A Design-Based Research Study of Staff-Facilitated Family Learning at Interactive Math Exhibits (Pre-Publication Version)

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Abstract

Staff facilitators in museums and science centers are a critical but often overlooked component of the visitor experience. Despite assertions about the important role they play in visitor learning, there continues to be almost no research to understand staff facilitation in these settings or identify effective practices. To address these gaps, we conducted a design-based research study to describe the work of experienced museum educators and iteratively refine a model of staff facilitation to support family learning at interactive math exhibits developed through a prior project. The resulting facilitation model identifies three visitor experience goals, outlines the cycle of responsive facilitation (observe, support, reflect) that educators used to support these goals, and highlights the physical, personal, and sociocultural factors that appeared to influence the nature and outcomes of the interactions. The model provides empirical support to guide professional development for museum educators and suggests future directions for visitor studies research.

Keywords: museum, facilitation, family, informal learning, mathematics education, design-based research

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In museums, science centers, and other informal learning environments, staff facilitators and educators[1] are a critical but often overlooked component of the visitor experience. Front-line educators at these institutions lead tours and programs for school groups and visitors, interpret natural resources and science phenomena, connect with visitors' interests, and facilitate hands-on learning opportunities. Perhaps most critically, these educators create personalized, social learning experiences beyond what is possible through displays, exhibits, or even interactive media (Falk & Dierking, 2000, 2013; National Research Council, 2009; Pattison & Dierking, 2012, 2013).

Despite the ubiquity of educators in museums and science centers across the country, assertions about the important role these individuals play in visitor learning (e.g., Astor-Jack, Whaley, Dierking, Perry, & Garibay, 2007; Falk & Dierking, 2000; National Research Council, 2009), and ongoing calls for the professionalization of the field (e.g., Tran, 2007), there continues to be little research to describe staff facilitation in these settings, assess its impact, or identify effective practices tailored to specific educational goals. Although there has been an explosion of research on museum learning, and learning outside of school more broadly, only a handful of studies have examined the impact or practices of museum educators. Consequently, these professionals have been forced to rely on classroom research, which may not transfer well to the unique learning goals and contexts of museums (Pattison & Dierking, 2013).

In 2013, the Oregon Museum of Science and Industry (OMSI), in partnership with TERC and Oregon State University (OSU), launched an NSF-funded project, *Researching the Value of Educator Actions on Learning* (*REVEAL*), to begin to address this lack of research by systematically developing a model of staff-facilitated family learning in museums and rigorously testing the impact of this model on visitor experiences and learning. Building on the predecessor NSF-funded project, *Access Algebra* (Garibay Group, 2013a, 2013b), *REVEAL* focused particularly on family interactions at math exhibits designed to encourage algebraic thinking (Kaput, Carraher, & Blanton, 2008; National Council of Teachers of Mathematics, 2000). Although the present study was conducted in the context of mathematics, we intended the initiative to generate empirical findings related to the nature and impact of staff facilitation in museums that would transfer to other topic areas and educational goals.

In this article, we present the results of the first phase of the *REVEAL* project: a design-based research (DBR) study to describe the work of experienced museum educators and iteratively develop and refine a model of staff facilitation to support family learning at interactive math exhibits. DBR, also known as design experiments, is an iterative research approach situated in authentic learning environments and focused on simultaneously improving educational practices and advancing theory about the ways those practices impact learning (Brown, 1992; Kelly, Lesh, & Baek, 2008). The study had two primary goals: (a) better understand staff facilitation strategies that support family learning and engagement and (b) explore other important factors that affect family interactions around exhibits. The study resulted in a theory-based model identifying the most salient factors related to facilitated family interactions at exhibits that can be used to inform educational approaches and practices for facilitation at exhibits on the museum floor.

We begin by laying out the initial frameworks and theoretical perspectives that served as a foundation for our work. Following a description of our data collection and analysis methods, we then outline the model of facilitation that we developed through the iterative DBR study, including our conceptualization of visitor outcomes, staff facilitation strategies that appeared to support these outcomes, and other factors that influenced the nature of the experiences.

Staff Facilitation in Museums

Front-line staff members in museums engage with visitors and families in a variety of ways and in a variety of contexts. The study described in this article focused particularly on unstructured interactions, defined as unscripted conversations between staff and visitors during educational activities—in this case, at exhibits. These interactions are distinct from more structured programs, including school group tours, classroom activities, or stage presentations, in which the length of the interaction and the relationship between visitor and staff are largely predetermined (Cunningham, 2004; Pattison & Dierking, 2012). Although this distinction has rarely been made, recent research suggests that it may be critical for understanding these interactions (Pattison & Dierking, 2012, 2013). In particular, without a predefined role, staff may find it more challenging to establish connections with family groups and successfully support learning. As the National Research Council (NRC) report on learning in informal environments noted, facilitation in designed informal learning environments "may not always be desirable, as it can interfere with leisure experiences and interrupt other important developments in the participant experience" (National Research Council, 2009, p. 162). Understanding how and when educators can effectively support learning in these contexts is critical, therefore, to ensure that these staff members contribute positively to the impact of museums and other informal learning institutions.

Although the NRC (2009) synthesis report suggested the potential challenges of staff facilitation in free-choice learning environments, the authors did not review any studies directly investigating staff facilitation in designed settings. In general, the majority of research that has been conducted to date has focused on highly structured interactions, such as school group tours (Cox-Petersen, Marsh, Kisiel, & Melber, 2003; Martin, Durksen, Williamson, Kiss, & Ginns, 2016; Tal & Morag, 2007), classroom programs (Tran, 2007), scheduled stage presentations (Anderson, Kelling, Pressley-Keough, Bloomsmith, & Maple, 2003), or interactions in laboratory settings (Gutwill & Allen, 2010, 2012). For example, in the *GIVE* project (Gutwill, 2010), Gutwill and colleagues tested a specific staff facilitation approach with families at exhibits and found that staff facilitation using a "juicy questions" inquiry game improved visitor inquiry behaviors during a subsequent exhibit interaction without the educator, compared to groups in several control conditions. However, this research was conducted in a tightly controlled laboratory setting with recruited visitor groups, and it was not clear the extent to which the impact of the staff facilitation might generalize to a more naturalistic setting.

The few studies focused on unstructured interactions outside a laboratory setting indicate conflicting findings. Although there is evidence that the presence of museum staff in exhibitions can increase visitor satisfaction and engagement times (Marino & Koke, 2003; Pattison, 2011), staff facilitation may also interfere with visitors who wish to experience exhibits on their own (Marino & Koke, 2003). Some groups, such as adults and teenagers, may be less interested in engaging with staff members (Marino & Koke, 2003; Pattison & Dierking, 2013). Mony and Heimlich (2008) found that the length of unstructured staff-visitor interactions and the number of key educational messages communicated were associated with location, visitor group composition, and how the interactions were initiated but did not explore visitor learning outcomes or staff facilitation strategies in more detail.

To date, beyond the study conducted by Gutwill and colleagues described above, there has been almost no research to compare facilitated and unfacilitated learning experiences in informal science education settings or to identify effective facilitation strategies, particularly for unstructured interactions.[2] Given this lack of research, therefore, the goal of this study was to inductively develop an empirical model of staff-facilitated family learning at exhibits (unstructured interactions) to guide future research.

Theoretical Framework

DBR begins with a thorough understanding of prior work and an explication of the theoretical frameworks and assumptions underlying the investigation (Cobb & Gravemeijer, 2008). To guide and focus our research, this study drew from two interconnected theoretical perspectives: (a) interactional sociolinguistics and (b) asset-based perspectives on education and learning.

