Examining Distributed Scaffolding in Museums: Investigating How Social and Material Scaffolds Support Learning in a Science Exhibit

By

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Abstract

As an informal learning context, science museums offer opportunities for visitors to engage in shared meaning-making as they interpret the concepts and phenomena presented in exhibits. As visitors engage in social meaning-making, they may provide support by scaffolding others' learning. Scaffolding describes support that is tailored to learners' needs, and it may be distributed across people, tools, technologies, and activities, referred to as scaffolds. Certain kinds of interactions between these scaffolds may be especially helpful for supporting learning. While we have begun to understand how distributed scaffolding supports students' learning in museums, we have yet to understand how distributed scaffolding supports families' learning in museums. In response, I investigated how social and material scaffolds in an interactive, facilitated pop-up exhibit about compost supported families' learning. I first reviewed prior research about scaffolding and its evolution as a metaphor for support, along with prior research about museum learning, to understand how people and/or exhibits provided scaffolding for learning. Next, I studied how 23 families acted as social scaffolds by participating in a process of scaffolding, as seen in their interactions with the exhibit. While I expected parents to provide scaffolding to their children, children also provided scaffolding to their peers. Lastly, I studied how material scaffolds in the exhibit interacted with social scaffolding provided by the same 23 families. The material scaffolds complemented social scaffolding by affording joint activity on a regular basis and affording access to information and feedback at key moments in visitors' interactions. Echoing research in classrooms, shortcomings in the design of distributed scaffolding in the exhibit resulted in a need for additional support from social scaffolds. These studies contribute a deeper understanding of the ways in which families participate in the process of scaffolding in science exhibits, and the ways in which material scaffolds complement support from social scaffolds. The theoretical implications point to future research examining peers' motivations and strategies for providing support along with permutations of exhibit design that afford social interaction and learning. The practical implications point to broader accommodations in the design of material scaffolds for visitors, especially younger children.

1. Introduction

Science museums often showcase a wide variety of objects and phenomena in exhibits. To understand these exhibits, families may engage in conversations in which they make connections to past experiences (Mai & Ash, 2012) and share this information with others (Zimmerman, Reeve, & Bell, 2008). These conversations support a process of shared meaning-making in which families mutually support each other's learning (Allen, 2004; Zimmerman et al., 2008).

Shared meaning-making in museums can help families to understand content that they could not understand on their own (Paris, 1997). For example, Falk and Dierking (2000) described a visit in which a father helped his daughter to estimate the relative sizes of hearts:

> Dad then attempts to get her back into looking at the exhibit. "Look how tiny the mouse heart is." "Oooh, it's so tiny," she says in a tiny voice. "So," says dad, "Isn't it interesting that your heart is smaller than the cow's heart and bigger than Scamp's heart, because you are in between the size of a cow and a dog like Scamp?" "Yep," says the girl. The father then asks: "So, show me how big your heart is." The little girl then holds up her hands and says about this big, fairly accurately indicating the size of her heart, a size between that of the cow and the dog. (pp. 37-38)

The father used the objects in the exhibit to help his daughter understand the relative size differences between human and animal bodies, and, in turn, their hearts. By demonstrating this strategy, the father helped his daughter estimate the size of her own heart. Falk and Dierking (2000, p. 45) concluded that "the father assisted [his daughter] in solving a problem that she would have struggled to solve alone."

This conversation is just one example of how visitors can support each other's learning in museums. Museum learning is often a process of social interaction, conversation, and negotiation (Diamond, 1986; Falk & Dierking, 2000; vom Lehn, Heath, & Hindmarsh, 2001). Even visitors interacting with an exhibit on their own engage in silent conversation with the exhibit designer (Schauble, Leinhardt, & Martin, 1997). As families make sense of exhibits, they develop shared goals (Henderson, 1991), ask questions (Ash, 2004a), and demonstrate strategies for learning (Falk & Dierking, 2000; Mai & Ash, 2012), allowing them to learn more with assistance. Thus, families' conversations can indicate that they are *scaffolding* learning in exhibits.

Prior research suggests that scaffolding is essential for supporting families' learning in museums (Puchner, Rapoport & Gaskins, 2001; Wolf & Wood, 2012), but we have yet to understand how families participate in the process of scaffolding in museum exhibits. While there are many studies that investigate how families support each other's learning (see Ash, Rahm & Melber, 2012; Leinhardt, Crowley, & Knutson, 2002), few of these studies specifically investigate scaffolding as the mechanism for providing that support. Also, while there is considerable research about scaffolding in classrooms (Koole & Elbers, 2014; van de Pol, Volman, & Beishuizen, 2010), we cannot assume that scaffolding in classrooms describes scaffolding in museums. We do not yet know if our understanding of classroom-based scaffolding applies to museum contexts. Thus, to understand families' scaffolding in exhibits, we must examine how each individual participates in the dynamic process of diagnosing needs, providing support, and demonstrating learning (e.g., van de Pol, Volman, Oort, & Beishuizen, 2014). We must also investigate the role of material scaffolds in providing this support (e.g., Yoon, Anderson, Park, Elinich, & Lin, 2018). Researching these components of scaffolding can help us to conceptualize scaffolding as a process (Pea, 2004; Stone, 1998b) and as a distributed system of support (Yoon et al., 2018) in museums.

In this dissertation, I investigated how family members provided scaffolding as they visited an interactive, facilitated pop-up exhibit about compost. The portable exhibit leveraged activities to communicate content about compost. From a sociocultural perspective, my goal was to understand the nature of support in this exhibit as provided by people and exhibit materials. To do this, I first examined prior research about scaffolding and its evolution and research about supporting museum learning through exhibit design. I then conducted a study to investigate how family members and the facilitator provided support (as *social scaffolds*). I then researched how *material scaffolds* embedded in the exhibit complemented this support.

In this introduction, I provide a brief history of scaffolding and describe three key challenges in researching museum-based scaffolding, with corresponding sets of research questions that address these challenges. Next, I describe the format of my dissertation and its contributions to the learning sciences and museum research. Finally, I include a research schedule and a background statement describing my personal motivation for this research.

1.1 Scaffolding Across Learning Contexts

1.1.1 Defining Scaffolding

Scaffolding is a metaphor for just-in-time support that is tailored to the learner's understanding (Stone, 1998b). This support helps the learner to solve a problem that the learner could not solve on their own. Scaffolding functions as both a noun, to refer to resources that provide support, and a verb, to refer to the ongoing process of providing support (Pea, 2004; Stone, 1998b). Thus, scaffolding describes a dynamic process facilitated by resources that are provided at key moments and eventually removed. For the sake of clarity, I will use *scaffolding* to refer to the process of providing support, and *scaffolds* as the supportive resources that facilitate scaffolding.

Scaffolding originally described the kind of support provided during tutor-learner interactions (Bruner, 1975; Wood, Bruner, & Ross, 1976). In these interactions, the tutor performed several *scaffolding functions* tailored to the learner's abilities: (i) recruiting the learner's interest, (ii) maintaining direction, (iii) reducing degrees of freedom, (iv) marking critical features, (v) managing frustration, and (vi) demonstrating problem-solving (Wood et al., 1976). These scaffolding functions helped the learner to eventually accomplish tasks independently.

However, since its inception, scaffolding has come to describe a wide variety of teaching-learning interactions, such as those between parents and children (Cazden, 1979), teachers and students (Tharp & Gallimore, 1988), and peers with similar knowledge (Fernández, Wegerif, Mercer, & Rojas-Drummond, 2001). We can describe the support provided by people in these interactions as *social scaffolds*. People providing support may be described as *scaffolders*, and people receiving support may be described as *scaffoldees* (Granott, 2005).

Scaffolding also came to include supportive tools, activities, and technologies, which we can describe as *material scaffolds* (Belland, Walker, Kim, & Lefler, 2017; Palincsar & Brown, 1984; Puntambekar & Kolodner, 2005; Quintana et al., 2004). Material scaffolds facilitate the process of scaffolding by structuring and problematizing students' work (Reiser, 2004), thus making learning more tractable (Quintana et al., 2004). To do this, the design of material scaffolds must anticipate learners' abilities and needs in relation to the task and acts required to complete it (Puntambekar & Kolodner, 2005; Wood et al., 1976).

Support may be distributed across multiple sources, a notion referred to as *distributed scaffolding* (Puntambekar & Kolodner, 2005; Smagorinsky, Clayton, & Johnson, 2015; Tabak, 2004). Distributed scaffolding describes the inclusion of multiple scaffolds as a system of support, which can be further tailored for students with different needs, at different times, as they work through complex tasks (Tabak, 2004). Scaffolds may be added when learners struggle or removed when learners succeed. This calibration of support allows learners to make progress in a complex task while avoiding frustration and boredom (Palincsar, 1998; Wood et al., 1976).

While originally described in a tutoring context, scaffolding can support learning in both formal and informal contexts. Many early studies of scaffolding described support in everyday contexts (Sherin, Reiser, & Edelson, 2004; Stone, 1998b). For example, Greenfield (1984) analyzed scaffolding in parents' support provided in question-asking and basket-weaving. However, once Cazden (1979) suggested a role for scaffolding in classroom instruction, much of the research on scaffolding described teacher-student interactions in classrooms (Stone, 1998b).

Scaffolding is indeed effective for supporting students in classrooms, as the kind of dialogic instruction specified by scaffolding helps teachers to identify and respond to students' needs (Belland, Kim, & Hannafin, 2013; van de Pol et al., 2010). However, we have yet to understand how the characteristics of scaffolding described in tutoring and classroom contexts might apply to museums. We do not yet know how the on-on-one support described by Wood and colleagues (1976) applies to families' interactions in museums. Thus, we must bridge the gap between research that advances theory about scaffolding and research that describes how social and material resources support learning in museums. I discuss examples of museum-based research in the next section.

1.1.2 Social and Material Scaffolds in Museums

Science museums offer diverse potential scaffolds as family members interact with each other and objects and activities in exhibits (Ash & Lombana, 2012; Falk & Dierking, 2000; Mai & Ash, 2012; Schauble et al., 1997). Family members and museum staff may act as social scaffolds, while tools, activities and technologies may act as material scaffolds. When social and material scaffolds interact, they may augment the support provided by any one scaffold, referred to as synergistic scaffolding (Tabak, 2004; Yoon et al., 2018). In this section, I discuss examples of museum scaffolds based on research investigating social scaffolds, material scaffolds, and the interactions between them in museum exhibits.

Social scaffolds. Both family members and museum staff can act as social scaffolds in museums. Families comprise the largest audience in museums (Borun, 2008), and, accordingly, there is considerable research about how family members support each other's learning in exhibits (Leinhardt et al., 2002). Ash's (2002, 2003a, 2003b, 2004a, 2004b) research about families' learning in museums is particularly informative for understanding scaffolding in museums. For example, Ash (2004a) found that parents' use of open-ended questions helped them to diagnose needs for support while encouraging dialogue among family members. Ash later described these interactions as "scaffolding scenes" that emphasized reciprocity in dialogue among family members (Mai & Ash, 2012).

While we might assume that parents do most of the explaining in exhibits (as demonstrated in Crowley et al., 2001), children can also help other family members to construct explanations, given sufficient prior knowledge and encouragement (Ash, 2004a; Mai & Ash, 2012; Zimmerman et al., 2008). Allen and Gutwill's (2009) study of families' inquiry showed that each family member could collaboratively contribute to inquiry when asked to identify questions that were new to everyone in the group. The distributed nature of support in families was evidenced in parents' and children's contributions to their shared inquiry.

Peers visiting museums, such as students in school groups, also benefit from collaborative activities. Many studies about school groups focus on how students engage in collaborative meaning-making in exhibits (Griffin, 2004). For example, Sturm and Bogner (2010) found that collaboration was an essential scaffold for supporting students' learning about flight in exhibits. Similarly, Yoon and colleagues (2012; 2013) found that collaborative exhibit activities supported students' conceptual understanding of electrical circuits by encouraging students to co-construct explanations of their observations.

In addition to interactions among families and peers, museum staff (i.e., docents, educators, facilitators, etc.) can act as social scaffolds by helping visitors to make sense of exhibits (Adams, Tran, Gupta, Creedon, & O'Hurley, 2008; Allen & Crowley, 2014). Museum staff are trained to provide information and context about exhibits (Foreman-Peck & Travers, 2013; Grenier, 2005). Museum staff must learn to establish rapport with visitors and gauge their understanding in a short period of time (Adams et al., 2008; Taylor & Neill, 2008). Museum staff must also learn to respond to differences in visitors' knowledge, experiences, and interests (Foreman-Peck & Travers, 2013; Griffin, 2004; Schauble et al., 2002). While museum staff are often encouraged to use dialogic pedagogy that responds to visitors' learning goals (Adams et al., 2008; Ash, 2014), not all museum staff do so (Allen & Crowley, 2014). As a result, museum staff may do more "telling" than discussing (Adams et al., 2008).

In summary, families, peers, and museum staff can serve as social scaffolds in museums. Families and peers may help each other to explain exhibits and answer each other's questions, while museum staff may share additional information about exhibits. However, museum staff may struggle with providing an appropriate level of scaffolding for visitors they have just met.

Material scaffolds. In addition to sparking curiosity, many science exhibits aim to educate visitors by including materials designed to support learning (Allen, 2004; Falk & Dierking, 2000). These materials (such as objects, text, representations, activities, and technologies) act as material scaffolds when they help visitors to understand new concepts, relationships, or practices (Allen, 2004; Paris, 2002; Yoon et al., 2013).

Material scaffolds can support learning in various ways, such as by recruiting and sustaining families' interest. Exhibits featuring authentic objects or novel experiences can inspire curiosity and sustain inquiry (Allen, 2004; Paris, 2002). Active Prolonged Engagement (APE) exhibits support inquiry by bridging new objects and phenomena with prior experiences (Allen, 2004). APE exhibits support learning by encouraging families to ask questions and develop explanations as they interact with objects, phenomena, and text in exhibits (Allen, 2004; Allen & Gutwill, 2009). Material scaffolds can also highlight conceptually-relevant features of exhibits. For example, the zoetrope studied by Crowley and colleagues (2001) featured static images that, when viewed through a slit, appeared to be moving. This optical illusion generated a need for families to investigate the workings of the zoetrope and develop explanations for the illusion. As another example of object-supported learning, Jant, Haden, Uttal, and Babcock (2014) found that families who received conversation cards and exhibit-relevant objects were more likely to identify and discuss conceptual themes in exhibits. Also, families who received conversation cards recalled more exhibit content at home, indicating that the conversation cards, as material scaffolds, supported learning beyond the exhibit.

There are many such studies of how exhibit materials support learning, and I discuss more examples in the literature review. However, it is important to note that many of these studies also consider how family members act as social scaffolds when interacting with exhibit materials. Thus, studying how material scaffolds support learning often requires understanding the role of social scaffolds, too. Thus, we must understand how social and material scaffolds interact in each learning context, which I discuss in the next section.

Interactions between scaffolds. Museum learning is mediated by social interactions in object-rich spaces (Kozulin, 2003; Paris, 2002; Schauble et al., 1997). As such, we must analyze how social and material scaffolds play roles in supporting learning (Ash, 2014). We can use distributed scaffolding as a lens to identify how available scaffolds support learning and complement support provided by other scaffolds as well (Puntambekar & Kolodner, 2005; Yoon et al., 2018). Analyzing the interactions between scaffolds helps us to understand how individual exhibits support learning, and offers insights about the design of distributed scaffolding.

As an example, Eberbach and Crowley (2005) studied how three different representations of plants–living, model, and virtual–supported children's learning about pollination. The authors also described how parents adapted their support based on the kind of representation. The authors found that parents provided a particular kind of support–connecting exhibit objects to past experiences–only when interacting with the plant models. This study demonstrates how social and material scaffolds can interact in different ways in the same exhibit, and how these interactions affect how support is provided.

When scaffolds augment the support provided by other scaffolds, they can be described as synergistic scaffolds (Tabak, 2004). In one study of synergistic scaffolds, Yoon and colleagues (2018) investigated how the complementary affordances of distributed scaffolds supported middle-school students' learning in exhibits. An augmented reality scaffold allowed visitors to visualize "hidden information," while a text scaffold provided instructions for interacting with the exhibit. Also, a collaboration scaffold encouraged students to provide feedback to each other as a group. Students who interacted with the combination of all three scaffolds demonstrated greater learning than students interacting with other combinations. This study shows how the complementary affordances of social and material scaffolds in the exhibit created a synergistic system of support (Tabak, 2004; Yoon et al., 2018).

Thus far, this section described a small pool of studies that demonstrate the rich potential for social and material scaffolds in museum exhibits. I provide a more extensive review of museum-based scaffolding in the literature review.

1.1.3 Challenges in Museum-Based Scaffolding

Next, I discuss three key challenges in studying museum-based scaffolding. These challenges include the limited amount of research investigating scaffolding as a mechanism for support in museums; variability in how studies of museum-based scaffolding ground their discussion of scaffolding in prior research; and a need to understand the interactions between social and material scaffolds in museums. These challenges have implications for how we apply what we understand about scaffolding from other contexts (e.g., classrooms) to museums, and how we characterize supportive interactions among adults and children in museums.

While scaffolding seems essential for learning in museums (Puchner et al., 2001), we have yet to understand how families participate in the process of scaffolding. This is demonstrated by the lack of research that specifically investigates scaffolding as a mechanism for providing that support. As of October 17, 2018, a search of EBSCOhost Education Research Complete gave a maximum of fifteen results for "museum" and "scaffolding" or "scaffolds" within studies' titles, subjects, keywords, and abstracts (see Table A1 in Appendix A). These limited results illustrate the lack of research at the intersection of scaffolding and supporting museum learning. As there are considerable differences in learning across formal and informal contexts (Borun, 2008; Wellington, 1990), and even within informal contexts (e.g., art versus science museums), there may be corresponding differences in how scaffolding is enacted in each context. In response, I conducted a literature review based on the following research question: *based on research about scaffolding and museum learning, what evidence do we have that family members are scaffolding each other's learning, or that exhibits are scaffolding families' learning?*

Second, studies that have investigated museum-based scaffolding (e.g., Cahill, Kuhn, Schmoll, Pompe, & Quintana, 2010; Kuhn, Cahill, Quintana, & Soloway, 2010; Melber, 2007;

Yoon et al., 2012; Yoon et al., 2013; Yoon et al., 2018) do not ground their discussions of scaffolding in prior research in a consistent way. As such, we cannot tell if scaffolding in one museum context reflects scaffolding in another context. For example, Melber (2007) attributed scaffolding to Vygotsky (1978) and his notion of the zone of proximal development. In contrast, Yoon and colleagues (2012; 2013; 2018) provided a deeper background of scaffolding related to student collaboration and knowledge building. These differences in how researchers ground their discussions of scaffolding make it challenging to generalize findings to other contexts, as researchers may use broader or narrower definitions of scaffolding (Palincsar, 1998; Pea, 2004; Stone, 1998a). In response, I conducted an empirical study that investigated how family members participated in the process of scaffolding in this exhibit. This study asked a set of four research questions: *How did family members demonstrate need for support? Who provided support? What kinds of support did family members provide? What kinds of learning did family members demonstrate?*

Third, to understand how family members participate in museum-based scaffolding, we must also analyze the interactions between social and material scaffolds. We can use a distributed scaffolding lens to understand how the design of exhibit supports scaffolding. However, our understanding of distributed scaffolding in exhibits is limited. Yoon and colleagues (2018) showed that the combination of collaboration, text-based instructions, and “hidden” information can deepen students’ learning. Also, mobile inquiry systems can help students use objects from museums as evidence to support inquiry activities back in the classroom (Cahill et al., 2010; Kuhn et al., 2010). However, both of these studies focused on students’ interactions with exhibit materials. In response, I analyzed how families interacted with exhibit materials, using data from the previous study. I asked the following research questions: *How did exhibit materials afford of joint activity, access to information, and access to feedback?*

How did family members acting as social scaffolds interact with material scaffolds in the exhibit? How was support distributed among social and material scaffolds in the exhibit?

