinate how they need to move to create the line as close as possible to the line on the screen.

Table 4. Example of Refining Activity Frame at “Drawing in Motion”

Line No.	Conversation	Behavior
1	C1: Wait, am I going to 5?	Educator has explained the coordinates and kids are exploring which number of the coordinates belongs to their slider.
2	C2: No, I am going to 5.	Explaining to C1.
3	C1: Yes, 1, 5.	Saying coordinates aloud.
4	C1: Now we are going to 8 together, slowly. Ready...	
5	C2: Go!	Coordinating movement.
6	Ed: Looking good! Looking good.	
7	C1: Go faster. We are going to 8.	They continue moving slowly to complete diagonal and start smiling as they get to the end completing the drawing. They move to the next challenge.
8	C1: Ok, we need to go slow, you go to 4.	Coordinating movements of sliders.
9	C2: I got to 4! I stay in 4! I don’t have to move.	Singing and dancing with educator.
10	C1: Ok, wait you go to 10, I go to 4 but we are going to have to go slow, you ready?	
11		C2 singing.
12	C1: Slow, slow ready? You have to go slower.	
13	Ed: You are doing good, stay the course!	
14	C1: You are going too fast, look at the screen. You have to move slower and I have to move faster.	Referring to the slope of the line. To achieve the slope one person has to move their slider twice as fast as the other.
15	C2: I am already at 4, almost!	

Notes: C1: Child 1, C2: Child 2, Ed: Educator. Transcript from video 143 at DiM, from minutes 7:40 to 9:59.

The transcript in Table 4 shows both children working together, refining to finish the challenges with accuracy. Once they reviewed the coordinates and explained the direction they needed to move in (Lines 1–3) they started working on the drawing challenges, taking their time. They articulated that they needed to move slowly (Lines 4, 8, 10 and 12), perhaps realizing that this will allow them to coordinate their motions more easily than if they go faster. The children finished all of the challenges set forth by the Drawing in Motion exhibit and articulated how they needed to move the sliders, especially when they reached diagonal lines (Line 8–14). Of particular interest is the mention of the speed of movement when encountering the diagonal (Line 14). Here one child explained to the other that one of them will have to move slower to be able to complete the line due to the slope.

Once the children finished the challenges, an adult who is part of the group and who had been at a set of exhibits nearby walks over and joins the activity. The children explain to the adult what they need to do, but the adult wants to start and complete the activity quickly and does not wait for the children to be done with their explanation. From the start of this interaction there seem to be conflicting activity frames between the children and the adult, with the children prioritizing accuracy and the adult prioritizing speed. The excerpt of this transcript in Table 5 illustrates this negotiation.

Table 5. Example of Negotiation in a Refining Activity Frame at “Drawing in Motion”

Line No.	Conversation	Behavior
1	A: Ok, we will do it at 1, 2, 3. 1, 2, 3…	Showing children how to move the slider.
2	C1: You have to do it slow.	
3	C1: I am going to 8.	
4	Ed: Now, explain to him...	Asking kids to explain to adult how they had moved the sliders in the prior challenge. The adult interrupts educator.
5	A: Wait, on three, go to 8, ready?	
6	C1: Slowly.	Highlighting the speed they should go.
7	A: On 3. 1, 2, no, do it, do it fast! 1, 2, 3.	They move and make a line. The line is “crooked” and is not similar to the reference line on the screen.
8	C2: That looks ugly.	Talking about the drawing on the screen.

9	A: That's pretty close.	Laughing.
10	Ed: Did you follow your son's instructions?	Asking adult.
11	A: No.	
12	C1: He said to go fast.	Pointing at adult.
13	A: No	
14	Ed: Is he not following your directions?	Asking kids.
15	A: All right, the next one.	Reading coordinates.
16	A: (1, 2) (4, 4), go!	Reading coordinates.
17	C2: You are the Y.	Adult starts to move using the X coordinate, one of the children (C2) corrects him.
18	C1: I am going to 10.	
19	A: You are going to 10 and I am going to 4. Ready 1, 2, 3.	They move the sliders creating the line.
20	A: Ohhhh!	Calling attention to the line. The line doesn't look like the reference line on the screen, it looks like an arch.
21	C1: He did it, he did it.	Pointing to adult, seeming to assign the "blame" of the arched line to the adult.
22	A: It arched, ha, ha, ha.	Laughing
23	C2: That's what you call a mouse?	Referring to the drawing on the screen.
24	A: It arched, instead. I can go slower.	
25	Ed: You think he can handle the fox?	Asking the kids about the next drawing challenge which requires multiple diagonal lines instead of just one like the previous challenge.
26	A: (7, 10)	Reading coordinates for the diagonal lines.
27	C1: Dad!	Trying to get adult to go slower.

28	A: Ok, ready?	
29	C2: Dad!	Trying to get adult to go slower.
30	A: (6, 9). (7, 10) ready?	Reading coordinates for the diagonal lines.
31	A: I'm going to 4, right?	Checking in with kids to make sure he is using the right coordinate.
32	Ed: You saw how well your sons did right?	Adult laughs.
33	C2: This is going to be one ugly fox!	Referring to the drawing.

Notes: A: Adult, C1: Child 1, C2: Child 2, Ed: Educator. Transcript from video 143 at DiM, from minutes 14:48 to 16:27.

Throughout this transcript (Table 5), there is an active negotiation between the Completing and the Refining activity frames. The children had worked on the exhibit refining their approach and strategy and seemed to prioritize accuracy while the adult seemed to want to just complete the challenge and move on. The children tried to explain the instructions to the adult and consistently highlighted what was not going right, according to them (Lines 2 and 6). They appeared uncomfortable with the results (Lines 23 and 33) and pointed at the adult any time the lines in the screen didn't turn out like the reference lines, almost as to highlight who was at fault for the "messy" lines (Lines 12 and 21). The interaction ended when they completed the four challenges and the adult encouraged the children to move to a different part of the museum.

An interesting relationship exists between the contrasting frames in this set. When families are refining their approach and strategy there seems to be more of an opportunity to engage in conversations regarding math. For example, in the transcript in Table 5, Line 14, the children were observed talking about the coordinates and the relative speed they had to move so they could match the slope of the diagonal line. However, once the adult joined the activity and tried to get the children to just complete the task, the conversation shifted to be more about how they would complete the challenge as fast as possible.