Interactional sociolinguistics. Although often described using the language of teaching and education, unstructured staff-facilitated family learning in museums is more fundamentally a type of social interaction. And as researchers from sociology and anthropology have long argued, human social interaction is defined by the negotiation of roles, relationships, and identities (Gee, 2000; Goffman, 1990; Gumperz & Hymes, 1986; Schegloff, 1999; Scollon, 1998). The rules, patterns, and customs of conversations and human interactions revolve around this negotiation, such as opening and closing sequences, turn-taking, and supporting individual roles and goals (e.g., Kendon, 1990; Mchoul, 1978; Nevile & Rendle-Short, 2009; Schegloff, 1986). Synthesizing this work and drawing from theories of mediated action (Norris & Jones, 2005; Wertsch, 1998), Scollon (1998) articulated a unified view of “interactional sociolinguistics” that highlights the definition of relationships among participants as an essential component of human interaction before other goals can be accomplished, including the communication of information.

Aligned with this perspective, research has consistently highlighted the complex social dynamics of family learning in museums, with families often actively negotiating roles and agendas during their visits (Ash, 2002, 2004; Rowe, 2005). In a recent study at OMSI, Pattison and Dierking (2012, 2013) found that role negotiation is an important aspect of unstructured staff-family interactions, with adult family members acting as gatekeepers to staff participation. When adults ignored staff initiation attempts, the subsequent interactions were often brief or awkward. In contrast, when adult family members fully acknowledged staff initiation, staff members found opportunities to facilitate family learning more deeply. In the present study, this interactional sociolinguistic perspective influenced our view of staff-facilitated experiences as fundamentally social interactions, involving not only the communication of information, but also the ongoing negotiation of roles, relationships, and meanings. Instead of focusing exclusively on staff facilitation strategies and their connections to learning outcomes, we also explored what visitors brought to the experience and how visitor-staff social dynamics influenced the nature and outcomes of the interaction.

Asset-based perspectives on education and learning. Our approaches to the research and exhibit facilitation were also strongly influenced by asset-based perspectives on education and learning (e.g., Calabrese Barton, Drake, Perez, St. Louis, & George, 2004; Garibay, Yalowitz, & Guest Editors, 2015; Gutierrez & Rogoff, 2003; Lemke, 2001). Asset-based education is not a specific theory of learning or teaching but rather a broad group of related perspectives that share a common set of assumptions and commitments. Researchers adopting this stance reject a deficit perspective that "implies or even explicitly states that the cultural values and knowledge that circulate in nondominant cultural groups are deficient, not useful, or even counterproductive" (National Research Council, 2009, p. 214) or “in which cultural ways that differ from the practices of dominant groups are judged to be less adequate without examining them from the perspective of the community's participants" (Gutierrez & Rogoff, 2003, p. 19).

Instead, researchers studying learning from an asset-based perspective often focus on understanding, valuing, and building on the funds of knowledge (González, Moll, & Amanti, 2005) and repertoires of practice (Gutierrez & Rogoff, 2003) that individuals and groups bring with them to different experiences, including the variety of ways that individuals and groups learn across different cultures (Lareau, 2003; Rogoff, Paradise, Arauz, Correa-Chávez, & Angelillo, 2003) and the opportunities and the agency that individuals and groups use to shape their own learning paths (Gutiérrez & Calabrese Barton, 2015; Varelas, Settlage, & Mensah, 2015). Aligned with sociocultural perspectives on learning (e.g., Cobb & Bowers, 1999; Lave & Wenger, 1991; Vygotsky, 1978), these researchers emphasize the ways history, culture, context, and social relationships shape and constitute learning and learning processes and acknowledge and attempt to understand the complex interactions among individuals, cultural and historical context, and learning (Gutierrez & Rogoff, 2003). Asset-based studies acknowledge variation within communities, avoid essentializing groups, and often highlight structures of power and privilege that help to explain group differences, rather than focusing on individual traits or stereotypes (Gutiérrez & Calabrese Barton, 2015; Gutierrez & Rogoff, 2003; Varelas et al., 2015).

Scholars have argued that these perspectives are essential for creating successful and inclusive STEM learning experiences (e.g., Gutierrez & Rogoff, 2003; Lareau, 2003; Lemke, 2001). Influenced by asset-based perspectives on education, as well as the literature on culturally inclusive and responsive research (e.g., Allen et al., 2007; Frechtling, 2010; Okazaki & Sue, 1995), we began the study focusing on the resources and assets that families bring to staff-facilitated experiences and sought to develop facilitation strategies that were sensitive and responsive to the unique knowledge, experiences, goals, and social dynamics of each visitor group. We were also attentive to the literature on family learning in museums, which has highlighted the prior experiences and knowledge families bring to informal learning experiences (Ellenbogen, Luke, & Dierking, 2007; Falk & Dierking, 2013; National Research Council, 2009), as well as the research on everyday mathematics and how social goals and context shape the way individuals and groups approach learning math outside of school (Pattison, Rubin, & Wright, 2017).

Research Questions

The theoretical perspectives and prior research described above formed the foundation of the study and the educational approach that we developed and refined throughout the process. Based on these perspectives, the study focused on two broad research questions:

1) What are promising staff facilitation strategies for deepening and extending family mathematical reasoning at interactive exhibits that are also sensitive to the social dynamics of family learning and build on and support families' prior experiences, funds of knowledge, identities, and goals?
2) What other factors influence the nature of staff-facilitated family mathematical reasoning, including the negotiation of roles and identities within family groups?

To address these questions, it was critical for the team to have a clear articulation of the intended outcomes of the facilitated experiences. Therefore, as part of the DBR, we also refined our definition of mathematical reasoning appropriate for staff-facilitated family learning experiences at interactive exhibits and prioritized other outcomes of the exhibit experiences that were important to consider from the perspective of families. Aligned with the DBR approach, our overarching goal for the study was not to develop a generalized model of staff facilitation but rather a localized theory of staff facilitation with families at interactive math exhibits that could be subsequently tested and refined in other contexts and with different audiences and content areas (Cobb & Gravemeijer, 2008; Sandoval, 2013).

Method

This study used a DBR approach (Brown, 1992; Cardiel, Pattison, Benne, & Johnson, 2016; Kelly et al., 2008), particularly informed by Sandoval (2013) and Cobb and Gravemeijer (2008), in an effort to create a model based on the literature and refined through an iterative process of data collection. Video, survey, and observation data were collected in a public space at OMSI, a science center in Portland, OR, USA, where visitors self-selected to engage with three exhibits previously developed through the *Access Algebra* project. Data collection took place over the course of five months through an ongoing series of minicycles (Cobb & Gravemeijer, 2008). Each minicycle consisted of gathering data, reflecting on and discussing the data to refine facilitation strategies, identifying areas of interest and pondering relationships among factors, revising the facilitation model to address changing or emerging ideas, and planning for the next cycle.

The early DBR minicycles focused particularly on identifying and detailing the aspects of the model to be included and studied. At this stage, the aim was to define a successful exhibit experience, identify what mathematical reasoning looked like for families at the exhibits, document facilitation approaches that appeared to be effective, and ascertain which aspects of the experience were vital to include in the model. During the later minicycles, the team gathered data to refine the model and to better understand the social dynamics and other factors that shape facilitation outcomes, such as mathematical reasoning. Following the data collection minicycles, a final phase of retrospective analysis (Cobb & Gravemeijer, 2008) was conducted, during which the team reviewed preliminary findings and conjectures in light of the entire body of data collected; reflected on decisions, assertions, and assumptions; and finalized the *REVEAL* facilitation model developed iteratively through the study.

Throughout the process, data collection and analysis were guided by the literature on culturally responsive research (e.g., Allen et al., 2007; Frechtling, 2010; Gutierrez & Rogoff, 2003; Okazaki & Sue, 1995), coaching and feedback from two culturally responsive research experts, and a multi-cultural validity framework from the field of evaluation (Kirkhart, 1995; Kirkhart & Hopson, 2010). Culturally responsive research recognizes that “the significance and implications of research results can be fully understood only if/when the physical, sociocultural, and historical contexts of the researchers and the participants frame the work” (Trainor & Bal, 2014, p. 204). Similarly, multicultural validity “refers to our ability to capture … multiple cultural perspectives accurately, soundly, and appropriately” (Kirkhart, 1995, p. 2). It “focuses attention on how well evaluation captures meaning across dimensions of cultural diversity, and it scrutinizes the accuracy or trustworthiness of the ensuing judgments of merit and worth” (p. 13). The *REVEAL* team adapted Kirkhart and Hopson’s multi-cultural validity framework to guide research practices, reflective questions, and tactics that were relevant, aspirational, and attainable.