Overall, the abundance of potential scaffolds in museums, combined with the ambiguity around how scaffolding occurs in museums, leaves considerable room for research. By addressing these challenges, we can further develop the notion of scaffolding in the context of museums (Mai & Ash, 2012); generalize aspects of scaffolding across learning contexts (Paris & Ash, 2000); and identify how the design of exhibit materials affords certain kinds of interactions and complements support provided by social scaffolds (Yoon et al., 2018).

1.2 Dissertation Format and Contributions to the Learning Sciences

In this dissertation, I investigated how family members and exhibit materials provided support in the context of an interactive, facilitated pop-up exhibit about compost, hosted in two science museums. I use the term "pop-up" to indicate that this was not a permanent exhibit, but rather a small portable exhibit with interactive components. This exhibit was more akin to a science festival display than a traditional built-in museum exhibit. Social scaffolds in the exhibit included the facilitator (myself, as a participant-observer) and family members. Material scaffolds included multiple components of a sorting activity about compostable materials and a simulation of a virtual compost bin.

As described above, my research questions respond to key three issues in researching museum-based scaffolding. My research questions were:

1. Based on research about scaffolding and museum learning, what evidence do we have that family members are scaffolding each other's learning, or that exhibits are scaffolding families' learning?
2. Concerning families' social scaffolding in the exhibit,
    a. How did family members demonstrate need for support?

   b. Who provided support?
   c. What kinds of support did family members provide?
   d. What kinds of learning did family members demonstrate?
3. Concerning the interactions between social and material scaffolds,
   a. How did exhibit materials afford joint activity, access to information, and access to feedback?
   b. How did family members acting as social scaffolds interact with material scaffolds in the exhibit?
   c. How was support distributed among social and material scaffolds in the exhibit?

I answered these three sets of questions in three papers. In the first paper, I reviewed prior research about how people and exhibit materials supported learning in museums. In the second paper, I analyzed how 23 families provided scaffolding in their discourse as they interacted with the exhibit, using a coding scheme based in prior research about scaffolding in tutoring (Wood et al., 1976), classroom (Tabak & Baumgartner, 2004), and museum contexts (Mai & Ash, 2012). In the third paper, I analyzed the same video data from the 23 families, but instead focused on how the affordances of the exhibit materials shaped families' social interactions, using a distributed scaffolding lens. I described how material scaffolds complemented support from social scaffold in the exhibit and visualized the distribution of support in the exhibit.

This research offered five contributions to the learning sciences. The first dissertation paper contributed a unique review describing the intersection of research about scaffolding with research about supporting museum learning. This review described how the two bodies of research overlap in their aim of describing supportive interactions in museums. Yet, there is work to be done in building theory across classroom and museum contexts (Paris & Ash, 2000).

The second dissertation paper focused on families' scaffolding by describing the kinds of support families provided while interacting with the exhibit, using a coding scheme informed by prior research about scaffolding (Wood et al., 1976; Koole & Elbers, 2014; Tabak & Baumgartner, 2004; Mai & Ash, 2012; Borun, Chambers, & Cleghorn, 1996). As a contribution of the paper, the coding scheme showed that scaffolding described in a one-on-one tutoring context (e.g., Wood et al., 1976) can describe support in a museum exhibit with complex activities, as well as in classrooms (Belland et al., 2013). Also, the findings showed that both parents and children provided scaffolding in the exhibit despite multiple barriers, such as a lack of pedagogical training (Allen, 2004; Haden, 2010).

The second dissertation paper also showed how parents and children took on dual roles as scaffolder and scaffoldee (Granott, 2005). While parents provided more support than children, all family members contributed to the process of providing support, echoing findings from Mai and Ash (2012). Notably, some children provided support to other children, echoing research about students' scaffolding in classrooms. Even though children do not have pedagogical training, they can support other children by adopting scaffolding strategies modeled by adults (Guk & Kellogg, 2007) or co-constructing knowledge in their dialogue (Brown et al., 1993; Fernández et al., 2001). This warrants future research that investigates children's motivation to provide scaffolding to peers and the language they use to provide support (Webb & Farivar, 1999).

The third dissertation paper illustrated how exhibit material could complement support provided by social scaffolds, depending on the affordances of the material scaffolds. Material scaffolds that afforded joint activity were integrated in families' scaffolding on an ongoing basis, echoing earlier discussion about the social nature of museum learning (Falk & Dierking, 2000). However, material scaffolds that afforded access to information and feedback were incorporated in families' scaffolding at key moments. For example, families referred to these scaffolds only when making decisions in the simulation. By studying the interactions between social and material scaffolds, we can identify how material scaffolds might complement support from social scaffolds.

The third dissertation paper also demonstrated the need for responsive human support when the design of material scaffolds was inadequate, echoing issues described in prior research about classroom-based scaffolding (Belland, Gu, Armbrust, & Cook, 2015; Ge & Land, 2004; Saye & Brush, 2002). When material scaffolds failed to accommodate the needs of families with younger children, the facilitator needed to provide additional support so that families could participate in the activities. This study showed how support was distributed across social and material scaffolds in the exhibit, and also showed the importance of careful design of exhibit scaffolds when encouraging particular kinds of social interactions (i.e., scaffolding).

Taken together, these studies add to our understanding of how families participate in museum-based scaffolding. The first paper bridged research about scaffolding from a learning sciences lens with research about supporting museum learning. The second paper showed how families provided social scaffolding in an interactive, facilitated science exhibit. The third paper showed how material scaffolds could complement support from social scaffolds, but also reveal flaws in the design of distributed scaffolding. While this dissertation is limited by its sample size and my participation as the facilitator, it offered insights into how distributed scaffolding supports families' learning in museums.

1.3 Research Schedule

Table 1 summarizes the research schedule for this dissertation. I began my literature review as part of my preliminary essays in March – May 2017. I defended my preliminary essays and completed coursework in May 2017. I then wrote my proposal and defended the proposal in November 2017. After revisions to the proposal and a pilot study, I submitted my revisions to the committee in May 2018 and began to collect data from May–August 2018. I transcribed and analyzed data as it was collected. I began writing my introduction and literature review in June 2018; the two empirical studies in September 2018; and the conclusion in October 2018. I sent the final version of my dissertation to my committee on November 12, 2018. I defended my dissertation on November 26, 2018, and deposited my dissertation in December 2018.

Table 1

Dissertation Research Schedule

<table>
<tr><td>Year</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sept</td><td>Oct</td><td>Nov</td><td>Dec</td><td>Jan</td><td>Feb</td></tr>
<tr><td>2017-
2018</td><td colspan="4">Prelim writing and defense
Coursework completed</td><td colspan="4">Proposal writing
Proposal defense</td><td colspan="4">Proposal revisions
Literature review</td></tr>
<tr><td>2018-
2019</td><td colspan="2">Proposal
revisions</td><td>Pilot data
collection
Revisions
completed</td><td colspan="3">Data collection
Data analysis
Thesis writing</td><td colspan="3">Data analysis
Thesis writing
Thesis defense</td><td colspan="3">Thesis revisions
Thesis deposited
Manuscript drafts</td></tr>
</table>

1.4 Background Statement

In this dissertation, I used methods from quantitative ethnography and learning analytics. while positioning myself as a participant-observer in the exhibit (e.g., Allen & Crowley, 2014). In this section, I explain my reasoning for this research approach by briefly describing my background in museum education and subsequent graduate studies.

I began working at the Milwaukee Public Museum (MPM) in March 2008 as a member of frontline staff. After graduating with a Bachelor of Science in microbiology and a Bachelor of Arts in psychology in May 2011, I began working as a museum educator with MPM from November 2011 until January 2014. When beginning this role, senior educators encouraged me to turn facts into open-ended questions, to provide answers only when necessary, and to allow visitors to drive interactions at all points. I also began prototyping pop-up activities that encouraged visitors' hands-on participation in otherwise static diorama exhibits.

My department did informal evaluation of the pop-up activities, but my background in science motivated me to seek out ways of conducting more rigorous research about how these activities influenced visitors' learning. I began pursuing graduate programs that would allow me to do this research in museums. I found Prof. Sadhana Puntambekar's research on scaffolding, and I realized that the notion of scaffolding encompassed the kind of instruction and support I provided to visitors on a daily basis. After beginning my studies with Prof. Puntambekar in January 2014, I realized that there were very few studies that investigated the intersection of scaffolding theory and museum learning. I also studied methods for learning analytics with Prof. Martina Rau and Prof. Matthew Berland as part of my doctoral coursework. This shaped my research throughout my Ph.D. program, and thus is the focus of this dissertation.

2. Supportive Interactions in Museums: The Intersection of Research About Scaffolding and Museum Learning

Scaffolding has been used to describe a broad range of learning contexts that provide temporary support tailored to learners' needs (Palincsar, 1998; Puntambekar & Hübscher, 2005). As a metaphor for instruction, scaffolding originally described support provided in one-on-one tutoring (Bruner, 1975; Wood, Bruner, & Ross, 1976), but evolved to describe other supportive contexts, including interactions between parents and children (Stone, 1998b), teachers and students (van de Pol, Volman, & Beishuizen, 2010), and peers working together (Fernández, Wegerif, Mercer, & Rojas-Drummond, 2001). Scaffolding can also provide support provided by tools, activities, environments, and/or technologies (Luckin, 2008; Puntambekar & Hübscher, 2005; Quintana et al., 2004; Tabak, 2004). Scaffolding can describe the process of providing support along with the entities that provide support (Pea, 2004; Stone, 1998b). In this paper, I will use *scaffolding* to describe the process of providing support, and *scaffolds* to describe the social and material entities that support this process.

Early studies of scaffolding focused on parent-child interactions in everyday contexts (Stone, 1998b). However, after Cazden (1979) suggested a role for scaffolding in classroom instruction, many researchers began to investigate scaffolding in teacher-student interactions (Stone, 1998b; van de Pol et al., 2010). Thus, classroom-based research has shaped much of what we understand about scaffolding, its characteristics, and its mechanisms (Puntambekar & Kolodner, 2005; Saye & Brush, 2002; Smit, van Eerde, & Bakker, 2012; Tharp & Gallimore, 1988).

In contrast, we know relatively little about scaffolding in museums. While there are considerable studies about how people and/or exhibit materials support learning in museums, few investigate how this support reflects the characteristics and mechanisms of scaffolding. To demonstrate, I searched EBSCOhost Education Research Complete for journal articles that included “museum” and “scaffolding” or “scaffold” in their title, abstract, subject, or keywords. As of October 17, 2018, I found only 15 unique journal articles that fit these search requirements (see Table A1 in Appendix A for citations). These search results illustrate the relatively small pool of research concerning museum-based scaffolding.

The limited amount of research is a key issue on its own. However, it is compounded by a second issue concerning the semantics of scaffolding. Some studies investigating museum-based scaffolding ground their discussion within prior research about scaffolding, such as Wood and colleagues’ (1976) foundational study or subsequent research that describes its evolution as a metaphor for instruction (Boblett, 2012; Stone, 1998b). For example, Yoon, Elinich, Wang, Steinmeier, and Tucker (2012) discuss scaffolding from a learning sciences perspective that bridges scaffolding with knowledge building (Scardamalia & Bereiter, 2006). However, not all studies of museum-based scaffolding ground their discussion within learning theories, or do so in a perfunctory way. For example, Melber (2007) provided a brief discussion of scaffolding, but attributed scaffolding to Vygotsky (1978) and his notion of the *zone of proximal development* (ZPD). While scaffolding and the ZPD are often associated, they are not the same notion (Boblett, 2012; Granott, 2005), which I discuss later in this paper. The variability in theoretical grounding of scaffolding is problematic because it diminishes the usefulness of scaffolding as a term for describing temporary, adaptive support (Palincsar, 1998; Stone, 1998a) and risks overgeneralizing the term (Pea, 2004).

There are also studies of museum learning that describe temporary, adaptive support provided by people and exhibit materials, but do not explicitly refer to this support as scaffolding. For example, Crowley and Callanan (1998) described differences in how parents supported children’s scientific thinking in exhibits through processes of negotiating shared goals and mediating children's activity. While this research aligns with previous descriptions of scaffolding, scaffolding is not mentioned in the study. Also, entire edited volumes have described dialogues that support learning among visitors (e.g., Ash, Rahm, & Melber, 2012; Leinhardt, Crowley, & Knutson, 2002), but Ash's trajectory of research (as summarized in Mai & Ash, 2012) is one of the few research strands that focuses on museum-based scaffolding. This is not to say that researchers investigating supportive interactions in museums are required to refer to scaffolding. Rather, I mention this point to indicate that, in order for us to understand museum-based scaffolding, we must also evaluate research in which scaffolding is not specifically mentioned. This illustrates a gap between how we research scaffolding and how we research support for museum learning.

Finally, there is a third issue concerning the design of scaffolding within exhibits. The notion of *distributed scaffolding* describes social and/or material support provided across multiple scaffolds within a learning context (Puntambekar & Kolodner, 2005). Exhibits can include social scaffolds in the form of visitors and museum staff, and material scaffolds in the form of tools, text, activities, and technologies. To effectively support visitors' learning, we must understand how social and material scaffolds interact and impact learning. Yoon and colleagues began a trajectory of research (Yoon et al., 2012; Yoon, Elinich, Wang, van Schooneveld, & Anderson, 2013; Yoon, Anderson, Park, Elinich, & Lin, 2018) that investigated the design of distributed scaffolding to support middle-school students' learning. Similarly, the Zydeco mobile inquiry system (Cahill, Kuhn, Schmoll, Pompe, & Quintana, 2010; Kuhn, Cahill, Quintana, & Soloway, 2010) included multiple scaffolds designed to support learning across the museum and the classroom. Yet, there are no studies that use a distributed scaffolding lens to investigate families' interactions with social and material scaffolds.

In response to these issues, I reviewed prior research about scaffolding and its evolution as a metaphor for instruction. I also reviewed prior research about supporting museum learning. My review focused on the following question: *based on research about scaffolding and museum learning, what evidence do we have that family members are scaffolding each other's learning, or that exhibits are scaffolding families' learning?* I describe key studies that address this question in science centers, natural history museums, children's museums, and similar sites. I do not include art museums, though, as supporting art interpretation warrants its own review.

In the first section, I review research about the history of the scaffolding metaphor, its evolution across contexts, and examples within classrooms. In the second section, I review research about museum learning and evidence of support within exhibits. In the third section, I briefly review design considerations for scaffolding in museums. I conclude with ideas for future research that expand our understanding of museum-based scaffolding.

2.1 Expanding Definitions of Scaffolding

2.1.1 Original Description of Scaffolding

Wood, Bruner, and Ross (1976) originally defined scaffolding in the context of a tutor helping a young child building with blocks. The tutor engaged in process of gauging the child's understanding and identifying elements of the task that were within the child's abilities. These elements were presented to the child as acts within the overarching task that increased in challenge. This process of introducing acts within the task gradually shifted the responsibility for cognitive and motivational work involved in accomplishing the task from the tutor to the child, and the child was eventually able to complete the task independently (Campione, Brown, Ferrera, & Bryant, 1984; Belland, Kim, & Hannafin, 2013). For the tutor to provide support, the tutor needed both knowledge of the task and of the child, meaning that the tutor understood all elements involved in accomplishing the task and the child's abilities relative to each element

(Wood et al., 1976). Wood and colleagues (1976, p. 97) noted that scaffolding was "both *task* and *tutee* dependent, the requirements of the tutorial being *generated* by the interaction of the tutor's two theories." Thus, to support the child, the tutor did not alter the task itself, but instead identified acts within the task that the child could accomplish with assistance.

When scaffolding, tutors might help children to define the task; determine goals and end products; identify resources; and regulate learning (Reiser & Tabak, 2014). The tutor might also demonstrate strategies for identifying broad objectives of the task and specific knowledge or skills necessary to complete the task or acts within it. Wood and colleagues (1976) described six specific scaffolding functions, which included: (i) recruitment of the learner's interest; (ii) reduction in degrees of freedom, or the acts needed to accomplish the task; (iii) direction maintenance; (iv) marking critical features; (v) frustration control; and (vi) demonstration. Wood and colleagues clarified that demonstration should be done with the goal of imitation, so that the child learns to imitate that action and eventually perform it of his or her own volition. Belland and colleagues (2013) further noted that these scaffolding functions could be categorized as cognitive or motivational support, with recruiting interest, maintaining direction, and managing frustration serving as motivational support.

Elaborating upon scaffolding, Tharp and Gallimore (1988) described *assisted performance* in the context of classrooms. Assisted performance addressed concerns about providing scaffolding in classrooms with multiple learners, and the challenges inherent to that support, compared with other contexts (e.g., tutoring). To support multiple learners, Tharp and Gallimore (1988) suggested that teachers also use contingency management, feedback, questioning, and cognitive structuring as assistive strategies.

Since its inception, the conceptualization of scaffolding has changed considerably. To illustrate these changes, I first contextualize scaffolding within sociocultural theories of learning.

I then describe how scaffolding evolved as an instructional metaphor from one-on-one tutoring support to a variety of teaching-learning interactions facilitated by social and material resources.

2.1.2 Scaffolding in the Zone of Proximal Development

Scaffolding is grounded in sociocultural theories of learning, which emphasize social and cultural mediation of learning (Rogoff, 1990; Vygotsky, 1978; Wertsch, 1984; Wertsch, 1996). For socioculturalists, learning is a process shaped by shared language and signs, as well as a biological process that occurs in the mind (Bruner, 1996; Vygotsky, 1978). Learning is mediated by people and symbolic tools (Kozulin, 2003; Vygotsky, 1978), dialogue (Bahktin, 2010; Mercer & Littleton, 2007; Wegerif, Mercer, & Dawes, 1999; Wells, 1999), and participation in shared activities (Rogoff, 2008; Roschelle, 1992) and practices (Lave & Wenger, 1991; Lave, 1991).

Vygotsky's (1978) notion of the zone of proximal development, or ZPD, is a particularly influential notion in sociocultural theories of learning. The ZPD is also often associated with scaffolding. Vygotsky (1978) described the ZPD as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). The ZPD is useful for envisioning a range of what a learner can accomplish in joint activity with others (Vygotsky, 1978; Wertsch, 1984).

It is assumed that different learners have different ZPDs, and this variation has implications for how tasks or problems are introduced to different learners (Brown et al., 1993; Campione et al., 1984).When describing the ZPD, Vygotsky (1978) specified an asymmetrical relationship in which assistance was provided by a person (e.g., tutor) who had greater knowledge than the learner, and thus could assess the upper and lower bounds of the learner's ZPD. The lower bound represented what the learner could already accomplish independently, and the upper bound represented what could the learner could accomplish with assistance

(Hedegaard, 1990). The difference between these bounds could be large, indicating that the learner could accomplish much more with assistance, or small, indicating smaller changes in what could be accomplished with assistance.