Teaching and Exploring

This contrasting pair of activity frames refers to the ways in which families approach the learning goals underlying the activity. Families can perceive the activity as a didactic activity wherein a member of the group or the facilitator takes on the role of teacher and others take more of learner roles. In these cases, there seems to be a position of authority for a person relative to others. This person usually gives instructions to others, telling them what to do or how to do it. Conversations can include procedural assistance such as when members say "move to the circle," "go up to 7 and stay put," and "now, hang a 3 there." They can also include the person taking on more of the facilitator role asking leading questions such as "Where are you thinking of putting that?", providing suggestions such as "What if you put it here?", and/or giving hints such as "Is there anything times 3 that will give you 28?" Often this person was observed taking on more of the facilitator role asking for a summary statement, testing for understanding at the end of an interaction or providing a critique of the group's performance. For example, "So how does where you put the weight affect the bar?", "See when you move the slider, the line goes up," or "You went past 10." These questions and conversations appeared to be geared towards deepening conceptual understanding of, or engagement with, the exhibit.

Table 6 provides a transcript of two adults approaching the exhibit with a Teaching Activity Frame. They spend the interaction teaching a child about "Drawing in Motion." The first adult (A1) is not actively involved with the exhibit but is providing instructions for the child, while the second adult (A2) is actively involved with the exhibit while also providing instructions for the child. In this interaction, Adult 2 and the child approach the exhibit and go through the challenges. The child initially approaches the exhibit in a playful way without following the instruction in the challenges. Adult 1 joins them and directs/coaches the child from behind so the child can take turns with Adult 2 and follow instructions on the screen. Adult 2 moves the slider for the X coordinate and child (with Adult 1 instructing him) moves the slider for the Y coordinate.

Table 6. Example of a Teaching Activity Frame at "Drawing in Motion"

Line No.	Conversation	Behavior
1	A2: All right.	C immediately moves slider vertically up.
2	C: Agh….	A2 and C move slider at the same time, creating a curvy horizontal line.
3	A1: Go to 4.	Observes screen and sees that both A2 and C are far from the coordinates (4,10).
4	A1: No, I'm sorry, you need to go to 10.	After observing screen, C moves the slider in the wrong direction (down instead of up).
5	A2: Haha.	A2 laughs after seeing C went the wrong direction.
6		Child moves slider up past 10.
7	A2: You're past your 10.	After observing C went far up with slider. Smiles.
8	A2: Go to 4.	Points at the screen and makes a vertical line gesture with her hand.

9	A2: Makes a sliding noise here as she moves slider.	C moves slider down to 10 and then Adult 2 moves slider horizontally to 4. The next line is a diagonal one.
10	A1: All right. Now you slowlyyyyy need to make your way to 10.	Coaches C while looking at the screen coordinates (4,10)—a diagonal line.
11	A1: Start going.	Glances at C and observes screen: C barely moved slider.
12	A2: A little faster bud… Ha ha ha	While moving slider and seeing diagonal line is more horizontally slanted than in the pattern on the screen. Laughs.
13	A2: Ohhh… Ha ha ha.	After observing the diagonal line on screen was not similar to the reference line. A2 laughs and steps back.
14	A1: There you go, you guys made a triangle.	After observing triangle on screen.
15	Ed: Nice.	After observing the drawing from challenge 3. And A2 keeps laughing.
16	C: Close!	Observing motion drawing on the screen puts his hat on. A2 is still laughing.
18	Ed: Closer to some of the attempts I've seen.	
19	A2: Oh, yeah… I had to match him!	Suggesting that she had to watch C's speed and match it in order to make the diagonal line. Presses the button to move to the next challenge #4
20	Ed: I think that's good.	
21	C: Mommm… Ha, ha, ha.	Having fun and moving slider all the way down while bending his body towards the right.
22	A2: All right. You done?	
23	C: Yeah.	Turns to look at A1.
24	A2: Ok. Get up on number 9.	Looking at the screen and making a gesture with her finger.
25	A2: Oops!	After seeing C moved past number 9. She then proceeds to move slider horizontally.
26	A1: Move down a little.	Directs C to move slider so he can reach coordinates even if they miss diagonal.
27	A2: You're past your 10, baby.	Talks immediately after seeing how Child moved slider and next coordinates on the screen.
28	A2: There you go.	

29	A1: Now you gotta go to 8.	Directs C pointing at slider while observing coordinates on screen.
30	A2: Move at the same time.	After observing the next pattern and coordinates require them to draw a diagonal.
31	A1: Now you've got to slooooowly, make your way to 4.	Directing C to move slider.
31		Both A2 and C move sliders slowly
33	A1: Now you need to slowly go back to 8.	Directing Child to move slider.
34	A2: Uh oh. I'm sorry	While moving slider and observing that diagonal line is far from the pattern on the screen.
35	A1: Nice.	While observing screen and noticing that C moved slider.
36	Ed: It is exciting!	
37	A2: I know!	Smiles and laughs after looking at the screen- diagonal line she and C drew is far from the pattern.
38	A1: All right. Let's go all the way up to 10.	Directs C to move slider.
39	A1: All right. Come down just a little bit to 9.	
40	A2: ha, ha, ha, ha……..not quite!	Laughs after completing challenge.

Notes: A1: Adult 1, A2: Adult 2, C: Child, Ed: Educator. Transcript from video 214 at DiM, from minutes 3:06 to 5:33.

In the transcript (Table 6), the child appears interested in 'playing' at the exhibit (Lines 1, 2, 11, 21) while the adults seem to perceive the activity as a didactic activity where they will teach the child and complete the challenges. Lines 28–34 of the transcript show how the adults are providing constant instruction and direction for the child as he moves the slider. When families perceived the activity as didactic the person(s) taking on the teacher role was/were observed talking more with less talk from other family members. Most comments are usually directed at the members that have been identified by others as being there to "learn." Family members might work more under the Teaching Activity Frame because they could think that they "know" a concept that is important to teach to others. For example, in this transcript there seems to be a difference in the awareness of math for both adults and the child. The child might be aware of the numbers, shape, and direction, and the adults might be aware of the relationship between the speeds of the sliders. When encountered with the diagonal line in the drawing challenge, Adult 2 instructs Child to "go slowly" so that Adult 1 can match his motion and make the diagonal line.