This process included ongoing reflections on how the presence and perspectives of the researchers and educators influenced data collection, analysis, and interpretation and how researchers and educators were ultimately situated in the facilitation model relative to visitors. The *REVEAL* research team included two senior educators who were experienced facilitators, several researchers and assistants, and a math education expert from TERC. Two members of the research team were bilingual (Spanish/English), allowing the team to collect and analyze data in both languages. However, the educators that worked with visitors during the study were monolingual English speakers, presenting both challenges for working with culturally and linguistically diverse visitors and opportunities for exploring ways that monolingual educators could support multilingual families from different cultural backgrounds. The two educators on the research team also facilitated all the visitor interactions included in the study and, aligned with a DBR approach, were full participants in all team discussions and reflections.

In addition to this reflective process, conversations were arranged with staff and families from a local community-based organization, Adelante Mujeres, with extensive experience working with Spanish-speaking families in order to provide respectful and relaxed opportunities to meet and converse freely about research goals, questions, and measures, as well as staff-family interactions and family math learning in museums. The team met with staff and families from Adelante Mujeres and then invited several family groups to OMSI to interact with the *REVEAL* exhibits. These conversations and observations informed the team's approaches and perspectives during facilitation, data collection, and analyses.[3]

Data Collection Context

Data were collected at three bilingual (Spanish/English) prototype exhibits created as part of the *Access Algebra* project. *Access Algebra* was a five-year, NSF-funded project that developed a large traveling exhibition, called *Design Zone* (Garibay Group, 2013a), and staff facilitation strategies designed to engage visitors in algebraic thinking—specifically, reasoning about functional relationships among quantities. Similar to scientific inquiry, algebraic thinking with functional relationships is a way of understanding the world around us that involves finding and exploring mathematical patterns and relationships between quantities; representing those relationships in a variety of ways, including words, pictures, tables, graphs, and equations; and using those representations to describe, generalize, analyze, predict, and create (Kaput et al., 2008; National Council of Teachers of Mathematics, 2000). The *Design Zone* exhibits (http://www.designzoneexhibit.org/) capitalized on visitors' interest in design, engineering, art and music to create engaging and memorable learning experiences with math. Those exhibits selected for study in *REVEAL* had been designed with specific "facilitation affordances" to support staff-visitor interactions (Pattison & Dierking, 2012) and were identified as having particular promise for supporting staff facilitation and family mathematical reasoning during the formative evaluation of the *Access Algebra* project (Pattison, 2011). The three exhibits studied in *REVEAL* (Designing for Speed, Drawing in Motion, and Balancing Art) are described below.

At Designing for Speed, visitors work with wheels with weights distributed at different distances from the axis, comparing speeds of the wheels rolling down parallel inclines. Visitors compare the speeds of the wheels either by using electronic timers installed at the exhibit or by racing two wheels at the same time. Observing which wheels are faster and where the mass is placed on each wheel can lead visitors to explore relationships among mass distribution, acceleration, and angular momentum. After only a few races, many visitors can see that acceleration, and therefore the time it takes a wheel to reach the bottom of the track, is a function of the mass distribution in the wheel: the closer the mass is to the center, the more quickly the wheel speeds up. The exhibit also includes an adjustable wheel (i.e., weights can be positioned at different distances from the center) that facilitators can provide to visitors to further explore the relationship between weight distribution and wheel acceleration.

Drawing in Motion is, in essence, a large Etch-a-Sketch in which the position of the "pen" is determined by the position of two large sliders, one of which controls the X-axis and the other the Y-axis. The exhibit is so large that the sliders must be controlled by two different people, making it necessarily and purposely collaborative. The drawing created by visitor groups appears on a large screen that is visible to both users and observers. From the perspective of algebraic reasoning, the activity embodies the relationship between the position 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, with the relative speeds of the two sliders determining the slope (e.g., steep or shallow) of that line. The exhibit offers visitors four different shapes to match on the screen, as well as a free-draw mode, and staff facilitators have access to additional challenge cards with images that visitors can try to create (e.g., circle, star, house).

At Balancing Art, visitors hang pieces of different weights on either side of a pivoting rod to create a balanced mobile. Since each piece is labeled with its weight and the distances on the rod 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, or fulcrum, from which the rod is suspended. The exhibit signage challenges visitors to balance a number of simple and more complex configurations (e.g., a configuration with a 3-weight on one side and a 4-weight on the other). Staff facilitators can also share "mystery weights" and ask visitors to determine the relative value of those unknown pieces.

Participant Sampling and Recruitment

In line with a sociocultural perspective on learning (Cobb & Bowers, 1999), the target population and unit of analysis of the study were families visiting the exhibits at OMSI. For the *REVEAL* project, we defined a family broadly as a group of at least two individuals that included one visitor over 18 years of age and one between the ages of 4 and 17.[4] Data collection followed a posted-sign method of informed consent (Gutwill, 2003), with bilingual signage (English-Spanish) at the entrance to the museum, next to the exhibit, and on the exhibit itself notifying visitors that research was taking place and that they were being videotaped. The camera and researchers were clearly visible to family groups. When we collected survey data, families were also asked for verbal consent by a researcher. The final group of study participants included family groups that self-selected to approach and engage with the exhibit component for at least 30 seconds during data collection periods.

Since the purpose of the DBR was to develop a model of facilitation that had broad applicability, it was important for us to study a sample of families that represented the diversity of OMSI visitors, including racial, ethnic, and socioeconomic diversity and variability in visit frequency and education level. To this end, the team leveraged opportunities to involve a representative sample of families. For example, we collected data during monthly "$2 Days," when the diversity of OMSI visitors is typically higher.

Data Collection

Data were collected on weekend days between 11:00 a.m. and 3:00 p.m. to maximize the chance of engaging family groups. During data collection, *REVEAL* exhibits were made available to visitors one at a time and rotated approximately every hour. The two expert educators from the research team took turns facilitating the exhibit, or leaving the exhibit unstaffed, while researchers observed the interactions and took notes. Unfacilitated interactions were included in the study to provide a contrast to the nature and outcomes of the facilitated experiences and explore the potential benefits and challenges compared to family-only learning experience.

A wide variety of methods, including observations, surveys and reflective processes were employed to gather data for the study. Observational data included videotape of visitors interacting with the exhibits (using a stationary video camera and wireless microphone), field notes, and focused observations. Video data were collected during 14 of the 18 data collection days, allowing the team and educators four days to initially orient to the data collection context before adding the complexity of video recording. In total, we collected approximately 68 hours of video, which were subsequently parsed into 384 video clips (162 facilitated and 222 unfacilitated interactions), each representing one family interaction at a single exhibit.

During data collection, one researcher took open-ended running notes of interactions at the exhibit, recording perceived gender and age of participants, times of significant events (people entering or leaving, completion of activities, etc.), and activities and behaviors observed. In addition, a second researcher took notes focused on a specific family group, referred to as group notes, using structured observation forms appropriate to each minicycle. Observations begin when an individual approached and engaged with the exhibit for at least 30 seconds and ended when the last member of the group left the exhibit.

Following an interaction, the researcher taking group notes met with the educator who facilitated the interaction for an educator debrief. Together they reflected on the interaction to clarify what was observed and identify successful and unsuccessful attempts at facilitation and examples of mathematical reasoning. Educator debriefs were conducted on each data collection day, for a total of 113 educator debriefs across the study.