Researchers began to associate ZPD with scaffolding because the ZPD conceptualized a range for providing tailored support (Cazden, 1979). Scaffolding described the means for working within a learner's ZPD (Cazden, 1979; Granott, 2005; Stone, 1998b). As the learner demonstrated mastery over each element of the task, the upper bound of the ZPD expanded, allowing the learner to take on greater responsibility within the task until he or she could complete it independently (Ash & Levitt, 2003; Brown et al., 1993; Chak, 2001). Vygotsky (1978) described this as *internalization*, meaning that the knowledge and skills needed to accomplish the task became part of the learner's own psychology to be called upon at the learner's discretion.

In a similar vein, Rogoff (2008) described *guided participation*, which referred to the "processes and systems of involvement between people as they communicate and coordinate efforts while participating in a culturally valued activity" (p. 60). Rogoff emphasized the role of culture in shaping learners' participation in shared activity and adoption of others' knowledge and skills. Rogoff further argued that guided participation was a reciprocal process, in which the activity transformed the learner and the learner transformed the activity. Ultimately this transformation resulted in *appropriation*, which differed from *internalization* in its emphasis on mutuality among participants. This mutual, reciprocal characteristic of appropriation is also a characteristic of scaffolding (Puntambekar & Kolodner, 2005).

The association between scaffolding and ZPD can help tutors or teachers to develop tailored support for learners with different ZPDs. To respond to the learner's needs, the tutor may increase support when the learner struggles and decrease support when the learner succeeds.

Eventually, the learner should be able to accomplish each act within the task and understand the relationships between acts as part of the overarching task. This process of providing adaptive, timely support helps the learner to understand the "knowing how" of a task, which may be applied to similar tasks (Wertsch, 1996).

2.1.3 Extending Scaffolding to Scaffolds

While originally defined in a tutoring context, the notion of scaffolding has since expanded to include many other kinds of supportive interactions among people, tools, activities, and technologies (Brown et al., 1993; Lajoie, 2005; Puntambekar & Kolodner, 2005). This expansion reflects how various entities, or *scaffolds*, can support the process of scaffolding at key moments for learners. As both a noun and a verb, scaffolding described the process of providing contingent support and the entities or structures that facilitated this process. (Pea, 2004; Stone, 1998b). Stone (1998b) emphasized that "the core of the scaffolding metaphor rests squarely on viewing it as a process," (p. 412). Granott (2005) further illustrated the ongoing, dynamic nature of scaffolding as a process of adapting to the learner's needs during shared activity. The inclusion of entities and structures as *scaffolds* has allowed us to consider how various artifacts, resources, and environments can mediate scaffolding (Puntambekar & Hübscher, 2005).

As a flexible metaphor for support, scaffolding can describe many sources of support in a variety of contexts (Palincsar, 1998). However, when many different resources that can be considered a scaffold, a critical question arises – what are the *boundaries* of what can be considered a scaffold? While flexible, the extension of scaffolding to other contexts becomes problematic when divorced from theory, thus calling the usefulness of scaffolding as a distinct notion of support into question (Palincsar, 1998; Pea, 2004; Stone, 1998a) and generating debate over the qualities of scaffolding and scaffolds (van de Pol et al., 2010). For the purposes of this review, I argue that social and material resources are scaffolds when they are leveraged to support the adaptive, dynamic process of scaffolding.

To further clarify the boundaries of scaffolding, Puntambekar and Kolodner (2005) described several essential characteristics that differentiated scaffolding from other forms of instructional support, as based on teacher-student interactions. First, the teacher and student negotiated *common goals* and meanings within the task to establish intersubjectivity (Wertsch, 1984; Rogoff, 1990). In this process, the learner takes ownership for their learning, which, in turn, helps sustain the learner's interest. Next, the teacher engaged in *ongoing diagnosis* of the learner's understanding, which involved checking for understanding (and misunderstanding), such as by asking probing questions. Ongoing diagnosis is key to providing *dynamic, adaptive support* that is calibrated so that the learner is challenged without becoming overwhelmed (Stone, 1998a) and changes as the learner demonstrates (or does not demonstrate) mastery over the task. Additionally, scaffolding is characterized by *dialogic interactions* between teacher and learner as they mutually participate in meaning-making (Reiser & Tabak, 2014; Stone, 1998a; van de Pol et al., 2010). This dialogue is supported by the teacher's negotiation of meaning with the learner, rather than transmitting meaning (Ash & Wells, 2006; Rogoff, 1994; Tharp & Gallimore, 1988; Wells, 1999). As the learner accomplished acts with the task, the teacher began to reduce the level of support (i.e., *fading*) and *transfer responsibility for learning* to the student (Puntambekar & Kolodner, 2005; Smit et al., 2012). Several researchers (Guzdial, 1994; Lajoie, 2005; Pea, 2004 Stone, 1998b) have argued that fading highlights the temporary nature of support in scaffolding and thus is its cornerstone. Taken together, these characteristics help us to differentiate scaffolding as a distinct approach for providing support and operationalize scaffolding in various learning contexts.

2.1.4 Social and Material Scaffolds in Classrooms

Scaffolds can refer to a variety of entities that support the process of scaffolding. In this paper, I refer to support provided by people as *social scaffolds*, and support provided by tools and technology as *material scaffolds*. I use a social-material distinction (compared to a hard-soft distinction; see Saye & Brush, 2002) for two reasons. First, the differences between static support provided by tools and responsive support provided by humans have become less distinct with advances in computer-based scaffolding, as intelligent tutors and other adaptive technologies have shown that tools can provide responsive support (e.g., Azevedo, Cromley, Moos, Greene, & Winters, 2011; Belland, Gu, Armbrust, & Cook, 2015). Second, Saye and Brush's (2002) hard-soft distinction did not discuss interactions among social and material scaffolds in depth.

In this section, I discuss examples of social and material scaffolds from prior research in classrooms as a basis for identifying scaffolds in museums. While this section is not an exhaustive list of scaffolds, it describes representative examples that demonstrate how entities can support the process of scaffolding.

Social scaffolds. As stated earlier, Cazden (1979) played a major role in expanding scaffolding to classroom instruction. She claimed that parents playing peek-a-boo with their children engaged their children in a particular form of discourse. As children became more adept at the game, the game changed to become more challenging, and eventually children took on the parent's role. Cazden noted the similarities between the discourse forms in peek-a-boo with discourse forms in the classroom, and thus suggested that scaffolding could be incorporated into classroom instruction.

When discussing scaffolding in classrooms, Tharp and Gallimore (1988) noted that teachers needed to scaffold multiple students at the same time, thus requiring them to diagnose and respond to different needs (Smit et al., 2012). This kind of *ongoing diagnosis* requires that the teacher gauge the upper and lower bounds of students' ZPD and respond with corresponding levels of support. Teachers may diagnose students' understanding during lessons, such as by asking probing questions, or between lessons, such as by reviewing students' assignments (Smit et al., 2012). In responding to different ZPDs, teachers may provide support that responds to multiple, overlapping ZPDs (Brown et al., 1993) or a whole-class ZPD that exists alongside students' individual ZPDs (Smit et al., 2012). The teacher may also build on support from previous lessons so that learners can revisit content, practices, or skills (Smit et al., 2012).

Teachers may also demonstrate scaffolding strategies for peers to practice when collaborating in groups. Collaborative activities give students the opportunity to scaffold each other by encouraging students to share, explain, and evaluate their ideas (Smit et al., 2012; Tabak & Reiser, 1997) through a process of negotiation and constructive critique (Fernández et al., 2001; Guk & Kellogg, 2007; Wertsch, 1984; Brown & Campione, 1996). Teachers may use methods such as reciprocal teaching (Palincsar & Brown, 1984) to encourage participation among students with different ZPDs (Brown & Campione, 1996). When students reveal gaps in their understanding, their peers can provide alternative ideas and explanations. This process of co-constructing knowledge allows students to improve their individual and group reasoning (Fernández et al., 2001; Mercer, Dawes, Wegerif, & Sams, 2004; Oliveira & Sadler, 2008; Rojas-Drummond & Mercer, 2003; Roschelle, 1992; Scardamalia & Bereiter, 2014; Stahl, 2005).

While collaboration can be beneficial, there is no guarantee that students will know how to support each other (Dillenbourg, 1999; Mercer & Dawes, 2008). Students may need scaffolds to learn effective communication and coordination strategies in order to collaborate effectively (Dillenbourg, 1999; Fischer, Kollar, Stegmann, & Wecker, 2013; Oliveira & Sadler, 2008; Tudge, 1990). These scaffolds may include models of how to provide constructive criticism and resolve conflicts (Mercer & Dawes, 2008; Miyake & Kirschner, 2014). Activities that incorporate roles are useful for scaffolding collaboration, as roles give each learner an opportunity to engage in help-seeking and help-giving (Hare, 1994; Hoadley, 2010; Saleh, Lazonder, & de Jong, 2007; Spada, 2010; Strijbos & De Laat, 2010; Strijbos, De Laat, Martens, & Jochems, 2005; Strijbos & Weinberger, 2010).

One such approach that incorporates scaffolding for collaborative activity is problem-based learning (PBL). In PBL, learners take full responsibility for managing their inquiry toward solutions for an ill-structured problem (Hmelo-Silver & Barrows, 2008; Lu, Bridges, & Hmelo-Silver, 2014). The teacher takes on a facilitation role and offers prompts as needed to further students' progress. Learners develop hypotheses and coordinate their inquiry as a group. Because PBL problems have no one correct answer, students must develop collaboration strategies as they explain and justify their solutions. Other PBL scaffolding strategies include externalizing ideas; embedding expert guidance; structuring complex tasks; and reducing cognitive load (Hmelo-Silver, Duncan, & Chinn, 2007).

These examples illustrate how scaffolding extended beyond tutoring interactions to include teacher-student and student-student that help learners to develop their understanding and solve problems independently. Beyond social scaffolds, classroom-based scaffolding may be facilitated by material scaffolds as well, which I discuss in the next section.

Material scaffolds. Material scaffolds can support the process of scaffolding by offering structure, context, and information at key points (Reiser, 2004; Quintana et al., 2004). Material scaffolds can include cognitive tools, technologies, artifacts, guides, and other physical or digital devices (Azevedo et al., 2011; Luckin, 2008; Puntambekar & Kolodner, 2005; Tabak, 2004).The key constraint in defining these materials as scaffolds is that they must help the learner to accomplish more than they could on their own, but the materials must be removed at some point

(Luckin, 2008; Pea, 2004; Quintana et al., 2004). If not removed, these materials are better described as components of distributed intelligence, where removal is not expected (Pea, 2004).

Material scaffolds play major roles in in project- and design-based curricula (Puntambekar & Kolodner, 2005), where they help students manage planning and design processes, reflect on decision-making, use content, and engage in practices. As an example, Learning by Design integrated social and material scaffolds to support students' engagement in inquiry and design practices (Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998; Puntambekar & Kolodner, 2005). Social scaffolds included teachers and peers, while material scaffolds included a paper-and-pencil tool, design prompts, texts, videos, and physical experiments. The paper-and-pencil tool guided students' inquiry by helping students to record observations, note patterns, and engage in reflection. While this paper-and-pencil tool successfully prompted students to externalize their thinking, students did not refer to the evidence they recorded when supporting their reasoning (Puntambekar & Kolodner, 2005). In the next iteration of Learning by Design, Puntambekar and Kolodner (2005) provided more specific prompts to support students' reasoning, and they also orchestrated lessons to seamlessly interleave individual, small group, and whole class activities. The key takeaway of Learning by Design was that students required multiple, different scaffolds to effectively participate in inquiry and design processes and learn relevant content.

Technological and digital devices can also serve as material scaffolds. Reiser (2004) proposed that technological scaffolds provide support by *structuring* and *problematizing* tasks. Structuring can involve breaking down complex tasks into sub-tasks (e.g. Model-It; Jackson, Krajcik, & Soloway, 1998); bringing focus to conceptually challenging elements (e.g., ExplanationConstructor; Sandoval, 2003); or using tools to monitor progress (e.g., BGuILE; Reiser et al., 2001). *Problematizing* can involves adding context to the problem; directing the learner's attention to often-overlooked content; or recruiting interest. Methods of problematizing include eliciting articulation (e.g., CSILE; Scardamalia & Bereiter, 1994); facilitating decision-making (e.g., Galápagos Finches and ExplanationConstructor; Sandoval & Reiser, 2004); and identifying misinterpretations (e.g., Animal Landlord; Reiser et al., 2001; Smith & Reiser, 1998). While problematizing requires learners to engage in deeper conceptual engagement at the outset of a task, it results in more productive outcomes (Reiser, 2004).

Technological scaffolds can be designed to address anticipated student needs (e.g., Belland et al., 2013; Belland et al., 2015; Saye & Brush, 2002). For example, the CoMPASS e-textbook helped students to build connections among physics concepts by visualizing relationships between concepts and adding information that would help students proceed in their inquiry (Puntambekar, Stylianou, & Hübscher, 2003). Technological scaffolds can also provide adaptive support for students' ongoing needs (Azevedo et al., 2011; Lajoie, 2005). Adaptive technological scaffolds, such as cognitive tutors, provide support by comparing students' answers with an expert model (Koedinger & Corbett, 2006; Lajoie, 2005). Certain kinds of support in technological scaffolds, such as timely hints, can be removed as students demonstrates greater understanding, thus allowing fading of support (Lajoie, 2005; Pea, 2004).

To evaluate technological scaffolds, Quintana and colleagues (2004) developed a framework for understanding how computer-based scaffolds supported learners' sense-making, process management, and reflection and articulation. This framework identified obstacles faced by learners, along with scaffolding guidelines and strategies grounded in real-world challenges. These guidelines serve as both theoretical understanding of and design principles for embedding scaffolds within computer-based environments.

Systems of support. When describing examples of material scaffolds, it is difficult to describe how material scaffolds provide support without also describing their interactions with people. In reality, material scaffolds often interact with social scaffolds to provide support. For example, curricula are often designed to include a combination of social and material resources to provide support (Luckin, 2008). Activities supported by material scaffolds may be used in combination with small-group collaboration, which may be interleaved with whole-class discussion led by the teacher (e.g., Puntambekar, Nagel, Hübscher, Guzdial, & Kolodner, 1997; Puntambekar & Kolodner, 2005; Tabak & Reiser, 1997). In these cases, both social and material scaffolds play roles in a complex system of support (Tabak, 2004).

Also, while material scaffolds can provide support in important ways (Reiser, 2004; Quintana et al., 2004), their ability to respond to students' needs is still limited by their design. For example, the design of material scaffolds may misdiagnose the anticipated needs of students (Belland et al., 2015; Puntambekar & Hübscher, 2005; Reiser, 2004). Teachers can address this misdiagnosis by responding with additional support for students who are struggling, thus bridging the needs anticipated by the material scaffolds with students' actual needs (Ge & Land, 2004). Again, this demonstrates how interactions among social and material scaffolds have implications for students' learning.

Distributed scaffolding. Introduced by Puntambekar and Kolodner (1998; 2005), *distributed scaffolding* captures the reality that students often need multiple sources of support in addition to the teacher when working through complex problems. Distributing support across multiple scaffolds allows students to access support when needed and engage in higher-level thinking, such as metacognitive reflection.

The social and material scaffolds in distributed scaffolding may interact in different ways, depending on how they are presented in sequence or in combination. Different timing, sequences, and combinations of scaffolds influence how the distributed support mediates learning (Tabak, 2004; Puntambekar & Kolodner, 2005). Tabak (2004) described three patterns of distributed scaffolding in which scaffolds addressed students' needs. First, *differentiated scaffolding* includes one scaffold for each anticipated need. In contrast, *redundant scaffolding* includes multiple scaffolds for each anticipated need. This redundancy provides additional opportunities for learners to engage with content, practices, or reflection. The redundancy also allows individual scaffolds to be removed over time, thus fading support. Finally, in *synergistic scaffolding,* scaffolds are designed to complement each other in their support. Synergistic scaffolding emphasizes the interaction among scaffolds and considers how each scaffold contributes support and augments the support of other scaffolds.

To assess the interactions among scaffolds, we must identify the function of each scaffold, as different scaffolds can support different activities (Puntambekar & Kolodner, 2005). Small group and whole-class discussions can help students to externalize and negotiate their thinking (e.g., Tabak & Reiser, 1997), while tools and computer-based scaffolds can help students observe, understand, and explain their ideas within conceptual and epistemic frames (e.g., Sandoval & Reiser, 2004). By identifying the function of each scaffold, we can consider how individual scaffolds might complement and/or augment others, in sequence or in combination. Also, teachers may remove or re-introduce scaffolds as needed for different learners. Distributing support across multiple scaffolds offloads certain responsibilities from teachers, such as modeling explanations, and allows to focus on diagnosing and responding to individual students' needs (Tabak & Reiser, 1997; Ge & Land, 2004).

To describe additional examples of interactions among scaffolds, Puntambekar, Stylianou, and Goldstein (2007) described distributed scaffolding in which teachers' mediation of activities impacted students' conceptual outcomes. Students showed better learning outcomes when teachers actively made connections between individual activities and the overarching goals of the unit. As another example, Linn, Clark, and Slotta (2003) found that particular patterns of scaffolds for knowledge integration (e.g., make a conjecture, review evidence pages, and reflect on ideas) that were more effective than others. Similarly, Belland and Drake (2013) found that particular sequences of computer-based scaffolds impacted students' learning in an authentic problem-solving context. Finally, as a preview of distributed scaffolding in museums, Yoon and colleagues (2013) found that particular combinations of scaffolds, such as augmented reality and collaboration, supported greater cognitive gains for middle-school students.

These examples demonstrate how the interactions among scaffolds are shaped by the constellation of people, materials, and activities in the learning environment. The effectiveness of social and material scaffolds is impacted by students' needs; teachers' approach to instruction; and the available resources (Belland et al., 2015). Thus, incorporating distributed scaffolding into the design of a learning context requires us to use a systems-based approach (Reiser, 2004).

2.2 Learning and Scaffolding in Museums

Museums offer powerful opportunities for out-of-school learning (Bell, Lewenstein, Shouse, & Feder, 2009; Feinstein & Meshoulam, 2014). Museums can support a wide variety of learning that includes "the acquisition of scientific facts and concepts, but also application of these ideas, changes in attitude, aesthetic and kinesthetic experience, as well as socially mediated conversations and interactions that might lead to learning" (Dierking & Falk, 1994, p. 58). Falk, Scott, Dierking, Rennie, and Jones (2004) echoed this by listing changes in knowledge and skills, perspective and awareness, motivations and interests, and social learning as meaningful learning outcomes in museums. In general, museums are promising avenues for supporting conceptual change alongside positive social and affective outcomes (Adams, Tran, Gupta, Creedon, & O'Hurley, 2008; DeWitt & Storksdieck, 2008).

Museums can support multiple, meaningful learning outcomes by affording *free-choice learning* (Falk, 2004). In free-choice learning, visitors engage in self-directed exploration of exhibits, based on their interests and motivations (Bamberger & Tal, 2007; Falk, 2004; Falk, Moussouri, & Coulson, 1998). Visitors decide what they want to learn, when to visit, and how long to stay (Banz, 2008). Visitors do not follow pre-determined sequences or trajectories within museums (Ash, 2007; Diamond, 1986; Falk, 2004). However, there are several factors that influence visits to individual exhibits, such as composition of the group; prior knowledge and experiences; motivations and identities; degree of control over learning; and the exhibit's accommodation for multiple users (Borun, 2008; Falk, 2006; Falk, 2004; Falk et al., 2004; Falk & Dierking, 2000; Griffin, 2004).