In the Exploring Activity Frame, families appear to conceive of the exhibit as an inquiry activity where they will be engaging together. The activity is usually open-ended. Family groups coded as working under this activity frame, for the most part, work as equals at the exhibit. Family members may provide suggestions or directions to each other, but communication is not unidirectional from a place of authority to others; rather, it goes back and forth, or in multiple directions with everyone contributing. Researchers observed members of the group consult and advise each other with no individual taking a leadership or supervisory position. In most cases, family members are working toward a similar goal and the communication and discussion between them is constructive. All parties appear interested in using the exhibit and understanding it better.

In Table 7, a transcript of a family working in "Balancing Art," an adult and a child challenge each other to balance the bar by exploring mathematical relationships: calculations. In this excerpt, the child sets the bar by adding weights on one side of the bar, so the adult can try to balance the bar.

Table 7. Example of an Exploring Activity Frame at "Balancing Art"

Line No.	Conversation	Behavior
1	A: All right, is that it?	Observing Child hanging weights on one side of the bar; asks question when Child pauses.
2	C: No.	The Child proceeds to look for another weight.
3	A: You put on too many… Maybe over there.	Jokes after observing Child hanging a weight on bar.
4	C: There!	Child finishes hanging weights. Crosses arms.
5	C: All right here. Let's see here	Steps back slightly from the bar to see the weights.
6	A: All right, 6 times 4 is….. 24.	Points with his fingers at weights.
7	C: Plus	Interrupts Adult after his first calculation and smiles.
8	A: Three… Plus…	Laughs and bends to see weights and points at weights hanging on another weight.
9	C: This is 10.	
10	A: This is three times.	Points at weights

11	C: 24 plus 40	Looks at Adult.
12	A and C: Is 64	Looking at each other. Then Adult turns and points at the last weight.
13	A and C: 67!	
14	C: You need to get 67 over there!	Looking at the other side of the bar.
15	Ed: Don't tell him. Don't tell him. Let him figure it out.	Adult smiles.
16	A: All right.	Bends and grabs a weight.
17	Ed: You must be a math genius.	Approaches from behind.
18	A: Is 24.	Purposely hangs a weight 4 on the hole 6.
19	A: Let's see…	Bends and grabs a weight and the child also grabs another weight.
20	C: 48…….48.	After grabbing a weight hangs it on the weight Adult is still holding.
21	A: 48.	Repeats calculations and bends to grab another weight. Picks us the weight and puts it back down.
22	A: What do we want?	Stands up and looks at weights hanging on bar.
23	C: 67!	Holds a weight.
24	A: so we can put more on this.	Bends to grab a weight to hang under another other weight.
25	C: Okay… That is 12 plus…	Looks at the weights and performs mental calculation.
26	A and C: 60!	
27	C: We need to get…	Looks at the weights.
28	A: Here… It would be 6.	Takes the weight Child was holding and hangs it on the bar.
29	A: One more… Would be 7.	Grabs a weight 1 and hangs it with Child's help in hole 1.
30		Child holds both sides of the bar to make sure it balances while smiling.

31	A: It's getting there.	While looking at the bar and blue balancing zone.
32	C: Yeah. It's balanced.	After holding bar and letting it go to confirm it is balanced. Steps back to see it.
33	A: Perfect.	

Note: A: Adult, C: Child, Ed: Educator. Transcript from video 305 at BA, from minutes 17:47 to 19:09.

The transcript in Table 7 shows a dominant Exploring Activity Frame. Throughout the interaction, the child and the adult are taking turns speaking; both seem vested in the activity and share equal authority. Lines 5 through 13 demonstrate how the adult and the child are working together toward the same end—they are working closely as a team to calculate the force on one side of the bar. They are so well coordinated that they are finishing each other's sentences and at times saying the same thing at the same time. There is a lot of talk about calculation. Interactions are friendly and collaborative despite the nature of the challenge. The adult allows the child to intervene and in some instances prompts him to remember the numbers (totals were previously calculated for the most part).

Competing and Collaborating

This contrasting pair of activity frames involves the way that families approach the challenges provided by the exhibit, facilitators, or other members of the group. Families can perceive the activity as a collaborative activity where they need to work together to complete the activity. In this case, family members are observed working together toward a common goal. This is characterized by family members engaging in conversations and discussions about how to approach or solve a specific challenge or activity at an exhibit. These conversations happen either before engaging with the activities or during the time the family is working through the activity. In general, in this Collaborating Activity Frame, families decide together and agree on what they are trying to do as well as their approaches or solutions. In a collaborative frame, families use inclusive terms such as "let's," "we," and "us."

One example of a Collaborating Activity Frame is presented in the transcript below (Table 8) where an adult is working with a child at "Drawing in Motion." They are working on the third drawing challenge, which requires groups to create a diagonal line to make a triangle that turns into a mouse upon completion of the challenge. The adult and the child attempt the diagonal line but the diagonal line does not match the line that serves as a guide on the screen. The educator asks them if they would be willing to repeat the challenge and encourages them to think about strategies that they might use to draw the diagonal line. The adult and child engage in a short conversation, agreeing on a goal and approach.

Table 8. Example of a Collaborating Activity Frame at Drawing in Motion

Line No.	Conversation	Behavior
1	A: What do you think?	Referring to repeating the drawing challenge
2	C: Hmm, yeah.	
3	Ed: You want to try again? Okay.	
4		A different child approaches the exhibit and presses the button that starts the third drawing challenge.
5	Ed: Oh! And you are right where you needed to be! Look at that!	Observing the screen and remarking that the cursor is in the location (coordinates) marked as "start" in the drawing challenge.
6	C: You go down.	Suggesting to adult after observing the adult not moving the slider to create a vertical line.
7		Adult slowly moves the slider to get to the coordinates.
8		Child moves slider horizontally to the coordinate marked in the challenge.
9	Ed: You guys are getting faster on those horizontals and verticals [lines].	Watching the screen.
10	A: Ok, I move on every beat and you move every other beat.	Smiling, while gesturing with her hand. Trying to use the creation of a beat to coordinate their movements to make the line.
11	C: If I move every other beat, I will get it like that…	Gesturing to mimic a staircase.
12	A: Right, you will move….slowly.	Gesturing, moving arm slowly.
13	C: I know.	

14	Ed: Are you ready? One, two, three, go!	Educator starts clapping to keep a beat. This is a strategy so the adult and the child can move according to the beat and create the line.
15		Both adult and child move sliders slowly drawing a diagonal line using the clapping beat as a guide.
16	Ed: Ohhhhhh!	Remarking as the adult and child are finishing the line and the line looks much closer to the line on the screen.
17		Adult and child start smiling after seeing the result.
18	Ed: Look at that!	
19	A: Is that better?	Joking and smiling.
20	Ed: That is not bad!	Continuing with the joke.