As one researcher was debriefing with the educator, a second researcher administered visitor surveys. At the outset of the study, the survey consisted of demographic questions, designed to determine if the sample was representative of the general visitors to the museum. Later, additional questions were added related to visitor reactions to the facilitation they received, their level of satisfaction with the experience, what they thought the exhibit was about, and why they were motivated to approach the exhibit initially. A total of 83 demographic surveys were collected, including 61 surveys with the additional questions.

Data Analysis

A range of analyses were conducted throughout the DBR, primarily using an inductive, qualitative approach (Charmaz, 2006; Creswell, 2013; Patton, 2015). Following Cobb and Gravemeijer (2008), analyses were conducted both as part of *iterative refinement*, during the testing and exploration of facilitation strategies, and after data collection, as part of *retrospective analysis*. At several points in the process, we sought external expertise and feedback from project advisors and research oversight committee members, OMSI staff, and community members with diverse lived experience to provide outside perspectives and critiques on the emergent findings and developing theoretical model.

Iterative refinement. To inform the development of the facilitation model and prepare for upcoming data collection minicycles, data were reviewed and discussed weekly by the project team. These reflections were documented through a number of procedures, including conversation notes and updates to the evolving facilitation model. Iterative analysis also focused on observations of the OMSI educators and the subsequent debriefs led to a highly detailed description and record of exhibit facilitation. Analysis of group and running notes and educator debriefs included systematically categorizing and counting the different strategies used (specific actions), as well as their associated purposes (what educators hoped to elicit through the use of those strategies), and reflecting as a team on the factors that influenced educator choices and decisions.

Retrospective analysis. The final phase of the DBR was a retrospective analysis, during which the team documented the DBR process, continued to refine a theoretical model for facilitation, and conducted a more detailed analysis of video data collected during the previous minicycles. According to Cobb and Gravemeijer (2008), retrospective analysis involves reviewing data collected throughout the study, distinguishing between "what is necessary and what is contingent" for the success of the impacts, documenting the research process, searching for alternative explanations through a constant comparative method, and attending to issues of trustworthiness and generalizability. For the *REVEAL* project, this included checking the assertions made by the team against the full body of data collected to identify and explore any contradictory evidence; reviewing and comparing the multiple iterations of the facilitation model, exploring changes that were made and the thoughts underlying those changes; seeking out emergent themes across the full dataset which may not have been identified during more focused data collection; and refining the model of facilitation into a final version based on holistic analysis of project data.

A critical part of retrospective analysis was the comprehensive review, coding, and discussion of the video data that had been collected during the study, including video of both facilitated and unfacilitated interactions. During this review, the team developed codes for aspects of the interactions identified as important by the team during iterative refinement. Subsequently, the research team used this coding to query the video database, test emergent assumptions, identify confirming and disconfirming evidence, and locate important examples for further team discussion. This process was not intended as a quantitative study of the video but rather an extension of the team's ongoing qualitative review and exploration of the data. Reviewing, categorizing, and discussing the video helped to reveal aspects of the interaction that were not apparent during data collection, challenge the team's assumptions, and finalize the facilitation model described below.

Results

The ultimate products of the DBR were an inductively developed, theory-based model of facilitation and an articulation of educational approaches and practices for supporting family learning at museum exhibits. The final model, key aspects of which are highlighted in Figure 1, was developed iteratively, beginning with the team's theoretical framework and early conceptions of staff-facilitated experiences at exhibits, and constantly revised based on observations, data collection, and reflection during the study. As new insights emerged, these were documented in the evolving model and subsequently examined and evaluated based on further testing with visitors and educators at the *REVEAL* exhibits. The resulting model, therefore, is best understood as a series of interconnected, emergent hypotheses, developed through our in-depth qualitative study of two expert facilitators and hundreds of staff-family interactions, about the most critical factors and processes that define the nature and outcomes of staff-family interactions at interactive math exhibits in a museum.

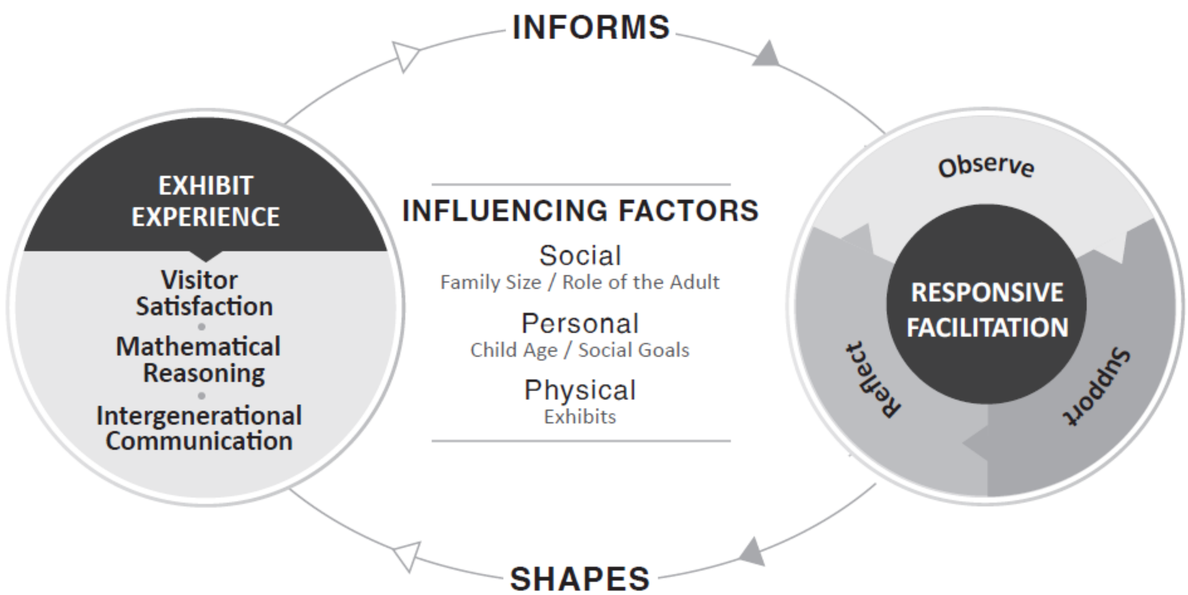

Figure 1. Primary elements of the REVEAL facilitation model.

As shown in Figure 1, the model includes three major components: (a) exhibit experience, or the critical outcomes that defined the success of the interactions for this project; (b) responsive facilitation approach, or the techniques and strategies that staff used to engage families and support the intended outcomes of the experiences; and (c) influencing factors, or the social, physical, and personal characteristics of the staff, family, and environment that appeared to shape how staff interacted with families and the results of the interactions. Below we describe each aspect of the model in more detail. First, we outline the set of visitor outcomes that defined the exhibit experience and guided our understanding of the facilitation strategies and influencing factors. Second, we provide an overview of the most common facilitation strategies used by educators and how these appeared to support the various facilitation goals identified by the team. Third, we highlight the influencing factors that we observed shaping the overall nature of the experiences and their outcomes, including the physical characteristics of the different experiences and the unique personal and social characteristics of each family. Finally, we describe the more fine-grained, moment-by-moment dynamics that characterized the responsive nature of the interactions.

Exhibit Experience: Mathematical Reasoning

Although we began the study with a general sense of the desired goals of the interactions, these evolved and were refined over the course of the testing and became an important aspect of the final facilitation model. Through the DBR process, the team defined indicators of mathematical reasoning that were relevant to the focus of the exhibits, varied across groups, and were readily visible through observations of staff-family interactions. The research team's holistic perception of the levels of mathematical reasoning, and subsequent review and discussion of the interactions, allowed us to develop increasingly refined definitions of each dimension of mathematical reasoning and the how it manifested at the exhibits.[5]

Table 1 summarizes the dimensions of mathematical reasoning developed through the project to guide staff facilitation at the three exhibits: (a) identifying mathematical quantities, (b) describing mathematical relationships, (c) exploring mathematical relationships, and (d) achieving mathematical goals. Understanding that in an informal learning context the salient mathematical variables are often not identified explicitly, we recognized that simply identifying these variables was an important aspect of mathematical reasoning for families. Once these quantities were identified, families could discuss how the quantities were related, track and systematically explore these relationships as they worked on the exhibit challenges, and use their understanding of the relationships to complete the challenges and achieve 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.