One outcome of free-choice learning is that visitors often interact with exhibits for brief durations of time (Adams et al., 2008). For example, when Block and colleagues (2015) studied visitors' interactions around a museum exhibit, they found that most visitors stayed at the exhibit for five minutes or less when they were not being recorded. Visitors' willingness to stay is also influenced by the presence of other visitors, as visitors tend to accommodate the desires of other visitors to move on and pursue other interests (Bengler & Bryan-Kinns, 2015; Diamond, 1986; McManus, 1987; vom Lehn, Heath, & Hindmarsh, 2001). Given the brevity of visitors' interactions, we may expect only small changes in learning as evidenced through conceptual change (Davis, Horn, & Sherin, 2013; DeWitt & Storksdieck, 2008).

Another aspect of museum learning is that it is often social, as visitors make sense of exhibits through interactions with each other and exhibits (Ash & Wells, 2006; Packer & Ballantyne, 2005; Leinhardt et al., 2002). Museums bring together visitors of different generations, languages, and experiences (Ash, 2002; Ash, 2003a; Ash, 2003b; Ash 2004), and visitors may share their distributed knowledge when making sense of an exhibit (Allen & Gutwill, 2009; Zimmerman, Reeve, & Bell, 2008). Riedinger (2012) described these conversations as "opportunities for groups (such as families) to socially interact and engage with one another to make meaning and sense of content presented in informal learning environments" (p. 126). Thus, one way to study visitors' learning is to evaluate the content of their conversations and mediation of shared activities, including meaning-making (Adams et al., 2008; Allen, 2002; Mai & Ash, 2012; Rowe, 2002; Rowe, 2004).

Visitors' conversations may reveal asymmetrical relationships in knowledge among individuals, which reflects the relationship described by Vygotsky (1978) in which an adult or more capable peer provided support. In museums, we might expect parents to adopt teaching roles in order to support their children's understanding (e.g., Crowley & Callanan, 1998). However, children may also adopt teaching roles, especially when they can share relevant prior knowledge (Ash, 2003a; Ash, 2004a; Crowley & Jacobs, 2002; Mai & Ash, 2012). These conversations may reveal more symmetrical, collaborative relationships among individuals (Allen & Gutwill, 2009).

When engaging in shared meaning-making through conversation, families may support, or scaffold, each other's learning. Wolf and Wood (2012) claimed that parents naturally scaffold their children's learning in museums. For example, parents can help children to externalize and elaborate on their ideas (Eberbach & Crowley, 2005), such as by asking open-ended questions that diagnose understanding while marking conceptually-relevant features of the exhibit (Ash, 2004a; Haden, 2010; Haden et al., 2014). These levels of support may vary accordingly to the type of exhibit (Melber, 2007; Puchner, Rapoport, & Gaskins, 2001), especially when parents anticipate additional support in exhibits that are less child-friendly. Ash and Lombana (2012) argued that this naturalistic scaffolding among family members differed from the "top-down teacher-to-student practices" found in classrooms, which echoes Tharp and Gallimore's (1988) distinction between support provided in formal and informal contexts. However, parents may not automatically know how to provide support (Eberbach & Crowley, 2017). Parents might be unaware of their child's needs (Chak, 2001) or conversational strategies that can support learning (Eberbach & Crowley, 2017; Jant, Haden, Uttal, & Babcock, 2014). Thus, parents may not consistently scaffold their children's learning (Puchner et al., 2001).

Exhibits intended to educate often support learning (Allen, 2004). Exhibits may include physical or digital objects that facilitate exploration, inquiry, meaning-making conversations, and connections to prior experiences (Bell et al., 2009; Davis et al., 2013; Falk, Koran, & Dierking, 1986; Paris, 2002). Eberbach and Crowley (2005) found that parents were more likely to build connections between exhibit content and prior experiences in the classroom when interacting with a particular representation of plants. The Zydeco mobile inquiry system (Cahill et al., 2010; Kuhn et al., 2010) helped students bridge content across the classroom and museum by supporting documentation of museum objects as evidence to support explanations back in the classroom. Exhibit objects can encourage collaboration, add information, and provide instructions (Yoon et al., 2018). These examples, among many others, demonstrate the important role that exhibit materials play in facilitating visitors' meaning-making (Rowe, 2002).

In summary, museum learning is self-directed, fluid, social, and mediated by people and exhibit materials. These characteristics shape visitors' shared meaning-making and affect how scaffolding unfolds as a process supported by both social scaffolds (e.g., family members, students, and staff) and material scaffolds (e.g., text, objects, and activities). In the following sections, I discuss examples of social and material scaffolds in museums. While many of these studies do not explicitly mention scaffolding, they illustrate how support for learning may be provided and distributed in museum exhibits.

2.2.1 Social and Material Scaffolds in Museums

Museums welcome visitors to interact with exhibits that feature a wealth of objects, texts, tools, activities, and technologies that can support museum learning and contribute to the process of scaffolding. As such, there are many potential social and material scaffolds in exhibits. In this section, I first describe examples of social scaffolds for families and for student groups. I then discuss examples of material scaffolds within exhibits.

Social scaffolds within families. Families make up the largest audience in museums (Borun, 2008). A family may be defined as a multi-generational group of visitors with some degree of close personal association (Borun, 2008). From past research, families spend more time at exhibits compared to other groups, which, in turn, is associated with more learning (Borun, Chambers, & Cleghorn, 1996; McManus, 1987; Sandifer, 1997). Family members support each other's learning by participating in shared meaning-making of exhibit content and phenomena (Allen, 2002; Ellenbogen, Luke, & Dierking, 2004). This meaning-making may be discontinuous, as families might switch to other topics and later revisit meaning-making in other exhibits, across multiple visits, and at home (Adams et al., 2008; Ash, 2007; Ellenbogen, 2002; Falk, 2004; Roberts & Lyons, 2017). Two ways that family members demonstrate learning are by identifying and describing objects and interpreting conceptual themes that apply to other contexts (Borun et al., 1996; Jant et al., 2014).

Family members may act as social scaffolds in exhibits, as demonstrated in research about families' inquiry in museums. Children often drive their family's inquiry (Martin, Brown, & Russell, 1991; McManus, 1987), with parents taking on a facilitation role (Diamond, 1986). To effectively support children's learning, parents must establish common goals with their children (Henderson, 1991), such as by focusing on one part of the exhibit. Once parents have established shared interest, they may use or demonstrate strategies that support inquiry, such as by helping children to establish goals; make predictions, observations, and decisions; and connect ideas to evidence (Ash, 2004a; Crowley et al., 2001; Gleason & Schauble, 1999; Rosenthal & Blankman-Hetrick, 2002). Families may participate in cycles of asking questions, gathering information, interpreting phenomena, constructing explanations, and reflecting on their experience (Allen, 2004; Allen & Gutwill, 2009; Ash, 2004a; Crowley & Callanan, 1998; Gutwill & Allen, 2010). Parents can also help children to understand themes that span multiple exhibits (Ash, 2002; Jant et al., 2014). Each family member may contribute unique knowledge in the process of shared inquiry (Zimmerman et al., 2008; Allen & Gutwill, 2009).

Supportive interactions in families are often collaborative and reciprocal, indicating that both parents and children benefit from participation (Diamond, 1986; Gioftsali, 2005; Schauble et al., 2002). The level of support between family members depends on the level of structure in the exhibit, along with the family's expectations for learning. Melber (2007) and Puchner and colleagues (2001) found that parents adapted the level of support provided to their children based on the type of exhibit they visited (e.g., diorama, hands-on area). Melber (2007) found that mothers were more likely to assist children in traditional natural history exhibits than interactive, play-friendly exhibits, as mothers assumed that children would need support in understanding how to interpret traditional exhibits. Also, parents' provision of support was more likely when exhibits indicated how adults could assist children (Puchner et al., 2001; Riedinger, 2012).

One way to encourage scaffolding in families is to prompt elaborative talk among visitors (Eberbach & Crowley, 2017; Jant et al., 2014). For example, Eberbach and Crowley (2017) found that parents' asking of open-ended questions recalled more information about exhibits. Similarly, Haden (2010) and Haden and colleagues (2014) found that parents who asked *Wh*-questions helped draw children's attention to salient features of exhibits while adding context. Also, Jant and colleagues (2014) found that conversation cards helped families to focus on conceptually-relevant objects and engage in more elaborative talk. While these three studies involved interventions to prompt elaborate talk, we may consider how the design of exhibits invites elaborative talk for deeper learning.

Social scaffolds within student groups. After families, student groups are the next largest audience of visitors (Borun, 2008). Museums offer experiences and objects that can build on students' conceptual understanding from the classroom, helping them to more deeply understand content (Bell et al., 2009). Museums can invite students to collaboratively investigate museum objects, explore phenomena, and reflect on their inquiry (Sturm & Bogner, 2010; Cahill et al., 2010). In addition to assessing learning in students' conversations, we may gain insights into students' learning with classroom assessments, such as written artifacts (Yoon et al., 2013).

For student groups, social scaffolds can include teachers, fellow students, and museum staff. Students collaborating in groups may support each other's learning (Sturm & Bogner, 2010; Yoon et al., 2012; Yoon et al., 2013; Yoon et al., 2018). For example, Sturm and Bogner (2010) found that students who used a science workstation in the museum showed greater conceptual understanding than students who used the same workstation in the classroom, which the authors attributed to the museum's affordance for collaboration. As another example, Yoon and colleagues (2012) found that collaboration played a vital role in supporting students' learning about electrical current in an augmented reality exhibit. Collaboration helped students to share their problem-solving process and reflect on their understanding (Yoon et al., 2012).

Students may also receive support from teachers and/or museum staff. Teachers can contextualize exhibit information, use questions to drive dialogue, and interpret text for students (Gilbert & Priest, 1997). Museum staff can also add information and context when students visit exhibits (Adams et al., 2008). However, many museum staff receive pedagogical training that is more transmissive than dialogic (Ash, Lombana, & Alcala, 2011; Allen & Crowley, 2014; Grenier, 2005, 2009; Adams et al., 2008). In response, museum staff may lecture more than listen, and thus fail to provide scaffolding (Cox-Petersen, Marsh, Kisiel, & Melber, 2003; Kamolpattana et al., 2015). To counter lecture-style delivery, Griffin and Symington (1997) suggested that teachers and museum staff practice more learner-centered pedagogy, rather than task-centered pedagogy, to support students' learning.

Material scaffolds in museums. There are many potential material scaffolds in exhibits, ranging from text labels to complex digital devices. Material scaffolds invite visitors to construct meaning by encouraging hands-on exploration and experimentation over memorization, as well as a "simple cycle of inquiry," in which curiosity and questions drive observations and explanations of exhibit objects and phenomena (Allen, 2004). As with classroom scaffolds, material scaffolds in museums often interact with social scaffolds. Thus, this discussion of material scaffolds in museums draws from distributed scaffolding as well.

Exhibit signage is a common kind of material scaffold that impacts how visitors interact with each other and the exhibit (Serrell, 2015). For example, exhibit signage indicating learning outcomes (e.g., math, science, cooperative play) can help parents notice educational opportunities that they might otherwise miss (Song et al., 2017). Signage can highlight concepts in exhibits, but the language used in signage can impact how families interact. Kim and Crowley (2010) found that parents who read signage encouraging visitors to "think like scientists" were more likely to support their children's learning than parents who read signage encouraging visitors to "think like engineers." Here, parents may have estimated that children needed more assistance with designing controlled experiments and using evidence to develop theories than with testing multiple variables for optimal solutions. This study revealed that parents had different expectations for different domains, and that these expectations ultimately impacted children's learning. Thus, while signage serves as a useful tool in exhibits, its design and language must consider the visitor's perspective (Serrell, 2015).

Exhibits can include multiple material scaffolds in their design, which may be physical or digital. For example, the *Build-a-Tree* exhibit (Block et al., 2015; Horn et al., 2012) incorporated an interactive tabletop surface, visual representations, and game-based challenges as scaffolds. The interactive tabletop allowed multiple users to collaborate as they worked through challenges within a game about evolution. Visitors could build evolutionary trees by "linking" different organisms. The game included visual representations and real-time feedback to help visitors make connections between different organisms and understand their evolutionary relationships. The game-based challenges added structure to earlier levels and increased the level of difficulty with subsequent levels. Visitors could access solutions, but many chose to build evolutionary trees on their own. The integration of the interactive tabletop with visual representations, real-time feedback, and game-based challenges helped visitors to engage in on-topic discussion for prolonged periods of time, which in itself can be considered a positive learning outcome (Horn et al., 2012). Also, the *Build-a-Tree* exhibit demonstrated how interactive tabletops can flexibly incorporate material scaffolds, as they feature a relatively low entry point (i.e., touching a screen) with options for progressive challenges, immediate feedback, and joint attention and collaboration (Fleck et al., 2009; Horn et al., 2012; Hornecker & Stifter, 2006).

Students also benefit from material scaffolds in exhibits. In a broad sense, field trips to museums often include some level of structure, such as worksheets or scavenger hunts (Griffin, 2004; Bamberger & Tal, 2007). This structure gives students a clear purpose for their visit along with choices for exploration, which reduces the degrees of freedom in their visit–a key scaffolding strategy (Bamberger & Tal, 2007; Cahill et al., 2010; Griffin, 2004; Wood et al., 1976). However, when added structure does not build upon students' prior experiences, it can negatively impact students (Griffin, 2004), as evidenced in their behaviors (Yoon et al., 2013) and attitudes about visiting the museum (Stronck, 1983). Thus, we must balance structured activities with personal choice during field trips so that students receive guidance without being overly constrained (Bamberger & Tal, 2007).

Hands-on exhibits can serve as scaffolds by adding concreteness to abstract concepts (De Freitas & Bentley, 2012). Flexer and Borun (1984) found that students who interacted with a hands-on science exhibit demonstrated greater conceptual understanding on a content test than students in a classroom. The authors attributed this difference to tangible interaction with the exhibit, which facilitated communication of content and sustained students' interest (Flexer & Borun, 1984). Similarly, De Freitas and Bentley (2012) found that students who visited a museum exhibit about airplane design demonstrated more higher-order thinking about mathematics and physics than students who not visiting the museum. This difference was attributed to the concreteness of the museum objects, which helped students to engage in spatial reasoning and develop embodied understandings of "invisible" concepts (De Freitas & Bentley, 2012). Together, these studies demonstrate how physical objects in museums can communicate abstract concepts, with benefits for both learning and motivation.

In addition to identifying collaboration as a social scaffold, Yoon and colleagues (2012; 2013; 2018) investigated how different combinations of material scaffolds impacted students' learning. For example, in Yoon and colleagues' (2013) study, different groups of students interacted with different combinations of scaffolds, including an augmented reality visualization, worksheets with highlighted content, embedded knowledge-building prompts, and student responses to these prompts. While the condition including all of the above scaffolds was associated with greater conceptual learning, students participating in this condition demonstrated fewer exploratory behaviors in the exhibit. Yoon and colleagues (2013) referred to this issue as *overformalization*, in which an exhibit became more like a classroom than a museum experience. Thus, we must consider the importance of cognitive and affective outcomes in museum learning, as one might come at the cost of the other (DeWitt & Storksdieck, 2008; Falk, 2004).

Finally, material scaffolds can be designed to span classrooms and museums as they support students' inquiry. The Zydeco mobile inquiry system leveraged structured activities in the classroom with tangible objects in the museum to support students' learning (Cahill et al., 2010; Kuhn et al., 2010). Students used Zydeco to prepare questions before their visit, conduct research about objects, and use objects as evidence for inquiry back in the classroom. This study illustrated how classrooms and museums can complement each other by facilitating different kinds of activities and assessments. The classroom offered structure and extended time for learning, while the museum offered objects, observations, and experiences that would be difficult to replicate in a classroom. Leveraging classroom and museum contexts may be a promising avenue for supporting students' conceptual understanding.

2.3 Designing Scaffolding in Museums

As described above, exhibits can be designed to include scaffolds for visitors' learning. When identifying examples of social and material scaffolds in exhibits, I noted that authors described common issues in the design of scaffolding for exhibits. Hsi (2003) summarized these issues in the following question: "How does one provide enough guidance, explanations, prompting, and assessment, yet retain flexibility for choosing personally-relevant problems especially in a museum setting?" (pp. 317-318). In this section, I describe how the *affordances* and *constraints* of scaffolds shape how visitors interact in exhibits. I then discuss issues in designing scaffolding for museums, along with solutions from prior research.

2.3.1 Affordances and Constraints

Gibson (1986) described affordances as the range of interactions between people, objects, and the environment, shaped by the abilities of humans and the properties of objects and environments. Gibson (1986) also described constraints, which limit the range of possible interactions between people and objects. From this perspective, affordances and constraints shape the ways humans manipulate, interpret, and interact with different objects and environments (Gibson, 1986; Greeno, 1994).

Exhibit design includes affordances and constraints for interaction and communication, and different exhibit components can be manipulated or interpreted in different ways (Achiam, May, & Marandino, 2014; Rowe & Bachman, 2012). For example, buttons can be pushed, and screens can be touched. In addition to physical affordances, exhibits also have social affordances that influence how visitors interact with each other (Gibson, 1986; Greeno, 1994). Exhibits featuring text or representations also have symbolic affordances, in that language and visual aids influence how visitors interpret exhibits and communicate with each other (Gibson, 1986; Greeno, 1994). Falk and colleagues (2004) found that visitors preferred interactive exhibits that afforded social interaction, feedback on actions, and "learning by doing." Exhibits can also constrain visitors' interactions, such as by accommodating one visitor at a time (Borun, 2008), thus limiting social interaction, or by encouraging behaviors that require fine motor skills, thus limiting participation from children and other visitors with fine motor coordination issues (Hornecker & Stifter, 2006).

While exhibit designers may intend for exhibits to afford certain kinds of interactions, visitors may not perceive these affordances and interact with exhibits in unexpected ways (Hornecker & Stifter, 2006). Allen (2004) described visitors' perception of exhibit affordances as *apprehendability*. Norman (1988) argued that designed objects should provide clues as to their operation, but he also described examples of objects that did not (i.e., Norman doors). In response, Norman (1999) recommended that designers consider users' conceptual models when mapping objects to actions. As with Gibson, Norman (1999) emphasized that humans' interactions are shaped by the properties of objects.

This section discussed how exhibit design can include specific affordances and constraints that influence visitors' interactions with exhibits. Yet, visitors may not perceive the affordances of exhibits, thus limiting intended interactions. The following section discusses issues surrounding the design of exhibits and their effects on interactions and communication, along with recommendations from prior research.

2.3.2 Design Issues in Museums

One important design issue is the design of physical space in which visitors interact, including entrances and exits in the exhibit (Block et al., 2015). Visitors are sensitive to the presence of others and will change their activities to accommodate others, such as by leaving exhibits (Bengler & Bryan-Kinns, 2015; vom Lehn et al., 2001). Borun (2008) noted that exhibits that are multi-sided, multi-user, and accessible to parents and children allow multiple family members to comfortably interact in an exhibit.

Exhibits that create space for multiple visitors also create opportunities for collaboration (Horn et al., 2012). To support collaboration, designers can include prompts for discussion or roles for different family members (Allen & Gutwill, 2009; Dierking, 1989; Crowley & Callanan, 1998; Falk et al., 2009; Gioftsali, 2005; Puchner et al., 2001; Riedinger, 2012; Zimmerman, Reeve, & Bell, 2009). Designers might consider how to leverage visitors' tendencies when creating roles for visitors (Diamond, 1986; Flexer & Borun, 1984). Adults often gravitate toward text, graphics, and symbols, while children tend to manipulate hands-on exhibits. When designing roles, Riedinger (2012) recommended that adults and child take on complementary roles that foster equitable participation within families.