Notes: A: Adult, C: child, Ed: educator. Transcript from video 91 at DiM, from minutes 4:28 to 5:26.

In the transcript in Table 8, the adult and child talk about the goal of trying the challenge again to draw the diagonal line (Lines 1–8). They also talk about the strategy they would use for drawing the diagonal (Lines 10–13) which will be to use a beat to coordinate the movement of the sliders. Then, in Line 14 of the transcript, the educator starts clapping and the adult moves the slider at every beat and the child moves his slider during every other beat. This strategy is useful because the adult has to move twice as fast as the child to get the slope of the diagonal required for the challenge. In Lines 17 to 20 the adult and the child seem satisfied about completing the challenge and improving their previous efforts. After this section of the transcript, the adult and child continue working in a Collaborating Activity Frame in DiM completing the fourth drawing challenge. They also worked on creating the coordinates to draw a figure in the free draw challenge of the exhibit.

In a Competing Activity Frame a group perceives the activity as a competition, and members are usually not working together to complete the activity but rather working as individuals to see who can complete the activity first or better. In videos where competitive frames were the most obvious, family members were observed trying to outdo others in their group by proving themselves to be more competent, better, or faster than other members at finding solutions to the challenges or activities.

Sometimes emerging competitive activity frames were observed even when the activity encouraged collaboration. For example, one of the exhibit affordances of "Drawing in Motion" is that it promotes collaboration by requiring two people to work together to create a picture; however, some groups would work competitively. For example, in some cases, the competition revolved around which member could get to the designated coordinate first. Similarly, with the "Balancing Art" exhibit, facilitators often encouraged families to work together by asking one member of the group to hang a weight on one side of the bar and asking another family member to balance it by placing weights on the other side of the bar. This strategy, intended to foster a collaborative interaction, sometimes set a Competing Activity Frame where a member of the group would try to "stump" another family member.

An example of a Competing Activity Frame is highlighted in Table 9. In this transcript, an educator encourages the child to add weights to one side of the bar so that the adult can balance the other side. The child tries to "stump" the adult and watches as the adult struggles to balance the bar, comparing it to a previous attempt where she balanced the bar by herself.

Table 9. Example of a Competing Activity Frame at Balancing Art.

Line No.	Conversation	Behavior
1	C: Now you do it, mister	Child adds weights to one side of the bar.
2		Adult approaches the exhibit picks up weights and hangs them on his side of the bar.
3	A: Don't touch it!	After seeing child moving and holding the exhibit. Adult proceeds to hang a weight.
4	C: This is balanced, this un-balanced, and this is un-balanced. You need it in the blue zone!	Prompted by educator to explain the blue zone, child makes gesture with her arm and finger pointing at an area in the exhibit.
5	A: Right. Wait for it.	Adult hangs a weight, the bar doesn't move, he then removes it.
6	C: My side is still heavier!	Child moves part of her body while holding on to exhibit frame.

7	Ed: Be careful with it.	Educator warns child to be careful with exhibit. Child moves closer and touches frame of exhibit to bring it back.
8		Child gets closer to exhibit and her side of the bar.
9	A: Get off of it!	Looks at child after hanging a weight.
10	A: No, Jaden!	Talks to a young child who approaches to the exhibit.
11	C: Stop.	Talks to the young child.
12	A: Hey there, my side…	Looks at his side while holding a weight
13		Educator suggests Child help the Adult, but Child leaves.
14	A: My side… My side is heavier!	Adult grabs a weight and hangs on Child's side, testing it, then brings that weight back to his side.
15	C: No, because you won't wanna stick it out here, you want to stick it here! Because mine is out there!	Child points and moves her arm from the outside side of the bar closer to the center.
16	A: Oh you think so?	Adult proceeds to hang the weight closer to the center, where Child pointed.
17	Ed: She picked up on that part right away. Where it hangs matters.	Adult hangs a weight closer to the center

Notes: A: Adult, C: child, Ed: educator. Transcript from video 066 at BA, from minutes 4:20 to 5:45.

In Lines 1, 3, and 6, comments related to a competitive dynamic with the child highlight the struggle the adult was going through trying to balance the bar. In Line 15 the child tries to provide a suggestion but in Line 16 the adult responds with a sarcastic tone.

Questions about relationships

Relationships between Activity Frames and Math Reasoning Behaviors

We have described and illustrated six activity frames observed during family interactions with interactive math exhibits. Our qualitative analysis suggests that these activity frames have implications for how families engage with mathematics; however, it remains unclear exactly how these frames interact with mathematical engagement and reasoning. During the analysis process, we used previously created math reasoning behavior rubrics to annotate the math reasoning behaviors present in the interactions. Here we provide two examples of this process with the goal of fostering further discussion about the relationship between these activity frames and math reasoning. Overall, we feel that additional research is warranted to understand the relationship and to distinguish between frames that are specific to math and those that are relevant to museum learning more generally.

In Table 7 we included a transcript of an adult and child working in “Balancing Art.” During the interaction, the adult and child seemed to perceive the activity as Collaborating and Exploring; both were active at the exhibit and were working toward the same goal. We observed the family exploring mathematical relationships (Lines 6, 9, 12, 13, 18, 20, 21, 35, 26, and 29), verbalizing calculations (Lines 6, 12, 18, 20, 21, 25, 26, and 29), and performing mental calculations (Line 9). While it may seem like the adult and child are doing “school-like” math, they are exploring the exhibit together. The adult and child work as equals, interrupting and helping each other balance the bar.

The transcript in Table 4 illustrates two children using a variety of math reasoning behaviors at the “Drawing in Motion exhibit.” Much of their reasoning behavior falls under the category of *Talking about mathematical quantities.* This includes verbalizing numbers associated with the axes (Lines 1, 2, 7, 9, 10, and 15) and using math language to describe a point location or slider movement (Lines 3 and 4). In Lines 4, 7, 8, 12, and 14, the children are *Describing mathematical relationships* as they negotiate drawing a diagonal line. They discuss moving together and the qualitative relationship between the line they are making and the speed of the sliders. They *Explore mathematical relationships* as they coordinate their movement aloud (Lines 4, 5, and 10) and check their progress as they go (Lines 7, 12, and 14). Finally, the children *Achieve mathematical goals* as they successfully draw diagonal lines with accuracy.