Table 1

Dimensions of Mathematical Reasoning Relevant to Algebraic Thinking

Dimension	Dimension description	Examples of exhibit-specific indicators
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 the piece (torque). • DfS: Commenting about the time it takes for a wheel to roll down the ramp or the distribution of the weights on a wheel.
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. • DfS: Discussing how wheels with mass closer to the center reach the bottom of the ramp sooner.
Exploring mathematical relationships	Visitors organize and track their actions to determine the relationships among quantities.	• DfS: Tracking the relative speed of each wheel in relation to the distribution of mass (i.e., closer or farther from the center). • 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).

Note. BA = Balancing Art, DfS = Designing for Speed, DiM = Drawing in Motion.

The Balancing Art exhibit provides a clear example of the four dimensions of mathematical reasoning identified through the project. Three mathematical quantities are involved as visitors work to balance both sides of the rod: the weight of each piece hanging from the rod, the distance of each piece from the fulcrum (center of the rod), and the relative force (torque) on each side of the rod based on the number of weights and their locations. This last variable was sometimes described or quantified for each side of the rod, while at other times visitors and facilitators talked about the balance of the rod as a whole (i.e., the relationship of the torque on each side). As visitors created different configurations of weights, they often discussed the relationship among weight, distance, and force either qualitatively (e.g., “the farther out on the rod, the heavier it is”) or quantitatively (e.g., “the total equals the weight times the distance of each piece”). At the same time, visitors used different strategies for exploring this relationship, such as trial and error (e.g., replacing one weight with another when the rod wasn’t balanced), systematic guess and check (e.g., moving a weight left or right), or numerically solving the equation (e.g., multiplying the weights and distances on each side and determining the difference). Through this exploration and discussion, most family groups achieved one or more mathematical goals by balancing configurations of different complexities, including simple symmetrical configurations (e.g., one piece of the same weight on each side) or complex asymmetrical configurations.

As another example, at the Designing for Speed exhibit the central mathematical relationship embodied by the activity was a connection between the distribution of the weights relative to the center of each wheel and how long it took the wheels to reach the bottom of the ramp. Families often identified mathematical quantities at this exhibit by pointing out the differences in weight distributions among the wheels (e.g., “see how the weight is farther from the center on this one”) and discussing how long it took each wheel to reach the bottom of the ramp, based on the timer displays (e.g., “that one took 10 seconds”). Similarly, some families also described the mathematical relationships in Designing for Speed by talking about which wheel reached the bottom faster relative to the other wheels (e.g., “the yellow one was faster than the red one”) and, more explicitly, how the wheels with weights distributed farther from the center took longer to reach the bottom. Families explored these mathematical relationships by tracking the time it took for each wheel to reach the bottom of the ramp and noting how this time related to the relative weight distribution of each wheel (e.g., “the farther from the center the weight is, the longer it takes to get to the bottom”). Depending on the interaction, this understanding allowed families to accomplish various mathematical goals, such as determining the order of the wheels based on their speed or designing a wheel that reached the bottom of the ramp faster than one wheel but slower than another (using the adjustable wheel provided by an educator).

Although the dimensions of mathematical reasoning in Table 1 are presented in a sequence, visitors did not always engage in the dimensions in a particular order and one dimension was not a prerequisite for others. Some dimensions did support other aspects of reasoning, however. For example, if visitors verbally identified the mathematical quantities in the exhibit, this identification often facilitated the group’s discussion of the relationships between the quantities. On the other hand, a visitor group might exhibit one dimension of reasoning, such as achieving a mathematical goal, and never provide evidence of any of the other three dimensions. This finding is consistent with other research on mathematical reasoning outside of school, which suggests that individuals and groups in these informal learning settings can be more flexible and adaptive in the approaches and strategies they use, rather than following a prescribed or linear sequence (Pattison et al., 2017).

Exhibit Experience: Intergenerational Learning and Visitor Satisfaction

Early in the project, the research team agreed that increasing mathematical reasoning through facilitation should not come at the expense of a pleasant and satisfying visitor experience, nor should it interfere with potentially rich social interactions within the family group. Satisfaction and enjoyment are central to informal learning experiences (National

Research Council, 2009) and, we believed, the primacy of these goals often distinguishes between mathematics that families experience in the classroom and the mathematical engagement we hoped to support in *REVEAL*. Similarly, intergenerational communication, or interaction and talk among adults and children, is a defining characteristic of family learning, inside and outside of museums (Ellenbogen, 2002; Ellenbogen et al., 2007; Falk & Dierking, 2013; National Academies of Sciences, Engineering, and Medicine, 2016). Although the timeframe of the facilitated experiences in the study was relatively brief, we hoped that by supporting intergenerational communication, and particularly the involvement of adult family members, we would increase the overall satisfaction of the experience and the likelihood that discussions and explorations that began during the interaction extended to other exhibits and beyond the museum visit.

During the initial phases of the DBR, satisfaction was conceptualized as the degree to which family members felt the experience was enjoyable and matched their own expectations and goals, as indicated by their behaviors and comments during the interactions and their reflections afterwards. Intergenerational communication was defined as the relative amount of time adult and child members spent talking to each other compared to the time adults talked only with other adults, children talked only with other children, or adults and children talked to the facilitator. At the outset of the study, these two outcome goals, and how they related to facilitation strategies and other influencing factors, were assessed primarily through holistic reflections and perceptions captured by the educators and research team. Later in the study, the team also piloted a visitor self-report measure of general visitor satisfaction, adapted from Packer (2004).

Collectively, mathematical reasoning, visitor satisfaction, and intergenerational communication served as the intended outcomes of the *REVEAL* facilitation approach. The definition of these outcomes then guided our exploration of the facilitation strategies that educators used to achieve these outcomes.

Responsive Facilitation: Strategies and Purposes

A central component of the *REVEAL* facilitation model was the strategies that appeared to support family mathematical reasoning, visitor satisfaction, and intergenerational communication. This included the overall "responsive facilitation" approach that was used by the expert educators (depicted in Figure 1 and described below), as well as the specific facilitation strategies they used. Data documenting the types and frequency of the strategies revealed that the facilitators in our study relied on a surprisingly small number to support visitors. In total, five strategies were identified as the most common (orienting, challenging, providing explanation, showing appreciation, and establishing visitor ownership), accounting for the vast majority of the strategies observed in the videotaped interactions. Challenging, orienting, and providing explanation were by far the most frequently used, followed by showing appreciation and establishing visitor ownership.

Table 2

Facilitation Strategies Supporting Exhibit Experience Goals

Strategy	Description	Primary roles in achieving intended facilitation goals	Exhibit-specific examples
Orient	The facilitator provides visitors with an overview of the exhibit and guidance on how to begin the activity.	Help both adult and child family members become comfortable with the activity; familiarize visitors sufficiently with the activity to avoid frustration and support further mathematical exploration.	• BA: Describing the general objective of the Balancing Art activity (balancing both sides of the mobile). • DiM: Orienting visitors to the different functions of the two sliders.
Challenge	The facilitator presents visitors with challenges to solve or complete using the exhibit.	Extend engagement; motivate and guide deeper mathematical exploration and reasoning in a non-threatening, family-friendly way; tailor the experience to support visitor satisfaction using challenges appropriate to the family; involve and engage multiple family members by providing a shared goal and creating multiple roles.	• BA: Challenging visitors to determine the value of a “mystery weight.” • DfS: Challenging visitors to design a wheel that finishes in between the times of two other wheels.
Provide explanation	The facilitator shares information about the key mathematical quantities and relationships in the exhibit.	Model mathematical reasoning; provide language and vocabulary to support family members, and especially adults, in exploring and discussing the mathematical elements of the exhibit; check for understanding in order to further tailor the interaction.	• DiM: Explaining how the two sliders must move together to create a diagonal line. • DfS: Suggesting that the distance of the weights from the center of the wheel is important for determining speed.
Show appreciation	The facilitator congratulates, encourages, or praises visitors throughout the interaction.	Encourage and extend engagement; provide positive feedback to increase visitor enjoyment and satisfaction.	• BA: Cheering, clapping, or giving high-fives when the rod is balanced. • DiM: Congratulating visitors when they match a diagonal line on screen.
Establish visitor ownership	The facilitator encourages and supports visitor control, leadership, and agency during the experience.	Support satisfaction and intergenerational communication by allowing visitors to lead the interaction and choose appropriate roles, challenges, and levels of participation; deepen mathematical reasoning by engaging adult family members.	• BA: Asking an adult family member to choose the location of the mystery weight for the next challenge. • DfS: Giving a family member a pen for tracking the times of the different wheels.