As discussed earlier in the signage examples (Song et al., 2017; Kim & Crowley, 2010), the ways in which exhibits communicate information have implications for visitors' interactions. Text and visual representations should be readable for visitors with different prior knowledge, interests, and experiences (Allen, 2004; Carliner, 2001; Davis et al., 2013; Dierking, 1989; Hornecker & Stifter, 2006; Serrell, 2015) and invite participation from visitors with different perspectives (Diamond, 1986; Povis & Crowley, 2015). Exhibit designers can leverage adults' and children's preferences for different forms of communication when designing activities that foster shared meaning-making (Diamond, 1986; Flexer & Borun, 1984). For more complex concepts, designers can create themes across exhibits (Carliner, 2001). "Thematic islands" can support visitors' understanding by cumulatively building upon concepts across exhibits (Hornecker & Stifter, 2006).

Distributed scaffolding can be integrated into exhibits as in classrooms, but designing distributed scaffolds requires designers to consider how individual scaffolds complement each other (Tabak, 2004; Yoon et al., 2018; Zimmerman et al., 2008). Yoon and colleagues' (2012; 2013; 2018) trajectory of research demonstrated how distributed scaffolding supported students' learning in exhibits, but future research is needed to understand how distributed scaffolding supports families' learning. Identifying the distributed nature of support in exhibits adds insight about the process of scaffolding and design of social and material scaffolds in learning contexts.

When designing scaffolds for families, Dierking (1989) recommended that designers consider families' agendas for learning and diverse prior knowledge while including concrete and accessible content that supports the notion of "doing the museum." As stated earlier, Falk and colleagues (2004) found that interactive exhibits best supported learning when they promoted collaboration; provided feedback; established connections to daily life; and encouraged "learning by doing." However, while we might embed material scaffolds in exhibits, we must recall that parents' participation can range from minimal interaction to active scaffolding (Swartz & Crowley, 2004). Thus, some parents may welcome the addition of material scaffolds when supporting children’s learning, while others may have a “hands off” approach (Swartz & Crowley, 2004).

When designing material scaffolds for school groups, designers must identify learning objectives that connect to classroom content and strengthen these connections (Griffin, 2004). Students benefit from field trips when they understand the reason for their visit; prepare in the classroom; collaboratively explore exhibits; and identify connections in activities that span the classroom and the museum (Griffin, 2004; Griffin & Symington, 1997). Exhibits that help students to build on content from the classroom and other experiences can deepen students’ learning. However, as discussed earlier, designers should ensure that the addition of scaffolds does not detract from the overall museum experience (Yoon et al., 2013).

Finally, time is an important constraint on visitors’ interactions. In general, most visitors spend about two to five minutes at an exhibit (Borun et al., 1996; Block et al., 2015; Serrell, 1997). This is considerably shorter than a classroom lesson, and, accordingly, learning outcomes are limited (Adams et al., 2008; Banz, 2008). When assessing museum learning, it may help to shift our focus from learning as an assessment of cognitive gains to “learning potential,” in which visits serve as an entry point for learning (DeWitt & Storksdieck, 2008; Falk, Koran, & Dierking, 1986). We can also design material scaffolds that demonstrate clear purpose (Allen, 2004; Yoon et al., 2018 so that visitors can easily incorporate them into their conversations.

2.4 Conclusion

In preparing this review, I aimed to understand how scaffolding might apply to museums from a learning sciences perspective. I reviewed research about the evolution of scaffolding as a metaphor for support, along with research about supporting learning in museums. I described examples of support provided by people, which I referred to as social scaffolds, and support provided by physical and digital resources, which I referred to as material scaffolds. I also described examples of complementary interactions among social and material scaffolds that supported deeper learning. Finally, I described issues in the design of scaffolding in museums, which included considerations for physical space, collaboration, communication, and time.

This review discussed many instances of research about scaffolding in classrooms and museums, but also revealed gaps in our understanding about the process of scaffolding in museums, along with interactions between social and material scaffolds. Studies that investigated distributed scaffolding in exhibits (e.g., Yoon et al., 2012; Yoon et al., 2013; Yoon et al., 2018) described scaffolds that benefitted middle-school students' learning. However, we do not yet know how distributed scaffolding benefits families' learning in exhibits. Thus, in the following paper, I describe how family members supported each other's learning by acting as social scaffolds in an interactive, facilitated pop-up exhibit about compost. In the subsequent paper, I describe how material scaffolds in the exhibit interacted with support provided by social scaffolds and show the distribution of support in the exhibit.

These studies offer contributions to our understanding of families' participation in museum-based scaffolding. The first study showed how parents and children took on dual roles as scaffolders and scaffoldees (Granott, 2005). The first study also contributed a coding scheme for social scaffolding based on foundations of scaffolding (Wood et al., 1976), which may be adapted for other exhibits. The second study showed how the affordances of material scaffolds impacted families' participation in exhibit activities and interactions with material scaffolds.

Research investigating museum-based scaffolding deepens our understanding of the mechanisms that support learning in museums and characteristics of this support that are comparable to other contexts, such as one-on-one tutoring and classroom teaching. These comparisons have implications for how we design museum exhibits and classroom curricula, as demonstrated by "borrowing" characteristics of museum learning when designing classroom-based activities (Brown & Campione, 1996; Paris & Ash, 2000). Researching scaffolding in museums can help us to identify how the characteristics and mechanisms of scaffolding may be situated within particular contexts or generalized across them. In turn, these insights can inform the design of innovative environments that foster collaboration, communication, and learning that is both conceptually deep and enjoyable.

3. Investigating Social Scaffolding in Families Visiting a Science Museum Exhibit

3.1 Abstract

Since its inception, scaffolding has come to describe a variety of contexts featuring tailored support. Prior research about scaffolding has investigated parent-child interactions in everyday contexts and teacher-student interactions in classrooms. However, there is relatively little research focused on museum-based scaffolding. We have yet to understand how families participate in the process of scaffolding, and thus are limited in how we generalize scaffolding to museums. In response, I investigated families' participation in scaffolding as they interacted with a pop-up exhibit about compost. I facilitated the exhibit as a participant-observer but did not provide training to families. I collected video data of 23 families' interactions and used sociocultural discourse analysis to understand: (i) how family members demonstrated need for support; (ii) who provided support, (iii) what kinds of support were provided, and (iv) what kinds of learning occurred. I found that children were more likely to demonstrate need than parents, indicating their role as *scaffoldee*. However, some children began to provide scaffolding to other children of their own initiative, thus taking on the role of *scaffolder*. Parents acted as scaffolders and scaffoldees, but mainly received support from the facilitator. Families tended to provide support and demonstrate learning in the same ways. This study revealed specific ways that family members participated in museum-based scaffolding as they interacted with a science exhibit. Both parents and children adopted dual roles as scaffolder and scaffoldee, with the balance of these roles being impacted by the presence of siblings or peers. This study also extended foundations of scaffolding to museums and re-emphasized the importance of dialogue in supporting families' learning in museums.

3.2 Introduction

Scaffolding describes tailored support aimed to help a learner accomplish tasks that they could not complete on their own (Palincsar, 1998). This support can target cognitive, metacognitive, and motivational aspects of the task (Belland, Kim, & Hannafin, 2013; Puntambekar & Kolodner, 2005). Scaffolding does not change the task itself, but introduces acts to the learner that build towards more complex tasks (van de Pol, Volman, & Beishuizen, 2010; Wood, Bruner, & Ross, 1976).

Scaffolding originally described the kind of support provided in one-on-one tutoring (Wood et al., 1976). Since its inception, scaffolding has expanded to include a variety of instructional contexts that emphasize responsive support (Palincsar, 1998; Stone, 1998b). While early studies of scaffolding investigated support provided in everyday parent-child interactions, later studies also focused on how teachers provide scaffolding to students in classrooms (Stone, 1998b; van de Pol et al., 2010). These studies have elaborated on the characteristics of scaffolding and process of providing tailored support (e.g., Belland & Drake, 2013; Koole & Elbers, 2014; Puntambekar & Hübscher, 2005; van de Pol & Elbers, 2013).

There is also a small but growing body of research that investigates scaffolding in museums, especially within families (e.g., Puchner, Rapoport, & Gaskins, 2001; Wolf & Wood, 2012). However, the findings of these studies do not always agree. Wolf and Wood (2012) argued that parents seemed to naturally scaffold their children, but Puchner and colleagues (2001) found that scaffolding was a relatively infrequent occurrence. These disagreements may be explained by barriers to parental scaffolding in exhibits, which I explain below.

Studies of museum-based scaffolding are reminiscent of early studies of parent-child scaffolding in everyday contexts (Stone, 1998b). Yet, different studies ground their discussion of museum-based scaffolding in different ways. Some studies discuss scaffolding as a distinct notion with its own history, yet others do not. For example, a study might conflate scaffolding with Vygotsky's (1978) *zone of proximal development* (e.g., Melber, 2007). These are frequently associated notions, but they are not the same (Granott, 2005). In contrast, other studies may clearly differentiate these notions and demonstrate how families' zones of proximal development are evidenced in shared activity (e.g., Granott, 2005; Mai & Ash, 2012). The variability in how researchers connect previous research about scaffolding in more formal contexts, such as classrooms, to scaffolding in museums makes it difficult to generalize findings across contexts. It also becomes difficult to establish discussions about scaffolding if we do not refer to the same notion, which also recalls past debate about the usefulness of scaffolding (Palincsar, 1998; Stone, 1998a). Consistent grounding of scaffolding in prior research allows us to build theory and evolve the notion of scaffolding without overgeneralizing (Pea, 2004).

To dig deeper into museum-based scaffolding, I first provide theoretical background about scaffolding, then describe a study of museum-based scaffolding among family members in a pop-up exhibit about compost. I then discuss the findings of this study in relation to prior research about scaffolding, including examples from classrooms (e.g., Guk & Kellogg, 2007) and museums (e.g., Mai & Ash, 2012).

3.3 Theoretical Background

In the original description of scaffolding, Wood, Bruner, and Ross (1976) described how a tutor helped children to build with blocks. The tutor helped the learner to accomplish individual elements of a task by aligning elements of the task with the learner's abilities (Bruner, 1975; Wood et al., 1976). The tutor introduced acts of increasing difficulty, with the eventual goal of helping the learner to accomplish the entire task and understand the role of each act. Wood and colleagues (1976) also described six scaffolding functions performed by the tutor: (i) recruiting interest, (ii) maintaining direction, (iii) reducing degrees of freedom, (iv) marking critical features, (v) managing frustration, and (vi) demonstrating with the intention of encouraging imitation. These scaffolding functions provide cognitive and motivational support adapted to the learner's ongoing needs (Belland et al., 2013).

Scaffolding now describes a diversity of supportive interactions, materials, and environments beyond the original tutorial context (Belland et al., 2013; Puntambekar & Hübscher, 2005). Scaffolding serves as both a noun and a verb, and thus describes both the process of scaffolding and the entities that facilitate this process (Pea, 2004; Stone, 1998b). In this study, I use *scaffolding* to refer to the process of providing support, and *scaffolds* to refer to the entities that support it. In particular, I focus on how people act as *social scaffolds* by participating in the process of scaffolding.

Regarding social scaffolds, early research about scaffolding focused on everyday parent-child interactions. However, after Cazden (1979) suggested incorporating scaffolding into classroom instruction, researchers largely began to investigate scaffolding in classrooms (Stone, 1998b). Cazden (1979) also connected scaffolding with Vygotsky's (1978) *zone of proximal development*, or ZPD (Stone, 1998b). Vygotsky (1978) described the ZPD as the range between what the learner could accomplish independently and with assistance from a more capable person. In turn, many sociocultural researchers began to describe scaffolding as the means for working within learners' ZPDs (Boblett, 2012; Campione, Brown, Ferrera, & Bryant, 1984).

One challenge that arose in applying scaffolding to classrooms was the reality of supporting multiple students' ZPDs. Tharp and Gallimore (1988) suggested additional strategies for supporting students in classrooms. Also, teachers can conceptualize students' ZPDs as multiple, overlapping ZPDs (Brown et al., 1993) or a whole-class ZPD (Smit, van Eerde, & Bakker, 2012). To provide support, teachers might model scaffolding strategies for students to practice among themselves (Guk & Kellogg, 2007). As peers, students may be better equipped to understand and respond to their classmates' difficulties (Webb & Farivar, 1999). The kinds of scaffolding provided in teacher-student and student-student interactions emphasize dialogue in co-constructing understanding (Guk & Kellogg, 2007; Fernández, Wegerif, Mercer, & Rojas-Drummond, 2001; Brown et al., 1993), as dialogue externalizes students' understandings and creates opportunities for responsive support.

Museums are another learning context in which dialogue plays a pivotal role in providing support to learners with different ZPDs, especially families (Ash & Lombana, 2012). We can use sociocultural theories of learning to understand how dialogue supports families' learning in museums (Schauble, Leinhardt, & Martin, 1997). Many studies of museum learning focus on meaning-making in families' conversations (Ash & Wells, 2006; Leinhardt, Crowley, & Knutson, 2002). Families might engage in shared sense-making by sharing distributed knowledge and new understandings (Allen, 2002; Ash, 2004a; Falk & Dierking, 2002; vom Lehn, Heath, & Hindmarsh, 2001; Zimmerman, Reeve, & Bell, 2008). Families may point out important objects or conceptual themes in exhibits (Jant, Haden, Uttal, & Babcock, 2014) and help others to build explanations of phenomena (Allen & Gutwill, 2009; Crowley & Callanan, 1998). Families' guidance may be open-ended (e.g., "What do you see?"), or more directive (e.g., "Try moving the lever."), especially when parents assume teaching roles for their children (Ash, 2004a; Wolf & Wood, 2012).

Families' participation in museum-based scaffolding faces several barriers. First, museum-based scaffolding imposes structure on a free-choice learning context in which visitors may not plan to learn during their visit (DeWitt & Storksdieck, 2008; Falk, 2004). Museums are fluid environments where visitors may quickly enter and exit exhibits (Allen, 2004; Block et al., 2015). Thus, the object of visitors' attention can change rapidly (Serrell, 1997). Also, visits are often short in duration, with the average time in an exhibit being two to five minutes, thus limiting time for learning and support (Allen, 2004; Block et al., 2015; Horn et al., 2012; Serrell, 1997). These barriers increase the level of challenge in providing any kind of pedagogical support and constrain the conceptual learning we might expect during a visit (Adams, Tran, Gupta, Creedon, & O'Hurley, 2008; Allen, 2004; Falk, 2004).

Parents face specific challenges in providing scaffolding to other family members. First, parents may not notice that their children need assistance, which limits their ability to provide responsive support (Song et al., 2017). Parents may not know how to provide support or may be unwilling to do so (Ash, 2004a; Chak, 2001; Eberbach & Crowley, 2017; Haden, 2010). It takes considerable effort for parents to engage in continuous cycles of interpreting exhibits, identifying critical features, providing support, checking for understanding, and adapting support (Allen, 2004). We can witness this as "museum fatigue" occurring after about 30 minutes of deep interactions (Allen, 2004). Parents' willingness to provide scaffolding may also be constrained by personal beliefs about mediating museum activities, as some parents may want children to explore exhibits on their own (Haden, 2010).

The difficulties families face in providing scaffolding in museums reflect other issues discussed in classroom-based research. Like parents, teachers also struggle with providing scaffolding (Howe & Abedin, 2013; Tharp & Gallimore, 1988; van de Pol, Volman, Oort, & Beishuizen, 2014). In particular, teachers may struggle with diagnosing students' difficulties (Howe & Abedin, 2013; Koole & Elbers, 2014), and thus struggle with providing responsive support that is tailored to students' needs (Littleton, 2013; van de Pol & Elbers, 2013). Also, both parents and teachers may drive learning interactions, which discourages dialogue in favor of one-sided learning (Stone, 1998b). However, some parents may use more open-ended strategies that invite children's input (Ash, 2004a; Benjamin, 2007). In museums, both adults and children encounter new experiences, which allows parents to take on dual roles as scaffolders and learners. This shift in relative expertise between parents and children creates more symmetric relationships within families, especially when children take on roles as scaffolders, too (Mai & Ash, 2012). Activities that promote greater "symmetry of action" (Dillenbourg, 1999) can encourage collaboration and distribute responsibilities for scaffolding and learning.

Although there is considerable research about how people support each other's learning in exhibits (e.g., Allen 2004; Ash, 2004a; Crowley & Callanan, 1998), we still have much to understand about how families participate in the process of museum-based scaffolding. We also face challenges in establishing shared definitions of scaffolding, reflecting earlier debate over the term (Palincsar, 1998; Stone, 1998a). If we are to understand how scaffolding unfolds in museums, we must ensure that we build upon past research and relevant learning theories (Hammerness, Macpherson, & Gupta, 2016; Schauble et al. 1997) to bridge theoretical and design principles across contexts (Palincsar, 1998; Paris & Ash, 2000; Pea, 2004;).

3.4 Current Study

To better understand museum-based scaffolding, I investigated how family members supported each other's learning as they interacted with a pop-up exhibit about compost. In describing families' support in exhibits, I considered how parents and children took on roles as *scaffolders* by providing support and *scaffoldees* by demonstrating need for support (Granott, 2005; Mai & Ash, 2012). Parents' adoption of teaching roles builds toward the kind of asymmetric relationship described by Vygotsky (1978) and Wood and colleagues (1976). However, children can also provide support so that scaffolding becomes less asymmetrical or one-directional (i.e., from an adult to a child; Mai & Ash, 2012).

Using sociocultural discourse analysis (Mercer, 2004), I developed a coding scheme that identified the ways that family members demonstrated a need for support (Koole & Elbers, 2014); the kinds of support they provided, using codes developed from tutoring (Wood et al., 1976), classroom (Tabak & Baumgartner, 2004), and museum contexts (Mai & Ash, 2012); and the ways they demonstrated learning (Borun, Chambers, & Cleghorn, 1996). Each code was based on prior research but modified for this particular exhibit, demonstrating a combined deductive-inductive approach (Derry et al., 2010). These codes allowed me to identify how family members took on dual roles when participating in scaffolding.

Overall, my goal was to understand how family members participated in the process of scaffolding (e.g., van de Pol et al., 2014). Thus, I asked the following research questions:

1. How did family members demonstrate need for support?
2. Who provided support?
3. What kinds of support did family members provide?
4. What kinds of learning did family members demonstrate?

These questions helped me to understand how family members participated in the process of scaffolding in the exhibit, along with the kinds of support family members provided in this process. This study contributes to our understanding of the roles parents and children can play when interacting with facilitated exhibits. It also adds a coding scheme that identifies different components of families' scaffolding in exhibits. This study also has implications for museum facilitators, in how they determine appropriate levels of support (Adams et al., 2008), and exhibit designers, in how they design exhibits to encourage equitable participation from all family members (Allen & Gutwill, 2009).

3.5 Methods

3.5.1 Exhibit Design

This exhibit was a variation of a school-based research project that investigated the design and implementation of curricula that incorporated distributed scaffolding to support middle-school students' learning about life sciences. I chose a subset of activities from a curriculum about compost, which included (i) a trash-sorting activity that helped students understand the impact of waste, and (ii) virtual experiments with a compost simulation that featuring the carbon-nitrogen ratio as the independent variable and the decomposition rate, odor, air circulation, and temperature as dependent variables. A "good" compost was characterized by its fast decomposition rate, low odor, aerobic air circulation, and ideal temperature range for microbial activity.