These two examples highlight math reasoning behaviors when Collaborating, Exploring and Refining activity frames are at play, however we currently do not have evidence of a direct relationship between math reasoning behaviors and activity frames. Future research in this area could help the application of this research to practice by elucidating math-specific activity frames or activity frames that could promote specific math reasoning behaviors.

Relationships among Activity Frames

While the examples described and discussed thus far mostly represent single activity frames at play during an interaction, it became evident during our analysis that multiple activity frames from the same contrasting pair or different pairs are often at play, and that there are ongoing negotiations (actions related to changing the activity frame, intentionally or not, regardless of the outcome) within a group to establish a dominant activity frame. Describing the overlap of activity frames was not a focus for this study, but some initial analysis suggests that interactions among activity frames can have a potential impact on exhibit interactions and math reasoning behaviors for families. The following paragraphs provide preliminary descriptions of multiple activity frames at play and possible implications for math reasoning behaviors.

In two separate videos that are part of the sample for this study, two groups were observed seemingly working with an Exploring Activity Frame at “Balancing Art.” However, in one video (Table 9), a Competing Activity frame emerges with the adult and the child each wanting to balance the bar individually without taking suggestions or ideas from each other. In the other video (Table 7), the adult and child worked together to balance the bar, asking each other questions and sharing ideas. Initial coding of math reasoning behaviors using rubrics created for the exhibits (Appendix C) indicated that there were more of these behaviors in the video, suggesting that there might be more opportunity for these if both Exploring and Collaborating Activity Frames are present. Similarly, differences in math reasoning behaviors were observed when groups worked in Exploring and Refining Activity Frames rather than in Teaching and Completing Frames.

Negotiations among activity frames were also observed in some of our sample videos. An example of negotiation was observed in the transcript in Table 5 where the children were coded as working under Exploring and Refining Activity Frames. In that interaction, the children were in agreement about their goals and were trying to work slowly to complete the challenge while listening to each other and the facilitator. When the adult joins in, he tries to negotiate a Completing Activity Frame that shifted the activity to finishing the challenge as fast as possible to move on to the next activity.

Another example of negotiation was observed with a different family group working at “Drawing in Motion” in Table 6. In this particular video, the child makes several attempts throughout the activity to shift the activity frame from a Teaching to Exploring frame. Each time a challenge concluded, the child would start moving the sliders quickly back and forth signaling that she wanted to play, but the adults continued to work on the challenges not accepting the change in activity frame.

Similar to understanding relationships between activity frames and math reasoning behaviors, additional research on the relationships between activity frames could expand the application of this research to practice. Educator awareness and understanding of activity frames at play could inform the interaction between the educator and families promoting activity frames that would enhance visitor satisfaction, intergenerational communication and math reasoning behaviors.

Discussion

As a whole, the REVEAL project was proposed to provide evidence-based understanding of staff-facilitated family math learning at exhibits that would inform facilitator strategies and professional development. The first REVEAL study resulted in the REVEAL model of exhibit facilitation (Figure 1). The second REVEAL study began to illustrate relationships between responsive facilitation strategies and exhibit experience outcomes.

This study presents the results of applying the construct of activity frames, instead of sociomathematical norms, to learn how situated understandings of facilitated interactive math exhibits might emerge among families and how this understanding, in turn, might shape the families' experiences at the exhibits. The construct of activity frames seemed more relevant to these experiences because it can apply to any social interaction in which participants negotiate expectations regarding what the situation is about. Furthermore, it also seemed like a better fit for the interactions seen in the videos, since these tend to be briefer and more flexible than those experiences that take place across longer periods of time in more established learning groups (such as classrooms) to which sociomathematical norms have previously been applied.

Using an inductive and qualitative study approach, the research team was able to identify and describe the overall pattern of six emergent activity frames related to how families approach the challenges set forth by the exhibits and facilitators. The presence of these activity frames and the negotiation of frames within groups seemed to interact with math reasoning behaviors, with some activity frames promoting or constraining these behaviors. While these activity frames seem to have implications for how families engage with mathematics at interactive exhibits, as seen in Table 4 and 7, they do not seem to be specific to mathematics. In fact, it seems that the six activity frames described in this study may be important to consider during museum learning around any content domain. Additional research is warranted to understand how these activity frames interact and shape mathematical engagement and reasoning in museums. Future studies can expand our understanding of relevant frames, analyzing in more detail the relationship between frames and mathematical reasoning, and distinguishing between math-specific frames and those that are relevant to museum learning in general.

It is possible that the analysis process used in this study, while successful in identifying emergent activity frames, was not successful in identifying math-specific frames, since the interactions observed in the videos were brief (i.e., less than five minutes). For example, it was not always clear to researchers if a coherent activity frame emerged at all during some of the shorter interactions. It is also a possibility that we were not able to identify math-related frames because, unlike classrooms, families usually do not come to the experience expecting to engage in mathematics. Further research might be able to shed some additional insights on this; however, in general it is always difficult to know whether an activity frame is specific to a content domain or if it is more general but has implications for that domain.

While it seems obvious that more research is needed to further understand activity frames and implications of these frames in informal science education, there appears to be a direct application of this research to practice by fostering awareness of activity frames for educators. In fact, this work has taken a similar approach to DOW in moving research findings into practice. In DOW, the research team created a Facilitator Reflection Tool that introduced facilitators to the concept of activity frames and provided a tool that allowed educators to think about their goals for a program, what activity frames they wanted to promote, and possible indicators of those activity frames. The goal with this tool was to allow educators to reflect on and improve their practice.

The current study supports application of the reflective practice promoted through DOW and expands the REVEAL facilitation model (Figure 1) by introducing facilitators to the concept of activity frames. In fact, we currently see and situate activity frames under the influencing factors that inform responsive facilitation in the model, along with the social, personal, and physical factors already there. As part of this study, we have created an additional professional development module that is available through the REVEAL website (https://reveal.terc.edu/Educator+Resources; Andanen et al., 2017) to introduce and create awareness of activity frames for educators. In the module, we encourage facilitators to observe and reflect on activity frames present in exhibit interactions. For example, in a hypothetical situation, if a facilitator observes two siblings exploring at "Balancing Art" becoming frustrated because they are trying to balance the bar and disrupting the other person's work, the facilitator can suggest an alternate setup. The facilitator can put weights on one side of the bar so the siblings can work together to balance the bar. This shifts the siblings to Exploring and Collaborating activity frames. Awareness of these activity frames may provide educators with a new perspective on how to guide family groups toward activity frames that appear to support math learning. Furthermore, it can also encourage conversations about how educators and other museum staff contribute or can take an active role shaping the visitor experience.