Note. BA= Balancing Art, DfS = Designing for Speed, DiM = Drawing in Motion.

Table 2 provides an overview of each of the five strategies, including a description, the primary role the strategy served in achieving intended facilitation goals, and exhibit-specific examples of each strategy. For example, presenting challenges, such as asking visitors to find the weight value of an unknown piece in the Balancing Art exhibit, was a highly effective and flexible strategy that educators reported using for a variety of purposes. First and foremost, challenges were a non-threatening, family-friendly way to motivate and guide deeper mathematical engagement with the exhibits. Educators also used challenges to support the needs and interests of different visitor groups, such as by offering simpler challenges to groups with young children or more complex challenges for groups that had already mastered the basics of the exhibit. Finally, challenges served as a tool for supporting intergenerational communication, providing a shared goal for family members, and were a clear way for adults to direct family engagement. In some cases, the challenge was embodied by props or objects (e.g., the mystery weights used in the Balancing Art exhibit) that could be handed to different family members to encourage their involvement.

Another strategy the educators used frequently was providing explanations at critical moments during the interactions. For example, if visitors were enjoying the Drawing in Motion exhibit but seemed to be having trouble completing challenges that involved diagonal lines, the educator might point out that these types of lines required both sliders to move together. Similar to the “explanatoids” described by Crowley and colleagues in their studies of family learning in museums (Callanan & Jipson, 2001; Fender & Crowley, 2007), these explanations were frequently short, strategic, and focused on the particular aspect of the activity currently being explored by the family. They were very different from the more comprehensive background information that an educator might provide during a more structured program, such as a classroom program for a school group. In this way, the educators used these explanations to advance family interactions at key moments and provide families language and ideas to help them explore the mathematical relationships in the activities, without making the interactions overly didactic or undermining the authority and knowledge within the family (and thus potentially decreasing visitor satisfaction and intergenerational communication).

Based on extensive debriefs with the educators working on the research team, it became clear that the facilitators selected strategies that would help them meet several purposes at once. For example, orientation strategies often helped put the visitors at ease or guided them in using the exhibit. Common examples included phrases such as: “Are you going for balance or art?” “Sometimes you have to tap the bar a little,” and “Hold the wheel here, then push the button.” Orientation was frequently seen as a means to enter a conversation with the visitor and assess visitor goals. Facilitators used these flexible strategies to respond to the particular needs and goals of different families and tailor the interactions based on different influencing factors. Thus, this small set of strategies provided the expert educators with a strong tool kit for supporting a variety of families and adapting to different situations.

Influencing Factors

Even though the facilitators who participated in the study employed a relatively small number of strategies, the ways in which they used these strategies varied greatly from one visitor group to another. The visitor experience appeared to be influenced by a variety of factors, including the number and ages of people in the group, the visitors’ social goals, and the exhibit with which they decided to engage. Influencing factors such as these shaped the way families engaged with the exhibits and helped facilitators decide how to interact with each family.

The model of facilitation diagram (Figure 1) includes the five influencing factors that we determined to be most critical in shaping exhibit interactions, based on observations and reflective discussions with educators. These included the exhibit, the size of the group, the age of children in the group, visitors' social goals, and adult visitor roles during the interactions. In the *REVEAL* facilitation model, these are grouped by personal, physical, and sociocultural dimensions, following the Contextual Model of Learning (Falk & Dierking, 2000, 2013).

Table 3
Factors that influenced staff facilitation and staff-visitor interactions

Influencing factor	Description	Example influences on educator strategies	Example influences on visitor outcomes
Exhibit	The three exhibits differed in their intended goals, physical design, mathematical content, interface type, activity structure, degree of open-endedness, and more.	• The intuitive nature of the activity and interface required different levels of facilitator orientation and guidance. • The degree of flexibility and openness inherent in the activity afforded or constrained the extent that facilitators could tailor or extend the experience.	• The accessibility and level of abstractness of the mathematics in the exhibit made it more or less likely that visitors would articulate the underlying mathematical quantities or relationships. • The physical design of activity required or supported different levels of intergenerational communication.
Size of group	Visitor groups ranged from one adult and one child to multiple adults and multiple children of varying ages and varying relationships to each other. Occasionally more than one family group approached and engaged with the exhibit at the same time.	• Larger groups required facilitators to balance tradeoffs between lower levels of facilitation for the whole group and more focused attention with specific group members. • Different ages and ability levels within groups required facilitators to provide different roles, creatively manage the appropriateness of activity challenges and goals, and continuously monitor engagement across the group.	• Larger group sizes could increase opportunities for intergenerational communication but also decrease satisfaction for individual family members when there was competition for time with the exhibit. • A focus on equal involvement for larger groups could enrich the mathematical experience for some family members, such as young children, but also limit the depth of mathematical exploration for the group overall.
Age of children	Children ranged in age from preschool to high school, with groups often including multiple children of different ages and different ability levels relative to the exhibit activity and content.	• The age of children influenced how facilitators tailored the level of challenges and found appropriate access points for the group. • Younger children required assistance with basic functions of the activity, such as hanging weights on the BA exhibit.	• Children of different ages engaged with the mathematics in the exhibits at different levels, influencing overall group mathematical reasoning. • The exhibits provided challenges that were more or less satisfying to different ages (e.g., the BA challenges appeared to be particularly compelling for middle school students who had encountered algebra previously).

Visitor social goals	Visitor behaviors suggested different, and often simultaneous, agendas for the exhibit interaction, including spending time with family members, building shared interests, enjoying the experience, practicing mathematical skills, and more.	• Facilitators continuously assessed and attempted to respond to visitor agendas, such as adjusting the relative emphasis on the mathematics in the exhibit depending on family members' interest and comfort. • Facilitators adjusted their level of involvement in the interaction depending on family member goals about spending time with each other.	• When visitors were more interested in exploring the artistic or experiential aspects of the exhibits, satisfaction and intergenerational communication could be higher than mathematical reasoning. • Strong adult visitor interest in engaging the group in the mathematics of the activities could decrease satisfaction for some group members.
Adult visitor roles	Adults engaged in the interactions at different levels, sometimes being more active participants while at other times providing more space for children in the group to explore the exhibits on their own. Adults also adopted different roles, such as facilitator, collaborator, or supporter.	• Facilitators adjusted their level of involvement in the interactions depending on the nature and degree of facilitation already being provided by adult family members. • Facilitators used a variety of strategies to engage adults who appeared hesitant to engage or appeared less comfortable with the mathematical content of the exhibit.	• Adults were often successful at gauging the appropriate levels of mathematical understanding for other group members and supporting mathematical reasoning across the family. • Satisfaction by adults who were interested in playing a strong facilitation role could be influenced by how well facilitators created space for the adults in the interactions.