I modified the activities for implementation as a "pop-up" exhibit in science museums. For the trash sorting activity, visitors sorted pictures of organic and non-organic materials into compost, recycling, and trash "bins" (large paper with labeled text and images). For the simulation, I created an Ideal Compost Guide to help visitors conduct experiments with the carbon-nitrogen simulation (see Figure B1 in Appendix B). This guide provided instructions and visual aids for simulating a "good" compost. The simulation also included resources about materials, carbon-nitrogen ratios, and experiment feedback. Visitors were welcome to conduct as many experiments as they desired.

I included three other objects aimed to invite curiosity and support learning. First, I created a *real-life compost model* of decomposing flowers in a clear container, which allowed visitors to see decomposition in action. I also included a *greens bag* filled with materials with lower carbon-nitrogen ratios (e.g., apple peels, sweet potato peels, banana peels) and a *browns bag* filled with materials with higher carbon-nitrogen ratios (e.g., shredded newspaper). These bags helped families to understand the difference between *green* and *brown* materials and make decisions about balancing these materials in the simulation. Finally, I included information pages about composting in the local area for visitors who desired them, along with coloring pages and crayons so that family members who were not actively participating could engage in a different activity as other family members participated.

I conducted a pilot study of the pop-up exhibit in May 2018. The pilot study indicated that visitors needed clearly identifiable sorting items, along with instructions for understanding how to proceed. The pilot study also indicated that visitors engaged in scaffolding strategies described in previous research, such as connecting to prior experiences (Mai & Ash, 2012).

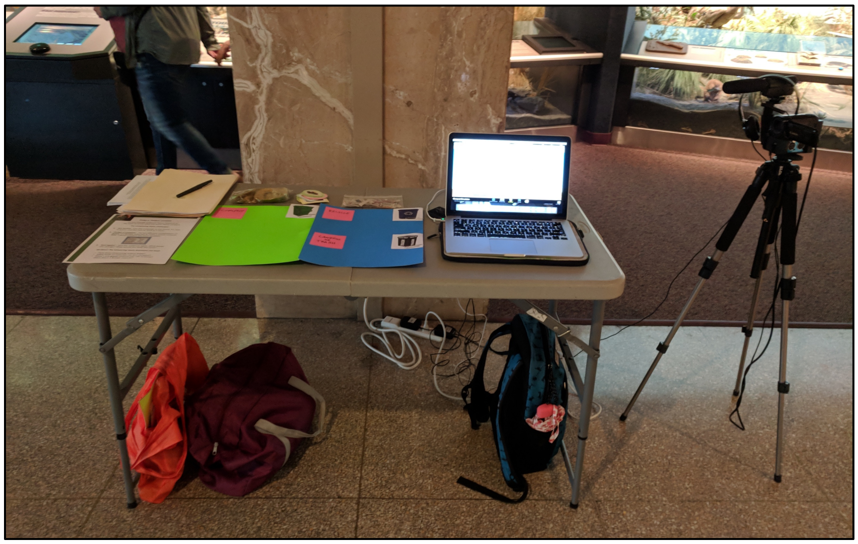

Figure 1. Photograph of sorting activity and simulation activity in pop-up compost exhibit.

I acted as a participant-observer by facilitating the exhibit. As a facilitator, I aimed to shift the responsibility for scaffolding to family members in order to understand how they participated in scaffolding. However, I also aimed to provide enough support so that families could successfully complete the activities. Before collecting data, I developed a facilitation script (see Table C1 in Appendix C) regarding families' reasons for visiting the museum; prior knowledge about compost; and decision-making during activities. I adapted this script as needed for family members of different ages (Grenier, 2009). When families completed the activities, or otherwise indicated that they were done participating, I asked if they had any open questions and thanked them for their participation.

3.5.2 Settings and Participants

The pop-up exhibit was hosted at two museum sites in a Midwestern U.S. city during the summer of 2018. The first site is a science center that attracts 300,000 visitors annually (Daykin, 2017). The second site is a natural history museum that attracts 520,000 visitors annually (MPM, 2018). The city's population includes over 594,000 residents, with a median age of 31.0 years (United States Census Bureau, 2016). About 46% of residents identify as White; 39% identify as Black or African American; 18% as Hispanic or Latino; and 4% as Asian, with smaller percentages of residents identifying as other races (United States Census Bureau, 2016).

I facilitated the exhibit for 22 hours over five weekend afternoons. When visitors approached the exhibit, I asked if they were interested in participating. If visitors indicated interest, I obtained their written informed consent (and assent, as needed) before engaging visitors in activities. I obtained consent from 34 groups of visitors consisting of 50 adults and 37 children. Because my research question focuses on families' scaffolding, I narrowed my sample to include only families (defined as at least one adult and one child under 18 years). This reduced my sample to 25 families, consisting of 36 adults and 36 children. Finally, I could not transcribe data from two families due to background noise that obscured children's voices. Thus, my final sample included 23 families, consisting of 34 adults and 33 children. Ten families participated at the science center, and 13 families participated at the natural history museum.

3.5.3 Data Collection

Families' conversations are an important data source for assessing learning in museums (see Leinhardt, Crowley, & Knutson, 2002). As such, I relied on video data of families' interactions with the exhibit as my primary data source. I set up two to three digital video cameras around the exhibit (as space allowed) to record visitors' interactions. The cameras were angled to record visitors' placement of materials on the exhibit table. I placed three audio recorders to supplement audio and account for background noise. I also used Screencastify (Screencastify, 2018) to capture visitors' actions in the simulation on the laptop screen. All data sources were listed in the informed consent/assent documents.

As described earlier, I asked about visitors' interest in the activities as they approached the exhibit. If visitors indicated interest, I read the informed consent/assent documents to visitors and asked if they had questions. Participants who indicated consent by checking a box on the consent/assent documents (or verbalizing assent, for younger children) were invited to step into the camera frame and interact with the exhibit. Non-participants were thanked for their time. I collected 13 hours of data at Discovery World on the dates of May 12, June 9, and August 18, 2018. I collected 9 hours of data at the Milwaukee Public Museum on the dates of June 10 and August 19, 2018. Families' interactions occurred over 3 hours and 36 minutes, with a mean duration of 9 minutes and 24 seconds per family (SD = 4 minutes and 18 seconds).

After collecting data, I transcribed visitors' discourse in two rounds. After the first round of transcription, I checked transcripts and added gestures from video data and actions from the screen capture data for context. In total, I identified 3,701 turns of talk, with a mean length of 160.9 turns of talk per family (SD = 75.1 turns).

3.5.4 Data Analysis

The goal of this study was to understand what kinds of support families provided in a science exhibit, based on prior research about scaffolding. I also aimed to understand who provided scaffolding; what prompted scaffolding; and how scaffolding supported learning in the exhibit. To do this, I used sociocultural discourse analysis (Mercer, 2004; Derry et al., 2010) to understand how each of these elements of scaffolding occurred during families' interactions with the exhibit.

Coding data. After transcribing the data, I generated a coding scheme (see Table 2) with macro-codes to reflect (i) demonstrated need for support; (ii) kinds of support; and (iii) learning. Within each macro-code, I included deductive micro-codes based on previous research about scaffolding in tutoring (Wood et al., 1976), classroom (Tabak & Baumgartner, 2004; Koole & Elbers, 2014), and museum (Mai & Ash, 2012; Borun et al., 1996) contexts. I used previously established scaffolding codes to understand how foundational research about scaffolding (e.g., Wood et al., 1976) might apply to museums. I adapted codes to the data so that they reflected families' discourse in the exhibit. For example, Wood and colleagues (1976) described reducing degrees of freedom as "simplifying the task by reducing the number of constituent acts required to reach solution" (p. 98). I modified this code to describe families' support that simplified the acts of sorting items or building a simulated compost. The following excerpt shows how a mother simplified acts within the task for a young child (approximately five years old):

Mother: How about we do one recycling, one compost? Find something that you can recycle.

Young Child: [picks up item and puts it in the recycling area]

Mom: Okay, super. And one compost.

Young Child: [picks up item and puts it in the compost area]

Mom: All right! Good work!

For micro-codes about demonstrating need for support, I included two codes (*Not Understanding* and *Help-Seeking*) based on research about responsive scaffolding in classrooms by Koole and Elbers (2014). This research identified how teachers diagnosed (or mis-diagnosed) students' understanding and provided responsive support. These codes were modified to reflect how family members shared misunderstandings and/or asked questions in the exhibit.

For micro-codes about kinds of support, I included the original scaffolding functions defined by Wood and colleagues (1976), with adaptations for this exhibit context. Wood and colleagues' (1976) study shaped the foundation of scaffolding, and I wanted to see how the scaffolding functions described in this study might extend to a museum context, as they have in other contexts (e.g., Belland et al., 2013). Based on observations of the data, I included *Revoicing* (Tabak & Baumgartner, 2004) as a micro-code, which I modified to reflect family members' dialogue in the exhibit. I also included *Making Connections* (Mai & Ash, 2012) as a micro-code, which reflected how family members connected exhibit content to prior experiences.

Finally, for micro-codes about learning, I included two codes (*Identifying and Describing* and *Interpreting and Applying*) that reflected family learning in museums as described by Borun and colleagues (1996). The authors originally described three learning levels (identifying, describing, and interpreting and applying), but I collapsed the first two levels into one code, as these were difficult to distinguish in families' discourse. These learning levels reveal more "learning potential" (DeWitt & Storksdieck, 2008) than learning as conceptual change, but they also reflect the reality that deeper conceptual change in a single museum visit is relatively unlikely (Adams et al., 2008; Falk, 2004; Yoon et al., 2012).

In summary, I used a deductive approach to identify theoretically- and empirically-relevant codes for the coding scheme. I then used an inductive approach to modify the description of each code to reflect scaffolding and learning in this exhibit (Derry et al., 2010). These codes allowed me to then identify who provided scaffolding, what prompted scaffolding, what kinds of support were offered, and what kinds of learning took place.

I established inter-rater reliability with an external coder who was familiar with scaffolding. We independently coded 20% of the data (763 turns of talk). I calculated the percentage agreement and Cohen's kappa for each micro-code based on the initial level of agreement. We established acceptable levels of agreement for all codes (see Table D1 in Appendix D). We resolved disagreements on codes, and I finished coding the data.

Table 2

Coding Scheme for Identifying Support Provided in the Exhibit

Macro-Code	Micro-Code	Description	Examples
Demonstrated need for support	Not understanding (Koole & Elbers, 2014)	The learner demonstrates a lack of understanding of the topic by: • Stating that they do not know something • Revealing misconceptions in their understanding • Showing confusion or uncertainty in their understanding	Facilitator: Have you heard of compost before? Child: No. Parent: [holds item over compost] Here, I think, I don't really know but I'm going with it. [places item in compost]
	Help-seeking (Koole & Elbers, 2014)	The learner asks for assistance or clarification from scaffolder.	Facilitator: Oh, that's a takeout container. It's got a little bit of food left in it. Parent: Is it Styrofoam? Facilitator: It's plastic. Child: Wait, how do we go…? Parent: You go up to the material, [points to screen] and click on that.
Kinds of support	Recruiting interest (Wood et al., 1976)	The scaffolder recruits the visitor's interest in the overall activity and/or parts of the activity.	Facilitator: Do you want to try the virtual compost? Facilitator: Based on what you learned, do you want to try sorting this again? Parent: Sure. [to child] Do you? Child: Yeah.
	Maintaining direction (Wood et al., 1976)	If the visitor becomes distracted or discusses unrelated ideas, the scaffolder brings the visitor's attention back to the activity and/or the goals of the activity.	Child: [selects Brown 2] Parent: Okay. What are you thinking this is gonna do, honey? Child: I have ribbons at home…they look just like that. Facilitator: Yeah, just like thin strips, right? So what about this pizza box?
	Reducing degrees of freedom (Wood et al., 1976)	The scaffolder simplifies the task by reducing the number of acts needed to complete the activity, such as by: • Clarifying what items are • Suggesting an item to sort or a material to include in the simulation	Parent: [holds up item] This looks like an egg? Facilitator: It's the top of a burger. Parent: What about uncoated paper plates? So, garbage or recycle? [holds up item] Child: [points to recycling]

		• Suggesting a particular amount or ratio of materials • Reducing available options for sorting or simulating • Focusing the learner's attention on one particular item or material	Parent: Maybe put some greens in now. Child: Yeah. [selects Green] Parent: So I think we want browns, but we want mostly greens? So -
	Marking critical features (Wood et al., 1976)	The scaffolder marks relevant features of the task in order to help the learner notice and interpret discrepancies between what they are currently doing and how they should do the activity. These could include: • Asking what makes something compostable or recyclable • Remarking on relevant options in the activity • Using information to provide relevant content • Using feedback to guide learners' thinking	Parent: I think that you can't reuse the chicken bone, right? So probably trash. Parent: Chopsticks are usually made of wood? And wood can be... Child: Composted. Parent: Don't forget about the blue, okay? [referring to compost] Facilitator: [points to Ideal Compost Guide] For a really good compost, it's going to decompose quickly, it's not gonna smell too stinky Facilitator: But it's decomposing kind of slowly. What do you think is something you might do to make it decompose faster?
	Managing frustration (Wood et al., 1976)	The scaffolder helps the learner to work through acts, cognitively or procedurally, if the visitor becomes frustrated or "stuck."	Parent: She can't read yet. Facilitator: I can read it for her, that's okay. Child: I can't make it work. Facilitator: Don't forget to press down and wiggle.
	Demonstrating (Wood et al., 1976)	Scaffolder models how to do the activity, or think about the activity, with the implicit goal of the learner imitating these actions.	Facilitator: So, to make a compost what you're gonna do is pick which material you want, so I'm clicking here. [opens Materials menu] Parent: What do you think? Child: Like…? Parent: Like if there was a glass container in here, we probably wouldn't put it in our compost.
	Revoicing (Tabak & Baumgartner, 2004)	The scaffolder revoices the learner's statements to align with content of the task *or* ability of the learner. For example, the scaffolder: • Echoes the learner's statements • Echoes support from another scaffolder	Child: Right there. [points to recycling] Parent: Right there. [places item in recycling] Facilitator: We're gonna say it's plastic. Parent: It's plastic.

		• Rephrases questions or statements from another scaffolder	Facilitator: It would probably take a long time. Parent: Take a long time. Facilitator: We've got some crab and animal bones. Parent: It's food.
	Making connections (Mai & Ash, 2012)	The scaffolder encourages connections between activities in the exhibit and prior experiences, knowledge, or contexts encountered in the visitor's personal life.	Grandma: What about your garden? Do you think the compost would help flowers in your garden? Parent: Where do we put our bottles at home?
Understanding and learning	Identifying and describing (Borun et al., 1996)	Brief statements or answers that indicate superficial or shallow understanding of content, including: • Identifying an object • Describing an object without including relevant concepts • Answering a yes/no question • Agreeing with a statement or decision without stating why	Parent: So remember we want something that - yeah - bugs wanna live in and it doesn't stink too much. Child: Because it could do, like, something to the other things. Adult Sister: Wood chips. I feel like compost. Teen Sister: Yeah, me too.
	Interpreting and applying (Borun et al., 1996)	Longer statements or answers that indicate deeper understanding of content, including: • Correctly sorting materials • Explaining reasoning, phenomena, concepts, or relationships • Applying information or observations from one's personal experiences to the exhibit activities Note: this code does not apply to responses to diagnostic questions asked by the facilitator at the beginning of the activities.	Teen Sister: What do you think about the eggshells? Adult Sister: The carton I feel is recyclable, and I feel like you can compost the shells, so maybe put it in the middle here. [points at dividing line] Child: I was thinking about what I would recycle at school. Parent: I don't have much knowledge about compost and I know a lot about recycling and I remember when my teacher talked about Earth Day when I was her age.

Emergent family types. As stated earlier, we might assume that parents naturally take on a teaching role to support their children's learning (Wood & Wolf, 2012), creating the kind of asymmetric relationship described by Vygotsky (1978) in his definition of the ZPD, as well as Wood and colleagues' (1976) description of tutoring. However, in museums, parents and children might share the responsibility for scaffolding (Mai & Ash, 2012). When children take on teaching roles to support other children, their relationship indicates more symmetry (Dillenbourg, 1999; Fernández et al., 2001; Guk & Kellogg, 2007). Additionally, peers' ability to understand and support other peers using familiar language can give them an advantage when scaffolding (Webb & Farivar, 1999).

Thus, when analyzing what kinds of support were provided, I noted *who* provided support and *to whom* that support was directed (i.e., parents or children) in order to understand teaching-learning relationships in each family. Three types of families emerged from these observations based on the presence or absence of parents and peers.

To reflect differences in scaffolding relationships, I differentiated three family types based on who provided scaffolding. The first type (*No Peer*, n = 15 families) involved parents, but not peers, providing scaffolding. The second type (*Peer Present*, n = 6 families) involved parents *and* peers providing scaffolding. The third type (*Only Peer*, n = 2 families) involved peers, but not parents, providing scaffolding. As the facilitator, I also provided scaffolding for all families.

After identifying family types, I classified participants into four groups: (i) parents, (ii) peers, (iii) other children, and (iv) the facilitator. I then sub-divided the total frequency of each micro-code into the four participant groups and converted frequencies to proportions. I visualized each participants' proportion of micro-codes by family type. I then used chi-square tests of independence (Preacher, 2001) to determine if there was an association between participant type and proportions of micro-codes within each family. I also used z-score tests of homogeneity to compare proportions of micro-codes across family types, with a Holm-Bonferroni correction to account for cumulative error. Finally, I qualitatively examined transcripts to identify excerpts that represented how families demonstrated micro-codes.

3.6 Findings

The goals of this study were to understand how family members participated in scaffolding, and, more specifically, what kinds of support they provided. To do this, I identified how families demonstrated a need for support; who provided support; what kinds of support were provided; and what kinds of learning were observed. I discuss each of these components of scaffolding for each family type below.

3.6.1 *No Peer* Families

The *No Peer* families involved scaffolding provided by parents, but not peers. These families generally consisted of parents and one child, but not siblings. As a result, children could access at least two adults (a parent and the facilitator) when he or she needed help (i.e., a 2:1 adult-child ratio).

While children were more likely to demonstrate need for support than parents (68.2% vs. 31.1%, respectively), and thus act as scaffoldees, parents also demonstrated need by seeking support. Children were significantly less likely to seek help than show a lack of understanding, while parents were significantly more likely to seek help than show a lack of understanding (χ^2 = 21.55, df = 1, $p < .001$). Parents' help-seeking often involved asking for clarification on a sorting item. However, parents also demonstrated uncertainty during activities, as shown in the excerpt in Table 3. Here, the parent asked driving questions to guide her daughter's thinking during the sorting activity, but also demonstrated uncertainty when sorting.