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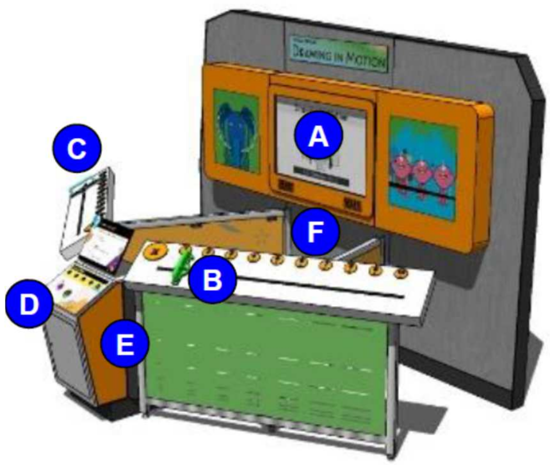
Appendix A: Exhibit Descriptions



A. Screen
B. X-axis slider
C. Y-axis slider
D. Challenge buttons
E. Facilitator controls
F. Prop storage

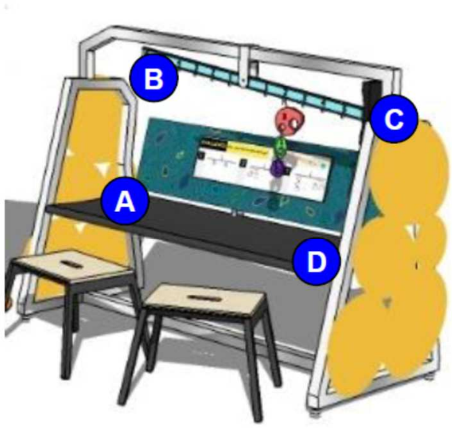
Additional facilitator props:

- Laminated challenge cards, dry erase board, markers and eraser
- Facilitator controls (turn off screen timeout, deactivate challenge buttons)

"Drawing in Motion"

"Drawing in Motion" (DiM) is, in essence, a large, computerized, Etch-a-Sketch in which the position of the cursor ("pen") is determined by the position of two large sliders, one of which controls movement along the X-axis and the other the Y-axis. These sliders play the same role as the knobs on an Etch-a-Sketch. The exhibit affords team-work and collaboration because it requires that the sliders be controlled by two different people. The "drawing" created by visitor groups appears on a large computer monitor that is visible to both users and any observers. From the perspective of algebraic thinking and functional reasoning, the activity embodies the relationship between the positioning and motion of the sliders and the resulting shape and direction of the line on screen. For example, both sliders must move at the same time to create a diagonal line, and the relative speeds of the two sliders determines the slope (e.g., steep or shallow) of that line. Visitors can select from a number of activities including four progressively more difficult challenges and "Free Draw."

“Balancing Art”



A. Weight bin
B. Balance bar
C. Balance scale
D. Facilitator prop storage

Additional facilitator props:

- Mystery weights (These are shaped like question marks and do not have their weight value labeled. The ordinary thickness piece is a 3, the “Swiss cheese” piece is a 2, and the hollow double thickness piece is a 3.)
- Dry erase board, markers, and eraser

At the mechanical “Balancing Art” (BA) exhibit, visitors hang pieces of different weights on either side of a pivoting bar in order to create a balanced mobile. Each piece is labeled with its weight, and the distances on the bar are also labeled. The exhibit engages visitors with the mathematical relationship among weight, distance, and force that underlies all mobiles: The force that an object exerts is the product of its weight and its distance from the point from which the bar is suspended, its fulcrum. The exhibit signage challenges visitors to balance a number of configurations (e.g., a configuration with a 3-weight on one side and a 4-weight on the other), and facilitators can make available a number of “mystery weights” and ask visitors to determine the relative value of those unknown pieces. Balancing Art is built at a scale that allows multiple people to interact with the exhibit at the same time.

Appendix B: Examples of Summaries and Qualitative Descriptions

Summary of video BA 305:

[Dad and son work to complete challenges on the exhibit sign despite facilitator's interruptions and distractions.][A] [Facilitator introduces mystery weights which the boy completes with qualitative mass trials.][B] [Boy decides to balance the bar with all of the weights and excitedly does so with coaching from his dad on the last couple of pieces.][C] [Finally, dad and son challenge each other with complex challenges and use calculation to balance.][D]

Notes:

Facilitator immediately orients mentioning balance, multiplication, weight, and distance. Seems a distraction to family

Dad adds 3 on 2 and 1 on 6 to show commutative balance, boy goes back to the sign challenge

Dad coaches asking where can you hang a 3 to get 8?

Facilitator introduces and explains the exhibit as part of a math exhibition, another distraction

Dad helps boy find factors of 28 while facilitator suggests trial and error

Boy puts mystery weights in hole 1 and uses qtm to determine mass

Boy gets excited at the idea of balancing with all of the weights

Dad helps to work out how 1 and 2 would balance

Dad suggests challenging each other, boy smiles and wants more

They switch roles with boy challenging dad

Clear the bar as another family approaches, facilitator engages in small talk

Symmetric, additive, commutative, asymmetric, systematic and qualitative trials, calculation