Table 3 provides an overview of each of the influencing factors identified in the model and how they were observed to influence facilitation strategies and visitor outcomes. The most significant physical factor was the exhibit that the visitors used. The three exhibits in this study had vastly different affordances for mathematical reasoning and required different support from facilitators. Drawing in Motion, for example, provided several explicit challenges for visitors, so facilitators were often not required to play this role. In contrast, at Designing for Speed facilitators frequently had to work to focus visitors on the challenge of determining which wheel was fastest and why. On the other hand, while the mathematical relationship in Designing for Speed was, at least conceptually, relatively straightforward (qualitative relationship between distance of the weights from the center of the wheel and speed at which the wheel reached the bottom of the ramp), the algebraic relationship embodied by Drawing in Motion was much more abstract (relationship between relative motion of sliders and shape and direction of the line on the screen). Therefore, it was harder to guide visitors to engage with the mathematical relationships in this exhibit, and educators often used a variety of creative strategies to support mathematical reasoning, such as designing specific drawing challenges to highlight different aspects of the relationship between slider motion and line slope.

There were also several factors related to visitors and the social dynamics among group members. For example, adult visitor roles had a significant impact on the approach that the facilitators took during the interactions. When adults in the group took an active role in the exhibit experience, the facilitator often played a relatively passive role, letting family members guide their own learning. The facilitators did not need to promote intergenerational communication, so their primary function was to support the family if needed and provide suggestions or materials for extending the exhibit experience. On the other hand, when adults were less engaged with the exhibit, the facilitator often took a more active role in both guiding the exhibit experience and encouraging intergenerational communication. In both cases, facilitators had to be sensitive to the negotiation of roles between adults and staff, as well as how willing adults were to either share the facilitation role with educators or become more involved in the interaction.

Responsive Facilitation Approach

The final aspect of the *REVEAL* facilitation model is the cycle of responsive facilitation (observe, support, reflect) that the educators used to tailor their strategies to each family. The influencing factors described above shaped the overall facilitation approach adopted by the educators. However, even after accounting for these factors, the interactions were not formulaic.

Perhaps the most important realization that came from the DBR process was that expert exhibit facilitation is not an established routine used in the same way with every visitor group, but rather an ongoing interaction between staff and visitors during which the facilitator is constantly adjusting his or her approach based on feedback, reactions, and subtle cues from the family.

In the responsive facilitation approach, educators strive to align the support they provide with the perceived needs of the family. Through the DBR, we identified five aspects of responsive facilitation, each representing a characteristic of families or the interactions that appeared to be particularly salient: basic use of the exhibit, deeper use of the exhibit, mathematical reasoning, visitor control and ownership, and intergenerational communication. These aspects are outlined in Table 4.

Table 4
Elements of Responsive Facilitation Approach

Element of responsive facilitation	Description	Example influences on educator strategies
Basic use of the exhibit	Some groups quickly oriented themselves to the exhibit and determined the basic elements and goals of the activity, while others appeared confused or asked for help.	• When families struggled with basic exhibit use, facilitators could provide orientation or a more basic level of exhibit challenge. • When families were comfortable with basic exhibit use, facilitators could look for ways to enhance other aspects of the experience, such as deepening mathematical reasoning with a new challenge.
Deeper use of the exhibit	Some groups naturally transitioned into deeper, more extended ways of exploring the exhibit, such as trying multiple challenges, while other groups seemed unsure about how to proceed or less interested in spending more time at the exhibit.	• When families seemed unsure about how to move beyond basic exhibit use, facilitators could pose a series of challenges to guide deeper engagement and provide ongoing appreciation to support family interest and motivation. • When families naturally transitioned into deeper exploration, facilitators could offer opportunities not normally available at the exhibit, such as mystery weights at BA.
Mathematical reasoning	Some groups, without facilitator support, naturally began to explore the mathematical quantities and relationships in the exhibit, while others seemed confused or hesitant about this	• To deepen mathematical reasoning, facilitators might offer a new challenge specifically designed to move a family to a new level of mathematical exploration (e.g., creating asymmetrical configurations at BA).

	aspect of the experience. Some groups also expressed different degrees of interest in the math underlying the exhibit.	• When a family appeared to struggle with a particular aspect of the mathematical relationship, the educator could offer an explanation or vocabulary to an adult or pose a simplified challenge for the group targeting that aspect of the mathematics.
Visitor control and ownership	Some groups were comfortable steering the interaction, responding to facilitation, or engaging with the exhibit, while other groups were more reserved, less comfortable, or hesitant to be in control.	• When a family member appeared more hesitant to be involved, the facilitator could hand over an exhibit piece or tool (e.g., weight at BA) and ask him or her to help pose a challenge to the group. • When families seemed uncomfortable with the exhibit, the facilitator could suggest connections to everyday life, such as an Etch-A-Sketch for DiM and a doctor's scale for BA.
Intergenerational communication	Some groups had members of multiple generations who interacted with each other frequently, while others had little to no communication among adult and child family members.	• When adult family members seemed unsure or hesitant, facilitators could step aside and provide them special "insider" information or suggest a challenge for them to pose to the whole group. • Facilitators could step back from the interaction to provide more space for adult and child family members to be involved.

For example, when families first arrived at an exhibit, the educators frequently observed the extent to which family members were able to orient themselves to the exhibit and successfully engage with the activity. In some cases, families appeared hesitant or confused, and educators found a natural entry point by providing quick tips for getting started. On the other hand, if a family immediately began using the exhibit as intended, educators often stepped back for a moment and waited for an opportunity when their support was needed (e.g., helping families move beyond basic use to deeper engagement). In fact, we observed and educators often discussed the tension that could arise if they tried to provide basic use support when it was not needed, especially if an adult family member was already playing a strong facilitation role within the group.

Educators also attended to the amount of intergenerational communication occurring in a visitor group, since this was directly connected to one of the intended outcomes of the facilitated interactions. If an educator observed that adult family members were hanging back, they might try a variety of strategies, such as handing a challenge prop to one of the adults, to foster intergenerational communication. However, if they sensed that this was not aligned with the adult family member's goals, they often needed to shift approaches and search for an overlap between the project's facilitation goals and family expectations.

Discussion

The *REVEAL* project set out with two related goals: 1) better understand staff facilitation strategies that support mathematical reasoning, satisfaction, and intergenerational communication for families and 2) explore important influencing factors that affect family interactions around exhibits. To date, there has been very little research to describe staff facilitation in museums and science centers, especially during unstructured interactions such as conversations around interactive exhibits, or to identify effective strategies and approaches. Working with two expert museum educators and using a DBR approach, we described and refined a model of facilitation that was designed to support mathematical reasoning, intergenerational communication, and visitor satisfaction for families at interactive math exhibits. The resulting *REVEAL* facilitation model, depicted visually in Figure 1, identifies the three visitor experience goals prioritized in the *REVEAL* project, outlines the cycle of responsive facilitation (observe, support, reflect) that educators used to support these goals, and highlights the physical, personal, and sociocultural factors that appeared to shape the nature and outcomes of the interactions. As part of the model, we also identified primary aspects of mathematical reasoning salient to the exhibits and the museum setting, the most common and successful strategies that educators used to support visitor engagement and learning, and the visitor and interaction characteristics that educators noticed and responded to as part of their responsive facilitation approach.

Prior research suggests that although educators facilitating unstructured interactions with visitors can support satisfaction and engagement, they can also interfere with visitor learning experiences (Marino & Koke, 2003; Pattison & Dierking, 2013). Studying staff facilitation in two learning labs at OMSI, Pattison and Dierking (2012, 2013) found that staff often struggled to establish a role relative to adult family members and that in many interactions adult visitors acted as gatekeepers, using subtle social cues to determine whether or not educators could comfortably integrate themselves into the learning experience and shape the nature and goals of the interactions. Founded in an asset-based perspective on learning and a view of staff facilitation as a type of human social interaction, the present study suggests, although not conclusively, that by using strategies and approaches that are sensitive to the social dynamics of families and the unique roles of adult family members, educators in this type of exhibit context can successfully negotiate roles as facilitators that support mathematical reasoning without sacrificing essential characteristics of free-choice learning, including intergenerational communication, enjoyment, and satisfaction. The *REVEAL* facilitation model, therefore, provides a promising road map for training museum educators to deepen and extend family learning at interactive exhibits. In some cases, this may involve extensive facilitation by educators, very similar to the dynamics that might be seen in a more structured program, such as a classroom program or stage show. However, based on the unique goals, dynamics, and experiences of each family, the facilitation will often be subtler, with educators providing limited but strategic support at key moments in order to support the ongoing learning being driven by the families themselves.