Table 3

Example of a Parent Demonstrating Need for Support in the Exhibit

Speaker	Transcribed Talk and Actions	Code
Mother:	Where would you put that?	Reducing DOF
Girl:	Right there. [points to recycling]	Interpreting and Applying

Mother:	Right there. [places item in recycling]	Revoicing
Mother:	[holds up item] Meat.	Reducing DOF
Girl:	[starts to point but stops]	Not Understanding
Mother:	[holds item over compost] Here, I think. I don't really know, but I'm going with it. [places item in compost]	Not Understanding

Figure 2 shows who provided scaffolding in *No Peer* families. As indicated in the name, peers did not emerge to provide scaffolding. When children needed support, they were about equally like to receive support from the facilitator (42.1% of responsive support) or parents (40.5%). When parents needed support, the majority of responsive support came from the facilitator (52.3%), and rarely from a child (2.3%). Children's support of parents' learning was found in one family in which a girl provided scaffolding for her mother (see excerpt in Table 4). The girl had earlier stated that she could not compost oranges but did not explain why. In this excerpt, the mother asked her about composting oranges. When the girl struggled to articulate her reasoning, the mother indicated that the girl helped her understand. I included this family with *No Peer* families because child scaffolding was relatively rare (0.3% of *No Peer* scaffolding codes), and a peer was not present.

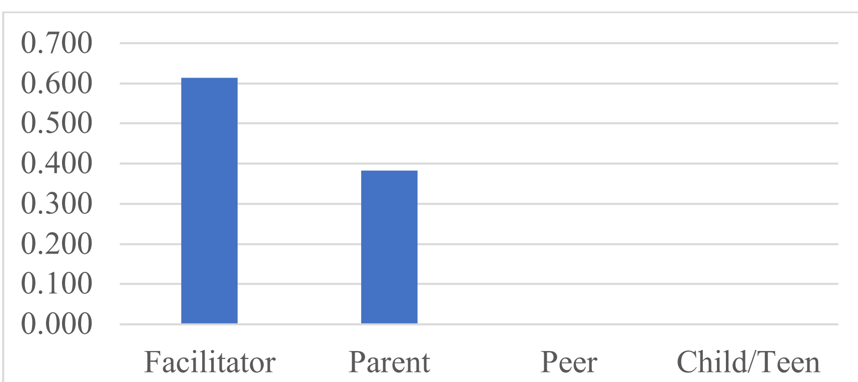

Figure 2. Participants providing scaffolding in *No Peer* families.

Table 4

Example of a Child Providing Support for an Adult

Speaker	Transcribed Talk and Actions	Code
Mother:	How did you know that, [girl's name]? 'Cause I didn't know that.	Help-seeking
Girl:	Well, citrus hurts the ground sometimes.	Marking Critical Features
Mother:	Is it too acidic?	Help-seeking
Girl:	It's not like water, it isn't like water.	Marking Critical Features
Facilitator:	Okay, I learned something new.	
Mother:	Good thing we have you with us, to tell us all this stuff.	

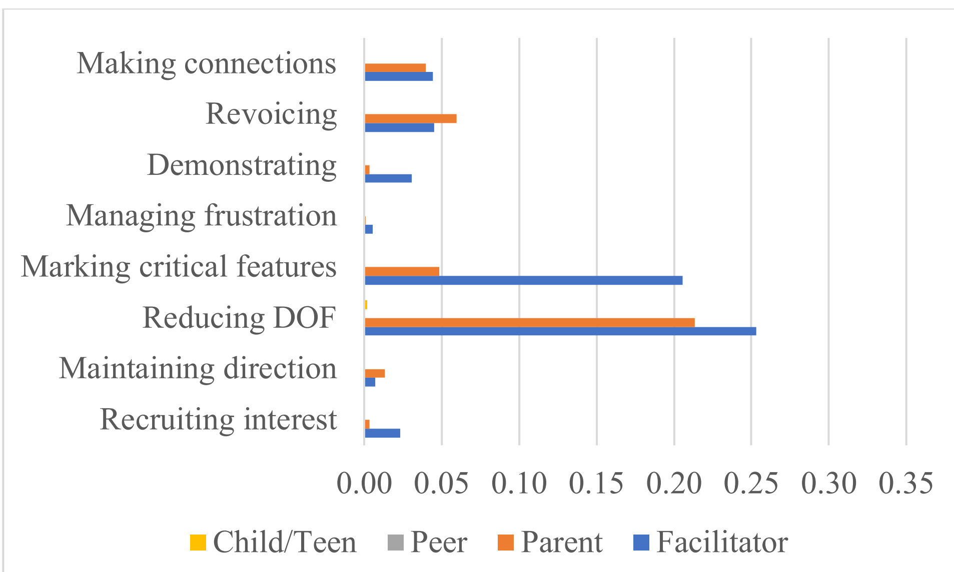

Figure 3. Support provided by participants in *No Peer* families. These proportions are calculated from a total of 1110 scaffolding codes.

The most common kind of support was reducing degrees of freedom (DOF) in the task (see Figure 3). Of 425 scaffolding codes attributed to parents, 55.8% involved reducing DOF. Another 15.5% of parents' scaffolding involved revoicing, and 12.7% involved marking critical features. Parents rarely needed to provide motivational support (e.g., recruit interest, maintain direction, or manage frustration). The facilitator did significantly more reducing DOF, marking critical features, and connection-making than parents, but parents did significantly more direction maintenance and revoicing than the facilitator ($\chi^2 = 79.95$, df = 4, $p < .001$).

The excerpt in Table 5 shows how parents reduced DOF by suggesting materials for the compost simulation. Table 5 also includes an example of revoicing as repeating suggestions from the facilitator. The excerpt in Table 6 adds an example of a grandparent marking critical features when sorting items. This grandparent's support is more directive than dialogic, but this approach may have been necessary to support the activity of a three-year-old girl.

Table 5

Example of Parents Reducing Degrees of Freedom (DOF) and Revoicing

Speaker	**Transcribed Talk and Actions**	**Code**
Facilitator:	So why don't you try adding a little bit of Green this time.	Reducing DOF
Mother:	Just a little.	Revoicing
Boy:	[adds Green to compost]	
Mother:	Shake it. A little more.	Reducing DOF
Facilitator:	That's a good start.	
Mother:	That's enough. Now go get a Brown. [points to Materials drop-down menu]	Revoicing Reducing DOF
Boy:	[hovers cursor over Brown 1]	
Mother:	Let's try Brown 3.	Reducing DOF
Boy:	[selects Brown 3]	
Mother:	Okay, shake it…	Reducing DOF
Boy:	[adds Brown 3 to compost]	

Table 6

Example of Parents Marking Critical Features

Speaker	Transcribed Talk and Actions	Code
Grandma:	[introducing the exhibit] Okay, so, compost is the things that we don't eat. We put them all together kind of like in a recycling bin or a garbage bin. And then, we make other things with it. She's going to tell you what we can make with compost.	Marking Critical Features
Facilitator:	Yes. [Obtains informed consent before proceeding.]	
Grandma:	Okay, so what - what food might we put in a compost?	Reducing DOF
3 Y.O. Girl:	This!	
Grandma:	That. Okay, put that in your compost.	Reducing DOF

Children demonstrated more learning than parents (70.2% vs. 29.8%) in *No Peer* families. As children were often the recipients of support in the exhibit, they may have had more opportunities to demonstrate learning. However, parents also demonstrated learning in addition to demonstrating need, thus indicating their roles as scaffolder and scaffoldee (although they mainly acted as scaffolders). All family members were significantly more likely to interpret and apply content than to identify and describe objects ($\chi^2 = 12.74$, df = 1, $p < .001$). *Interpreting and Applying* accounted for 87.4% of parents' learning and 69.9% of children's learning. As *Interpreting and Applying* included making connection to prior experiences, parents could demonstrate learning when they helped children to make connections across contexts.

3.6.2 *Peer Present* Families

The *Peer Present* families were characterized by scaffolding provided by parents *and* at least one peer. These families typically included a parent and two siblings. At least one sibling provided scaffolding to the other; in some families, multiple siblings provided scaffolding.

Sometimes siblings worked alongside each other (see excerpt in Table 7) and sometimes siblings collaborated during activities (see Excerpt in Table 8).

Table 7

Example of Peers Working Alongside Each Other

Speaker	Transcribed Talk and Actions	Code
Older Brother:	Egg shells, I think they go in here - [puts item in compost]	Interpreting and Applying
Younger Sister:	Meat, that goes in here. [puts item in compost]	Interpreting and Applying
Older Brother:	Wrappers. Here go wrappers. [passes item to sister]	Help-Seeking
Younger Sister:	Wrappers go in the trash. [puts item in trash]	Interpreting and Applying

Table 8

Example of Peers Working Collaboratively

Speaker	Transcribed Talk and Actions	Code
Younger Sister:	Let’s do a lot of the green.	Interpreting and Applying
Older Brother:	Let's try doing - let's just try doing all green. [selects Green]	Not Understanding
Younger Sister:	Yeah. Wait, no. We should add a little, like, of one brown. Okay.	Reducing DOF Interpreting and Applying
Older Brother:	Yeah, but which brown? [opens Materials menu]	Help-Seeking
Younger Sister:	The brown… [selects Brown 1]	

Children who did not provide scaffolding demonstrated more need for support (57.3%) than peers who did provide scaffolding (35.0%) and parents (7.8%). All family members were more likely to seek help than show a lack of understanding ($\chi^2 = 0.05$, df = 2, $p > .05$). Help-seeking accounted for 62.5% of parents' need; 58.3% of peers' need; and 59.3% of children's need.

Figure 4 shows who provided scaffolding in *Peer Present* families. As indicated in the name, at least one peer provided scaffolding. The facilitator provided the most scaffolding, and parents provided more scaffolding than peers. When children needed support, 37.5% of support came from the facilitator, 21.9% came from parents, and 14.6% came from peers. When parents needed support, 33.3% of support came from the facilitator, and 16.7% came from other parents.

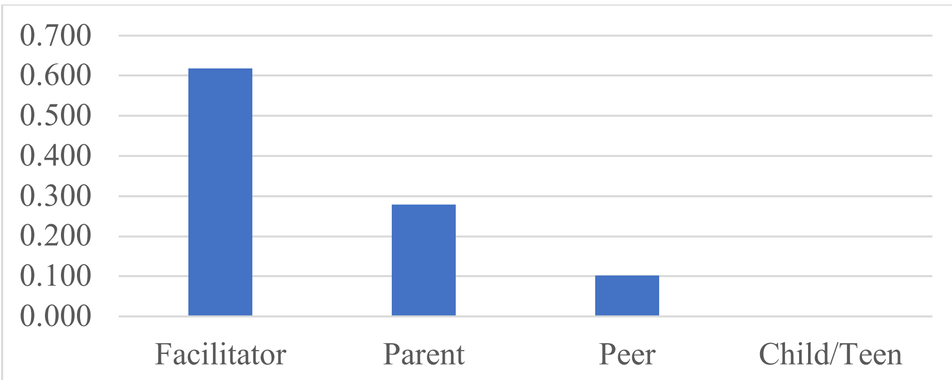

Figure 4. Participants providing scaffolding in *Peer Present* families.

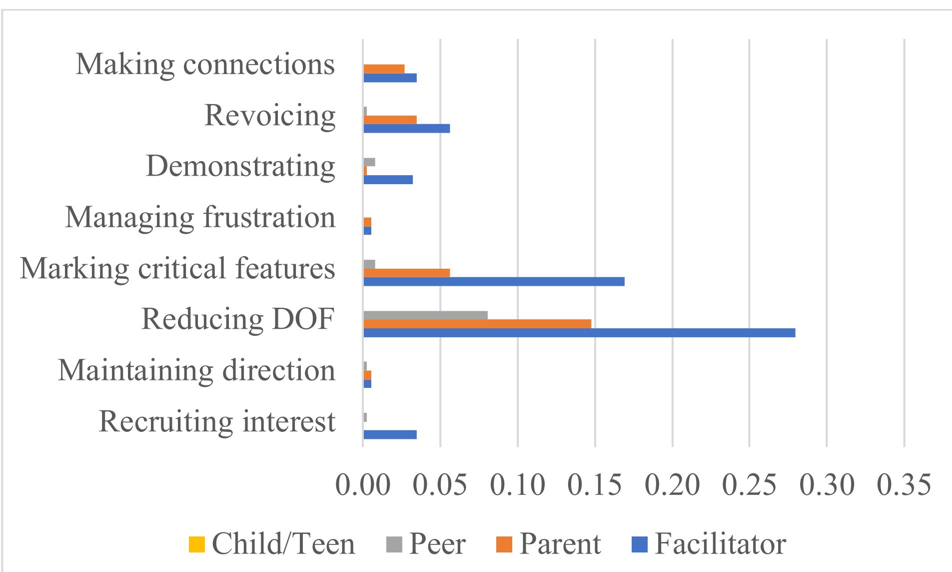

Figure 5. Support provided by participants in *Peer Present* families. These proportions are calculated from a total of 372 scaffolding codes.

As with *No Peer* families, the most common kind of support was reducing DOF (see Figure 5). Of 104 scaffolding codes attributed to parents, 52.9% involved reducing DOF; 20.2% involved marking critical features; and 12.5% involved revoicing. Of 38 scaffolding codes attributed to peers, 78.9% involved reducing DOF, and 7.9% involved demonstrating. Parents and peers rarely needed to provide motivational support. A chi-square test of independence was inappropriate for this data, as only one kind of support was provided at least five times by each participant type.

Peers in *Peer Present* families demonstrated slightly more learning than other children (40.2% vs. 35.5%), and more learning than parents (25.3%). When peers both provided and received support, their participation in both processes did not seem to harm their learning. Parents also demonstrated learning, indicating that parents acted as scaffolders and scaffoldees. All family members were more likely to interpret and apply content than to identify and describe objects ($\chi^2 = 14.13$, df = 2, $p < .01$). *Interpreting and Applying* accounted for 91.8% of parents' learning; 75.6% of peers' learning; and 61.2% of children's learning. Peers did more *Interpreting and Applying* than other children, but less than parents.

The presence of peers changed how support was provided, as parents in *Peer Present* families provided significantly less scaffolding than parents in *No Peer* families (.383 vs. .280, $z = 3.59$, $p < .01$). Thus, the amount of support parents provided changed when peers provided support. The excerpt in Table 9 illustrates both parent and peer scaffolding. This family included a father and two brothers, one about elementary-school age and one younger. The father had experience with composting at work, and he was familiar with materials having different carbon-nitrogen ratios, and thus different decomposition rates. Both brothers participated in the sorting activity at the same time, but only one brother could control the simulation at a time. The older brother initially controlled the simulation. As he simulated a compost bin, the father offered suggestions and focused on individual output variables. The younger brother watched his older brother and occasionally shared his observations. After simulating a "good" compost bin, the older brother helped his younger brother with the simulation by managing the trackpad, which the younger brother struggled to use.

Table 9

Example of Parent and Peer Scaffolding During the Simulation Activity

Speaker	Transcribed Talk and Actions	Code
Father:	Lots of green. Do lots of green guys. It'll go the fastest. More, more, more. Faster, faster, faster.	Reducing DOF
Older Brother:	[laughs] Okay!	
Father:	Faster, faster, faster! Oh, you got it now. Now you know what you're doing.	
Facilitator:	There you go. And whenever you're done, you can press that yellow button that says Simulate.	Reducing DOF
Father:	I bet you it's gonna go fast.	Interpreting and Applying
Older Brother:	[presses Simulate]	
Facilitator:	Are you surprised?	
Father:	Did it go faster this time?	Reducing DOF
Older Brother:	Uhh.	Not Understanding
Younger Brother:	The green one did.	Interpreting and Applying
Father:	It smells stinky because there's so much green in there.	Marking Critical Features

[Next, the older brother simulates a "good" compost. After, the father and facilitator begin a side conversation about composting at work.]

Older Brother:	Do you need help? <u>So what you do is you go up to here</u> [moves cursor to shaker], <u>you hold this</u> [<u>demonstrates on trackpad</u>], and <u>then you shake it</u>. Right?	Reducing DOF Demonstrating
Younger Brother:	<u>[attempts to move cursor]</u>	Not Understanding
Older Brother:	<u>So hold onto it</u>, and, um, no. [takes control of trackpad]	Reducing DOF
Older Brother:	<u>And then go here.</u> [<u>moves cursor for younger brother</u>]	Reducing DOF Demonstrating
Younger Brother:	[moves finger on trackpad to shake compost]	
Older Brother:	Do you want to do all? <u>You want to do all Greens?</u> [opens Materials Menu in simulation]	Reducing DOF
Younger Brother:	No.	Identifying and Describing
Older Brother:	<u>You want Browns?</u>	Reducing DOF
Younger Brother:	Yeah.	Identifying and Describing
Older Brother:	Okay. <u>I'll do it.</u> [<u>changes material for younger brother</u>]	Reducing DOF Demonstrating
Younger Brother:	Wait, what are those?	Help-Seeking
Older Brother:	<u>You want to do one of these Browns?</u> [hovers cursor over drop-down menu] Brown 3? [picks Brown 3]	Reducing DOF
Older Brother:	So... <u>[moves finger on trackpad to shake compost]</u>	Demonstrating
Young Boy	[laughs]	

Older Brother:	[presses Simulate]	
Older Brother:	Wow.	
Facilitator:	What'd you make?	
Father:	He used two Browns together, which is great.	Interpreting and Applying
Older Brother:	He used Brown 3.	Interpreting and Applying
Facilitator:	Brown 3? Remember I mentioned something called carbon? The Brown 3 has a lot of carbon in it. This has a little bit less carbon.	Marking Critical Features

In this excerpt, the father initially provided scaffolding for both brothers during the sorting activity. However, when the father was occupied in a different conversation, the older brother provided scaffolding for the younger brother. This showed a shift in responsibility for providing support from the father to the older brother, of the older brother's own initiative. While this scaffolding was not particularly open-ended, both brothers were able to simulate "good" compost bins–a complex activity.

3.6.3 *Only Peer* Families

In *Only Peer* families, peers provided scaffolding, but not parents. Without parents' guidance, peers needed to share and negotiate their understanding of the activities (Wertsch, 1984). As the facilitator, I limited my support in order to encourage this negotiation.

While we might expect children who do not provide support to request more support, I found that peers who provided support (i.e., peers) were more likely to request support (67.6%) than children who did not provide support (32.4%). The excerpt in Table 10 illustrates how this happened. Here, the older teen explained her reasoning out loud, which served two purposes. First, it externalized her thinking and demonstrated when she needed support, such as identifying what can be put in compost. Second, reasoning aloud appeared to support the younger teen's thinking. By externalizing her thinking, the older teen marked critical features of the task while indicating uncertainty, and thus revealed her roles as scaffolder and scaffoldee. Peers were equally likely to seek help or show a lack of understanding ($\chi^2 = 0.40$, df = 1, $p > .05$).

Table 10

Example of Peers Demonstrating Need for Support While Providing Support

Speaker	**Transcribed Talk and Actions**	**Code**
Facilitator:	Which parts [of the disposable coffee cup] do you think you could recycle with that?	Reducing DOF
Younger Teen:	The cardboard and stuff here and this paper thing.	Interpreting and Applying
Older Teen:	If it's a paper bottom, probably. But probably not the top [points at coffee cup lid] because it's plastic, but I don't know.	Interpreting and Applying Marking Critical Features Not Understanding
Younger Teen:	But can't you – I think you can recycle plastic.	Interpreting and Applying
Older Teen:	I think you can, but it would say recyclable on the top, right? I feel like some coffee cups are recyclable and some are not.	Help-seeking Marking Critical Features Interpreting and Applying
Facilitator:	So I have a real-life version here. [holds up a disposable coffee cup]	
Older Teen:	Yeah!	
Facilitator:	So I was actually saving this. This one is recyclable for number seven, so not all places [recycle] seven. It's really hard to break down, unfortunately. But the cup is kind of cool because it's lined with a plant product, so it can actually break down.	Marking Critical Features

When peers demonstrated need for support, they were equally likely to receive support from other peers (28.1%) or the facilitator (28.1%). However, the facilitator provided more support than peers (see Figure 6). Thus, the facilitator provided support that was not prompted by demonstrated need. Also, peers in *Only Peer* families contributed significantly more scaffolding than peers in *Peer Present* families (43.6% vs. 10.2%, $z = 8.43$, $p < .001$). Thus, when parents were not available, peers provided more support.