Segment	BA 305A	BA 305B	BA 305C	BA 305D
Purpose (Title)	Boy and father interact with exhibit.	Mystery weight challenge	Using all the weights-including mystery weights	Challenging each other
What's happening	Father and boy engage with exhibit, work as a cohesive team, balance the bar through a series of calculations.	After educator gives mystery weight challenge, boy clears the bar and hangs just that weight—therefore resetting activity.	After solving mystery weight challenge, both father and boy set the goal balancing the bar with all the weights-including mystery weight.	Father and boy challenge each other balancing one side of the bar each one. This is achieved using calculations.
Math Seen	Calculation: Father suggests balance the bar by grabbing a weight: let's do 1 times 6 to see if it works. 1:20" Boy agrees: 2 times 3 is 6. 1:31 Describe. Math relationships- Father: where can you put a (weight) 3 to get an 8? 2:19" Commutative Balancing: Kid—after realizing he can't get proper calculations to balance the bar moves weight on the other side. "Maybe it has to go 12?" 2:28 moves 4 in 3 and 3 in 4. Additive balancing- boy adds weights on another weight that adds 5 and hang it on 5 and then on 3 having a total of 15 and on one side and he hangs a weight 3 on a 5 in the other side. 3:48" Exploring math relationships—Commutative balancing. Father asks while coaching kid: Anything times 3 is going to give you 28? 5:28". Boy balances the bar by hanging 3+2+2 *4 and 3+3+1 *4	Exploring math relationships & Qualitative mass trial: boy hangs each mystery weight on 1 and uses qualitative trials to determine weight.	Symmetric balance. & Calculation- Boy hangs mystery weights (3 each) on 1 and 2 making a total of 9 and then hangs the same similar weights in the same position. 9:29" Boy keeps adding weights on the bar keeping in mind number on one side to match the other. Additive symmetric balance & systematic trial—after hanging all weights boy ended up with weights 1 & 2. With his father's prompt, he manages to use all the weights-including mystery w.	Exploring Math relationships: calculation & additive balancing. Boy calculates total amount on his father side before hanging weights on his side. Boy figures it out weight on his father side before balancing his side: 14+18 is 32. 16:16" Father challenges three times before boy challenges him. Calculation. Father and boy perform calculations together to determine weight on kid's side. "You need to get 67 over there." 18:17"

Negotiations	Educator immediately orients. "You are balancing with the weight and distance." 0:25" Showing the area where bar balances and the multiplication needed. Father leads boy to test weight and perform multiplications. Boy follows his lead- working collaboratively. Boy: Doesn't work quite right after balancing the bar and seeing it still moves. 1:50" Let me know if you need my assistance. 2:54"	Educator introduces mystery weight and father suggests to start over. Boy clears weights on the bar.	Educator suggests kid works with them in other "equation" after boy figured the weight of the mystery challenge.	Educator suggests boy challenges his father.
Social Dynamics	Both father and boy work collaboratively and as a cohesive pair. After achieving balance—father follows kid's lead and interest, but also coaches him: "So, what are your choices here? 2:13 When boy is stuck trying to get a total of 28 on the other side to balance the bar- father suggests factors approach and educator suggests trial and error: you know, you do don't have to think it through. You can just hang them up and give it a try. 6:20"	Father is engaged and focused while boy hangs weights.	Father is supportive and facilitates by asking questions- regarding quantities. Educator is mostly on the periphery- asks for picture once challenge has been completed.	Educator: "Do you even need my help? I don't think so." 14:13. Father and boy perform calculations together. Father acts as facilitator and makes boy aware of proper calculations. They solve last challenge as a team - balance bar with a total of 64 on the other side of the bar.

Appendix C: Math Reasoning Behaviors Coding Rubric for Balancing Art and Drawing in Motion

Math Reasoning Behavior Checklist: *Balancing Art* Coder initials:_______ Date:_______ Group #:_______

	Level 2	Level 3	Level 4	Level 5	Rating
Talking about mathematical quantities	Verbalizes number labels on weights Verbalizes number labels on bar		Mentions equals or equivalence (not counting "balance") Mentions distance from center or farther/closer Mentions heaviness, weight, or force		**(See below)** **Level 1: No boxes checked** Rating:______
Describing mathematical relationships	States that both weight and distance matter relative to force, balance, or "heaviness"	States that the farther out, the heavier States that some combination of distance and weight on both sides have to be equal	Describes a specific *quantitative* case, with numbers, an operator, and an equal sign (e.g., 2 x 3 = 6) States that weight needs to be multiplied by distance	States that the sum of weight times distance must be equal on both sides for bar to balance	**Highest level checked** **Level 1: No boxes checked** Rating:______
Exploring mathematical relationships	Places, replaces, or moves weight *incorrectly* after checking balance	Moves, replaces, or adds weight *correctly* after checking balance	Verbalizes or writes calculation and then places weight (no clear predication verbalized or written)	Verbalizes or writes calculation, verbalizes or writes prediction of needed weight and location, and then places weight	**Highest level checked** **Level 1: No boxes checked** Rating:______
Achieving mathematical goals	Balances symmetric configurations Number: __________ Balances additive symmetric configurations Number: __________ Balances inverse configurations Number: __________		Balances asymmetric configurations Number: __________		**(See below)** **Level 1: No boxes checked** Rating:______

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Rating math quantities for Balancing Art

- Level 1: No boxes checked.
- Levels 2-3: Level 2 for verbalizing either weight or distance labels, level 3 for both.
- Levels 4-5: Level 4 for verbalizing both weight and distance labels AND mentioning one or two types of quantity indicator words (i.e., one or two boxes checked). Level 5 for verbalizing both weight and distance labels AND mentioning all three types of quantity indicator words (i.e., three boxes checked). *Level 3 for mentioning one or more quantity indicator words but not verbalizing both weight and distance labels.*

Rating mathematical goals for Balancing Art

- Level 1: No boxes checked.
- Level 2: One symmetric configuration, no other configurations.
- Level 3: More than one symmetric configurations OR one or more additive symmetric configurations OR one or more inverse configurations (i.e., anything beyond one symmetric configuration but WITHOUT any asymmetric configurations).
- Levels 4-5: *Level 4 for one asymmetric configuration, level 5 for more than one. Levels 2 and 3 do not need to be achieved to be rated at levels 4 or 5.*

General mathematical reasoning coding instructions

- Families do not have to use the exact language stated in the rubric but can be coded for phrases with equivalent meaning.
- All family member talk and behaviors, from both children and adults, are included in ratings. Behaviors and talk can come from any family member and do not need to be restated or even acknowledged by the rest of the group.
- Facilitator talk and behaviors are not included in ratings. However, if visitors contribute substantively to a phrase or question-answer sequence that is initiated by the facilitator, the whole phrase or sequence can be coded. For example, the facilitator might begin a sentence, "the farther the weight is from the center…," and the visitor might finish, "the heavier it is." In this case, the whole phrase would count towards "level 3" describing mathematical relationships.
- Do not rate interactions based on your perceptions of visitors' understanding of the exhibits or the mathematics. Apply the checklist and ratings literally, as described in the rubric.
- Visitor talk is rated the same whether it is in the form of a question or a statement.
- For describing mathematical relationships, quantities must be connected grammatically by visitors (or by a combination of staff and visitor comments), rather than simply stated separately.