Below we discuss implications of these findings for research and practice. Aligned with the DBR approach, we view the *REVEAL* facilitation model and the research findings as highly situated within the unique context of the study, which was conducted with two highly experienced educators working with three exhibits in a specific science center as part of a project that was focused on particular learning goals and outcomes. Furthermore, each of the three exhibits was designed with specific facilitation affordances (e.g., the mystery weights at Balancing Art), which undoubtedly influenced the types of strategies used by the educators. The degree to which these findings transfer and generalize to other settings, exhibits, goals, and content areas is an open question and will require ongoing investigations to identify the aspects of the *REVEAL* facilitation model that are relatively stable across contexts and those that are highly specific. In other words, we see generalizability not as a goal of a single study but the work of many studies, conducted across multiple settings, by multiple researchers, from a variety of theoretical perspectives (Cobb & Gravemeijer, 2008; Sandoval, 2013). Nonetheless, the model developed through this study can serve as a framework for guiding future studies and shaping the ways that educators approach their facilitation with families at exhibits.

Implications for Research

In addition to exploring how these findings transfer to other contexts, including other settings (e.g., other science centers, children’s museums, history museums, zoos) and other content areas (e.g., science inquiry, engineering), a valuable next step for researchers will be to study the long-term impact of staff-facilitated family learning at interactive exhibits. Working in a controlled laboratory setting, Gutwill and colleagues (Allen & Gutwill, 2009; Gutwill & Allen, 2012) identified ways facilitators could use specific, structured activities to not only impact the nature of visitor learning and engagement during the interaction but also to influence the ways that visitors interacted with subsequent exhibits. As several of the *REVEAL* facilitation strategies have similarities to the approaches tested by Gutwill and his colleagues, a promising area of research will be exploring whether the guidance and support provided through *REVEAL* facilitation at exhibits can contribute to changes in subsequent visitor behavior and outcomes at exhibits where no facilitator is present. Similarly, a fundamental assumption of the *REVEAL* facilitation model is that supporting intergenerational communication during the interactions with staff will make it more likely that learning conversations between adults and children related to the experience continue throughout and after the museum. This is not, however, an assumption that we were able to test in this study.

Another next step for this line of work is to rigorously test the causal claims embedded in the *REVEAL* facilitation model, such as the assumed causal connection between responsive facilitation and visitor and family learning at exhibits. DBR is an ideal research method for describing and exploring the complex relationships among learning goals, resources, and support strategies, influencing factors, and outcomes, as well as for simultaneously improving educational strategies and developing theoretical understandings of the learning underlying those strategies (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Kelly et al., 2008). However, DBR cannot provide strong causal evidence for the impact of these educational resources and strategies.

Finally, the model developed through this study serves as a launching point for a much needed “science of facilitation” in informal learning environments. Decades of research in schools and classrooms have described and tested a variety of teaching strategies appropriate for different learning goals, settings, and students (e.g., National Research Council, 2005). This research has and will continue to offer helpful insights for the informal education field. However, the unique characteristics of informal and free-choice learning experiences, including the relative choice and agency of the learner, expectations about the nature and goals of the experiences, and the important role of social interaction and intergenerational communication (Falk & Dierking, 2013; National Research Council, 2009), suggest that successful facilitation in these settings may require unique approaches and strategies. Future research should continue to identify the strategies that successfully support learning and engagement in museums and other informal learning environments and explore how these are similar to and different from those used in classroom settings. Ultimately, teaching and facilitation inside and outside of school will benefit from the unique insights gained from research in both settings.

Implications for Practice

Although more research is needed to fully understand the impact of the *REVEAL* facilitation approach on visitor learning and how it might be used in other contexts and topic areas, the model provides a guiding framework for helping museum educators develop and improve their practice and identifies specific strategies for learning experiences that may be appropriate for other content areas as well. Keeping in mind the study limitations described above, we suggest that several concepts embodied by the *REVEAL* facilitation model have implications for the practices of educators in museums and science centers more broadly. For example, the model highlights the importance of balancing traditional learning goals prioritized by educators and educational institutions, such as mathematical reasoning, with goals that are frequently of high value to families and visitors, including intergenerational learning and general satisfaction and enjoyment. The *REVEAL* approach also suggests the need for educators to appreciate the physical, personal, and social factors that influence staff-family interactions and develop the ability to notice these characteristics in each interaction, such as the role that adult family members are taking or the ways that the age of children in the family and the overall size of the group are shaping the dynamics of the interaction. Finally, regardless of the content area, we believe that educators working in these settings must responsively adapt to the unique needs, goals, and experiences of families and develop tools and strategies appropriate to different situations. This includes the recognition that some families may need and desire a strong facilitator presence, while in other interactions it may be appropriate for a staff member to play a much smaller role, primarily supporting the facilitation and learning that is already going on in the group.

This study also provides empirical support for several professional development training resources currently available in the field and suggests further insights to complement and enhance these resources. For example, Ash and Lombana (2011, 2013) developed the *REFLECTS* professional development model for museum educators, which outlines a cycle of noticing, scaffolding, and evaluating that is closely aligned with the empirically based responsive facilitation model developed through *REVEAL*. Similarly, the *REVEAL* facilitation approach provides a concrete set of strategies and practices for educators to explore as part of the *Reflecting on Practice* professional development curriculum,[6] designed to offer a more general foundation to help museum educators understand informal learning and reflect on their own work as museum professionals. The *REVEAL* facilitation model is also a strong complement to the *Learning Together* guide (Porter & Cohen, 2012) developed by Boston Children's Museum and Chicago Children's Museum. The present study provides research evidence that, as highlighted in the guide, staff facilitators must prioritize nurturing the adult-child bond and respecting family cultures, and provides additional strategies and approaches to help staff pursue these goals.

To complement these resources, we are currently developing a set of video-based professional development modules with concrete examples of staff-family interactions at exhibits and discussion questions to catalyze reflection and professional learning for educators in museums and other informal learning environments (available for free on the project website: https://REVEAL.TERC.edu). As a field, we have much to learn about how educators can best support family learning in these settings, and how organizations can provide training and professional development to help staff improve their work. Nevertheless, this study, and the resources outlined above, provide a strong foundation for creating staff-facilitated family learning experiences that enrich and deepen engagement and learning at museum exhibits.

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Endnotes

[1] In this article, we use the terms *facilitator* and *educator* to refer to paid and unpaid staff in museums, science centers, and other informal education institutions who regularly interact directly with visitors, families, and school groups.

[2] Some recent research has looked at the professional development and practices of museum educators (e.g., Ash & Lombana, 2011, 2013) without directly addressing the effectiveness of the facilitation strategies they use when interacting with visitors.

[3] More details about the team's culturally responsive research practices and tools, including the coaching process and lessons learned, are available on the project website: https://REVEAL.TERC.edu. Spanish-speaking families were a particular focus of the project because Spanish is the second most common language spoken in Portland, OR, after English, and the Latino/Hispanic community represents an important and growing community in the region.

[4] Families without children over the age of three were not included in the study because prior data collection suggested that they engaged with the exhibits in a very different way and, as would be expected, rarely explored the mathematical relationships in the activities.

[5] In addition to mathematical reasoning, we also explored mathematical awareness and the support and development of sociomathematical norms (Yackel & Cobb, 1996) as possible outcomes and facilitation goals. However, these proved to be difficult to conceptualize and measure within the scope of this study.

[6] http://mare.lawrencehallofscience.org/professional-development/reflect-on-practice