Balancing Art-specific coding instructions

- For levels 4 and 5 of talking about mathematical quantities, the Spanish verb "balancear" is considered equivalent to "balance" but the verb "equilibrar" counts as a mention of equals or equivalence.
- Incorrectly using only addition to describe relationships between two sides does not count as a quantitative case, relationship, or verbalized or written calculation.
- For level 3 of describing mathematical relationships, "correct" means in the appropriate direction, in terms of weight or distance, to achieve balance based on the current configuration (e.g., adding more weight to one side that is currently "lighter" than the other).
- For level 4 of describing mathematical relationships, specific quantitative cases must clearly be in reference to weights and distances on the beam, rather than to an unrelated math problem.
- For mathematical exploration, if visitors appear like they might be doing mental math but do not write or verbalize any calculations, they should be coded as level 3.
- For achieving mathematical goals, groups do not need to balance a symmetric or inverse configuration to be counted at levels 4 or 5. Balancing just one asymmetric configuration counts as Level 4. Configurations with mystery weights always count as asymmetric.
- For achieving mathematical goals, symmetry is based on piece weight, not piece shape. A configuration that has the same weight pieces on each side is symmetric, even if the shapes of the pieces are different.
- (See table below for definitions of different types of balanced configurations.)

Configuration type	Definition	Example
Symmetric	Same weights at the same distances on both sides. Symmetry is based on piece weight, not piece shape. A configuration that has the same weight pieces on each side is symmetric, even if the shapes are different.	(4 at 2) <> (4 at 2) (3 at 2) and (2 at 5) <> (3 at 2) and (2 at 5)
Additive symmetric	Same weights at the same distances on both sides except that on one side, a single “weight” is made up of multiple weights hung together. More complicated additive symmetric patterns involving weights hung on more than one hole on each side are counted as asymmetric.	((1+1) at 3) <> (2 at 3) ((4 at 3) <> ((2+2) at 3)
Inverse	A single weight and distance pairing on one side matched with the reversed weight-distance pairing on the other side. More complicated inverse patterns involving more than one weight on each side are counted as asymmetric.	(4 at 3) <> (3 at 4) (2 at 4) <> (4 at 2)
Asymmetric	Any configuration that does not count as symmetric, additive symmetric, or inverse.	(3 at 2) and (1 at 5) <> (3 at 1) and (4 at 2) ((1+2) at 2) and (1 at 5) <> (3 at 2) and (1 at 5) (4 at 3) and (2 at 2) <> (3 at 4) and (2 at 2)

Math Reasoning Behavior Checklist: *Drawing in Motion*

Coder initials:_______ Date:_______ Group #:_______

	Level 2	Level 3	Level 4	Level 5	Rating
Talking about mathematical quantities	Verbalizes number (and possibly direction on the slider) associated with the x-axis (e.g. "you go to 4," "go up to 9," "you should be at 5") Verbalizes number (and possibly direction on the slider) associated with the y-axis (e.g. "you go down to 2," "move to 10 now," "I stay at 5 and you move to 6")		Describes direction and/or shape of line on screen, using words such as: "vertical," "horizontal," "up-and-down," "back-and-forth," "at an angle," or "diagonal" Note each occurrence: ____________________________ Uses math language to describe point location or slider motion, e.g. "I'm X and you're Y," "we move to (3,4)" Note each occurrence: ___________________________		**(See below)** **Level 1: No boxes checked** Rating:______
Describing mathematical relationships	States that people have to move together to make a diagonal line but not that their relative speeds matter (does NOT need to use the word "diagonal")	Mentions a qualitative relationship between line and relative speeds of sliders (e.g. "I have to go faster") or any kind of qualitative speed language	Makes an incomplete quantitative statement about relative speeds of sliders (e.g., "you have to move twice as fast as I do")	Uses the idea of steepness or slope to talk quantitatively about the relative speed of sliders, the slope of the line, or both (e.g., "this line is steeper than the last one, so you'll have to move twice as fast as last time," "this line has a slope of one, so we move at the same rate")	**Highest level checked** **Level 1: No boxes checked** Rating:______
Exploring mathematical relationships	No explicit coordination of movement for making diagonal line (e.g., "you go to 7, I go to 3")	Coordinates beginning of movement aloud (e.g., "3, 2, 1, go," "ready, set, go," "ready")	Counts to coordinate movement of sliders	Uses a more sophisticated coordination strategy, such as explicitly checking for intermediate spots on line (e.g., "we should both be on 5 now")	**Highest level checked** **Level 1: No boxes checked** Rating:______
Achieving mathematical goals	Successfully completes challenge 1 with some accuracy (no diagonal lines)	Successfully completes challenge 2 with some accuracy (diagonal lines with slope = 1)	Successfully completes challenges 3 and/or 4 with some accuracy (diagonal lines with slope $\neq$ 1)	Completes a planned free drawing (not random doodling) with some accuracy Number of level 2: ______ Number of level 3: ______ Number of level 4: ______	**Highest level checked** **Level 1: No boxes checked** Rating:______

Rating mathematical quantities for Drawing in Motion

- Level 1: No boxes checked.
- Level 2: Just ONE of the two boxes checked (either horizontal or vertical axis).
- Level 3: Both of the boxes checked (both horizontal and vertical axes).
- Level 4: Level 3 plus just ONE instance of describing direction or mathematical language. Describing direction and/or shape of line doesn't include directions to other visitors about how they should move (e.g., "go down to 4").
- Level 5: Level 3 plus MULTIPLE instances of describing direction or using mathematical language, using at least two different words.
- *Level 3 for mentioning one or more directional words but not verbalizing motion on both sliders.*

Drawing in Motion-specific coding instructions

- For achieving mathematical goals, "some accuracy" means that lines are close to pictures as intended. Horizontal and vertical lines go pretty much directly from one point to the next. Diagonal lines follow the general intent of the line slope. Using a horizontal and a vertical line to connect two points that are intended to form a diagonal line does not count as "some accuracy." Do-overs are fine. Being accurate on just SOME of the image is fine, as long as at least one diagonal line is drawn with some accuracy.
- For achieving mathematical goals, if a family skips all the challenges and just does free draw, the level is based on the difficulty of what they drew (i.e., if it had a diagonal line or not and whether diagonal lines had a slope of 1 or not). Drawing a curve automatically counts as "diagonal line with slope not equal to 1." If a family does two or more free draws, at least one of which would qualify as Level 4, the group should be rated Level 5.