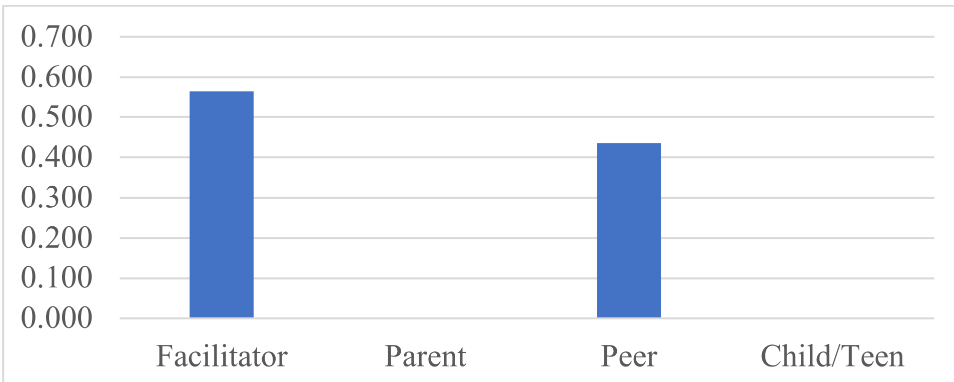

Figure 6. Participants providing scaffolding in *Only Peer* families.

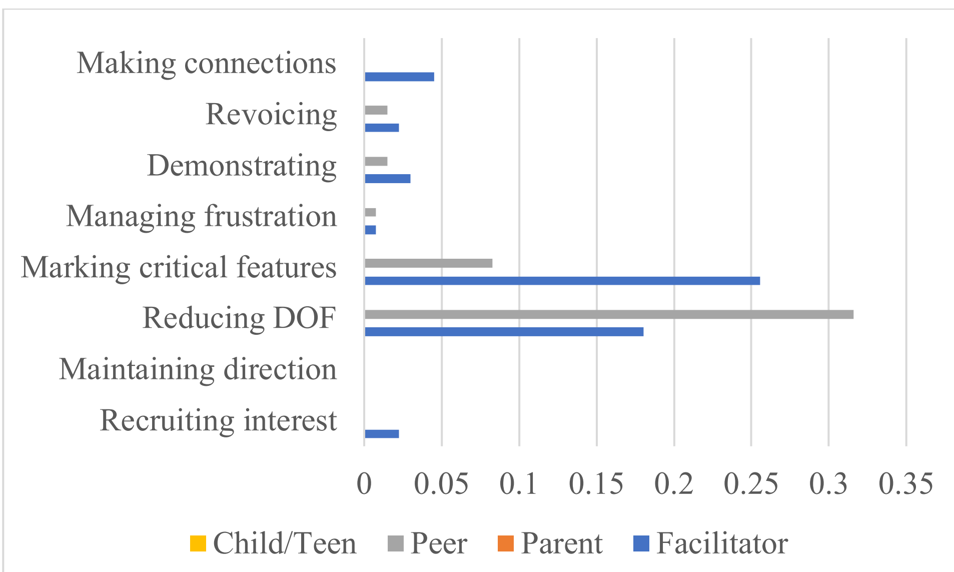

Figure 7. Support provided by participants in *Only Peer* families. These proportions are calculated from a total of 133 scaffolding codes.

As with *No Peer* and *Peer Present* families, reducing DOF was the most common kind of support (see Figure 7). Of 58 scaffolding moves attributed to peers, 72.4% involved reducing DOF, and 19.0% involved marking critical features. Peers rarely needed to provide motivational support. Peers reduced DOF significantly more often than the facilitator, but the facilitator marked critical features significantly more often than peers ($\chi^2 = 15.09$, df = 1, $p < .001$).

Children who did not provide scaffolding were slightly more likely to demonstrate learning (51.5%, versus 48.5% for peers). However, peers' participation as scaffolder and scaffoldee did not seem harmful to their learning. All family members were more likely to interpret and apply content than to identify and describe objects ($\chi^2 = 3.04$, df = 1, $p > .05$). *Interpreting and Applying* accounted for 90.3% of peers' learning and 73.5% of other children's learning.

Table 11 shows how peers supported others' learning by describing how an older teen supported a younger teen as they worked on the simulation. The younger teen controlled the trackpad while the older teen helped her to decide on amounts of materials. The older teen helped the younger teen notice increments on the compost bin that were incorporated into their decision-making.

Table 11

Example of Peer Scaffolding During the Scaffolding Activity

Speaker	**Transcribed Talk and Actions**	**Code**
Younger Teen:	[selects Brown 1 from Materials drop-down menu] Now, Brown 1 I'm going to fill it…[starts to add Brown 1]	Interpreting and Applying
Older Teen:	Okay, so think - <u>[points to screen]</u>	Reducing DOF

Younger Teen:	...up three notches. Then it would be [points to notches on beaker] one, two, three, and then, oh, no, no, no. [holds hand to head]	Interpreting and Applying
Older Teen:	<u>You should maybe empty again half way</u> and [points to increments on bin] <u>we'll count how many there are and then you can proportion them that way.</u>	Reducing DOF Marking Critical Features
Younger Teen:	[presses Reset button]	
Older Teen:	Okay so think. <u>[points to increments on bin]</u>	Reducing DOF
Younger Teen:	So there's going to be half. [points to increments on bin]	Interpreting and Applying
Older Teen:	<u>There is one, two, three, four, five.</u> [points to increments on bin]	Reducing DOF
Younger Teen:	One, two. Okay so I want to do maybe two, wait, [points to increments on bin] one, two, then one, two. Wait, if we do one, two, three, and then oh no. Dang it. [holds hand to head]	Not Understanding
Older Teen:	So, <u>we have five rows</u>, right?	Reducing DOF
Younger Teen:	Yes.	
Older Teen:	So Brown 1 is the easiest. <u>So how many of these do you want to be Brown 1?</u>	Reducing DOF
Younger Teen:	Maybe three, and then we'll do Brown 2 one, and then do Brown 3 one.	Interpreting and Applying
Older Teen:	Sure. <u>Or you could do two and then you could do two and then one.</u> Whatever you think, either way, but I liked the way that you break that down.	Reducing DOF

Younger Teen:	Yeah okay. [starts to add Green] I think I'm going to do three and then one and then one.	Interpreting and Applying
Older Teen:	Yeah, I think that's a great idea. That looks great.	

This excerpt shows how the two teens made decisions about how to fill the simulated compost bin by using increments indicated on the bin. The older teen guided the younger teen toward specific materials and/or amounts. The older teen also pointed out the increments and suggested that the younger teen use the increments to guide her decisions. In this family, the older teen provided guidance while acknowledging the younger teen's input.

3.6.4 Scaffolding Across Family Types

Thus far, I have discussed findings within family types. Here, I compare and contrast findings across family types, with emphasis on who took on what role(s) during activities.

My first research question asked how family members demonstrated need for support. I found that children were more likely than parents to demonstrate need for support, and thus act as the scaffoldee, in *No Peer* families. However, this relationship was not as straightforward in *Peer Present* and *Only Peer* families, as peers began to provide support to other children. Here, peers provided and received support, and thus took on dual roles as scaffolders and scaffolders. Evidence of both roles was witnessed within the same turn of talk, as shown in Table 10. In one clause, peers might externalize their thinking in ways that support others' understanding. However, peers might express uncertainty in the next clause. Thus, peers moved between states of providing and receiving support during the exhibit activities. This changed the relative levels of symmetry within families, as the introduction of peers as scaffolders appeared to decrease parents' role as scaffolders and add more symmetrical supportive relationships.

My second research question asked who provided support in the exhibit. Across all family types, the facilitator provided the most scaffolding, as we might expect in an interactive exhibit with complex activities. However, for *No Peer* families, parents were equally likely as the facilitator to respond to children's needs. Similarly, peers were equally likely as the facilitator to respond to children's needs in *Only Peer* families. However, in *Peer Present* families, both children and parents received the majority of responsive support from the facilitator. Also, parents in *No Peer* families received the majority of support from the facilitator. This reveals complexities in who attends to parents' and children's needs for support, as parents might expect to provide support to children but then defer to the facilitator when children ask questions outside of their expertise.

My third research question asked what kinds of support were provided by family members. Regardless of family type, families tended to provide support by reducing degrees of freedom (see Figure 8), often demonstrated as focusing attention on one material at a time or offering specific suggestions for how to proceed. Some suggestions were more open-ended ("What about a recyclable item?") while others were more directive ("Which bin? Where does that go?") when guiding others' activity. Other frequent kinds of support included marking critical features, often demonstrated as noting what made something compostable, and revoicing, often demonstrated as echoing others' learning and/or scaffolding. Motivational support (e.g., recruiting interest, maintaining direction, and managing frustration) was rarely needed.

My fourth research question asked how family members demonstrated learning. Children in *No Peer* families demonstrated more learning than comparable children who did not provide scaffolding in *Peer Present* and *Only Peer* families. This is reasonable, as children generally received support as scaffoldees. However, taking on dual roles as scaffolder and scaffoldee did not seem to hurt peers' learning. Peers in *Peer Present* and *Only Peer* families were about equally likely to demonstrate learning as other children in those families. If peers' learning had been harmed, they would have demonstrated lower frequency of learning than other children. Parents also demonstrated learning in *No Peer* and *Peer Present* families, with parents demonstrating more learning in *No Peer* families. This shows that while parents generally provided support as scaffolders, parents could also receive support as scaffoldees.

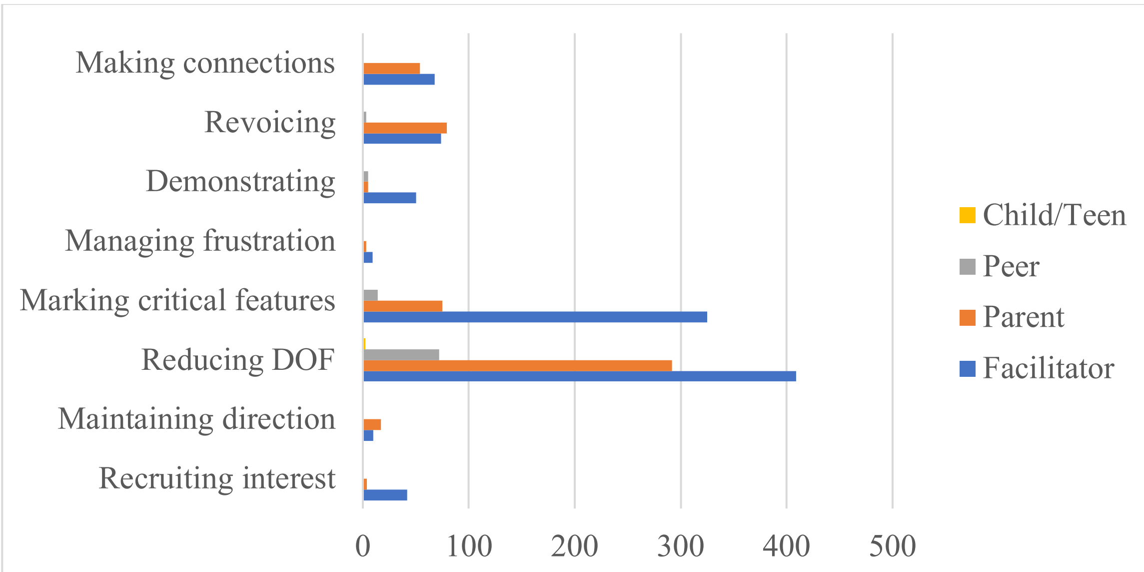

Figure 8. Chart showing the frequency of each kind of support and who provided that support.

3.7 Discussion

In this study, I aimed to understand how family members participated in the process of scaffolding. While there is considerable research about scaffolding in classrooms (van de Pol et al., 2010), we know much less about scaffolding in museums. Using codes derived from previous research, I addressed the following questions:

1. How did family members demonstrate a need for support?
2. Who provided support?
3. What kinds of support did family members provide?
4. What kinds of learning did family members demonstrate?

First, I found the children in *No Peer* families were more likely than parents to demonstrated need for support, and thus act as scaffoldees (Granott, 2005). Similarly, children in *Peer Present* and *Only Peer* families acted as scaffoldees, although some children also provided support to their peers. I distinguished peer scaffolders from other children because they took on dual roles as scaffolder and scaffoldee. Parents in *No Peer* and *Peer Present* families also demonstrated need for support, indicating that they also took on the role of scaffoldee at times. However, the facilitator was more likely to respond to parents' needs than other family members.

Children were about equally likely to seek help or demonstrate lack of understanding, whereas parents were more likely to seek help. Both demonstrations of need have implications for scaffolding. Help-seeking requires the learner to accurately diagnose their own problem to receive responsive support (Koole & Elbers, 2014). In contrast, the scaffolder must diagnose a lack of understanding in order to provide responsive support (Koole & Elbers, 2014). Diagnosis is not an easy task for teachers in classrooms (Koole & Elbers, 2014; van de Pol et al., 2014) or for parents in museums (Allen, 2004; Haden, 2010), and mis-diagnoses can result in support that is inadequate or over-prescriptive (Allen & Crowley, 2014; van de Pol & Elbers, 2013;).

Second, parents were more likely to provide support than children, which aligns with Wolf and Wood's (2012) observation that parents naturally support their children in exhibits. However, parents were not the only family members who provided scaffolding. As stated earlier, peers also acted as scaffolders by providing support for other children. Parents' and peers' dual roles as scaffolder and scaffoldee demonstrated how adults and children could share responsibility for support when participating in shared meaning-making (Mai & Ash, 2012; Granott, 2005; Ash, 2004b). Parents provided support to other family members, but also requested support as needed. Peers could provide support through dialogue with other children (Brown et al., 1993; Fernández et al., 2001) and appropriate the ways that adults provided support, as seen in Table 9 (Boblett, 2012; Guk & Kellogg, 2007; Tharp & Gallimore, 1988). While peers did not provide the most scaffolding in this exhibit, they played an important role in distributing support among family members (Granott, 2005). Future research can investigate peers' motivations to provide scaffolding.

Third, the kinds of support provided by family members most frequently included reducing degrees of freedom in the activities, marking critical features, and revoicing. Both activities featured a central goal (i.e., sort items correctly, build a "good" compost bin); however, the ways in which activities were completed was more open-ended. Family members could reduce this open-endedness by focusing on one item at a time in the sorting activity, or by suggesting particular materials in the compost simulation. This simplified the acts needed to complete the activity, thus making it more manageable (Wood et al., 1976).

Family members also provided support by marking critical features, such as noting what kinds of materials were compostable. Both reducing degrees of freedom and marking critical features were ways of providing cognitive support in the exhibit (Belland et al., 2013). In comparison, family members rarely provided support by recruiting interest, maintaining direction, or managing frustration, which are forms of motivational support (Belland et al., 2013). Families may not have needed motivational support because they already were motivated, as indicated by their choice to participate in these activities during their visit (Falk, 2004). While visitors could leave at any time, no visitors "quit" in the middle of the activities. Also, families were likely motivated by personal interest in compost. Eight families described composting at home, and nine groups gave detailed descriptions of the composting process or described prior experience with composting. While families' interest in compost limits the generalizability of the sample, it also emphasizes the importance of visitors' interests and agendas in free-choice learning contexts (Falk, 2004). Future research can analyze how visitors' interests impact how they participate in scaffolding.

Family members also provided support by revoicing statements from other family members or scaffolding from the facilitator. In the exhibit, revoicing helped create a dialogic space in which others' statements were acknowledged (Tabak & Baumgartner, 2004). Revoicing also allowed parents to mediate their children's learning by echoing scaffolding from the facilitator. For family members without composting experience, revoicing was a way to help others without calling on compost-specific knowledge. Also, in cases of mis-diagnosis of children's understanding (e.g., Koole & Elbers, 2014), parents could revoice the facilitator's support in ways that were better suited to their children's understanding. As scaffolders, parents could bridge knowledge of their children's abilities with their understanding of the exhibit activities (Wood et al., 2017).

Children were more likely than parents to demonstrate learning, especially in the *Peer Present* families. This might be explained by families' expectations for support, especially in who is prompted to demonstrate learning. To recall, families' discourse could indicate scaffolding and learning in the same turn of talk. When peers provided support, they could also demonstrate learning in the same turns of talk. Also, parents provided less support as peers began to provide support, and thus may have had fewer opportunities to show learning. Also, the physical arrangement of participants may have impacted demonstrations of learning. In *No Peer* families, one adult and one child sat together opposite the facilitator, with other parents participating from behind. In *Peer Present* families, however, multiple children sat opposite the facilitator, and parents participated from behind. This physical arrangement placed children in proximity to the activities, compared to the adults, and thus might explain who participated in scaffolding and learning.

Finally, family members were more likely to interpret and apply content than to identify and describe objects. This may be due to the interactive nature of the exhibit, as families were expected to partake in activities rather than look at objects. Family members also needed to recall prior knowledge and share it with others (e.g., Zimmerman et al., 2008). While the coding scheme for learning was limited to two broadly-defined codes, they reflected both constraints on museum learning (e.g., time) and the diverse nature of learning outcome in museums (Adams et al., 2008; DeWitt & Storksdieck, 2008; Falk, 2004).

This study made three contributions to our understanding of museum-based scaffolding from a learning sciences lens. First, this study described specific ways in which family members participated in scaffolding while in an interactive, facilitated exhibit. These finding show that families can overcome barriers and constraints in providing support. Many visitors move quickly from exhibit to exhibit (Falk, 2004; Serrell, 1997), thus limiting time to notice conceptual details and provide responsive support (Adams et al., 2008; Allen, 2004). Parents might not notice that children need support (Song et al., 2017) or may not be willing to provide support (Chak, 2001; Haden, 2010). Without training, parents might not know how to provide support (Eberbach & Crowley, 2017; Jant et al., 2014). As stated earlier, it takes considerable effort to interpret exhibits, provide support, and adapt support (Allen, 2004). These challenges echo classroom-based research of scaffolding, where teachers may fail to notice students' needs and respond accordingly (Howe & Abedin, 2013; Koole & Elbers, 2014). Parents and peers voluntarily chose to support other' learning, which has implications for learning in exhibits where children might not learn without others' support (Crowley et al., 2001; Puchner et al., 2001).

Second, this study described how parents and children could take on dual roles of scaffolders and scaffoldees as they interacted with the exhibit. While we might expect adults to support children (Puchner et al., 2001; Wood & Wolf, 2012), children can also provide support

(Granott, 2005; Guk & Kellogg, 2007; Mai & Ash, 2012). Multiple families included peers who provided support of their own initiative, and future research can investigate peers' motivation for doing so. Museums offer opportunities for children to provide scaffolding, compared with tutoring or classroom contexts where the adult is positioned as the expert (Littleton, 2013; Mai & Ash, 2012; Wood et al., 1976). Exhibits can also offer "symmetry of action" (Dillenbourg, 1999) in how they are read, observed, or manipulated. Exhibits can also offer distinct roles for different family members (Riedinger, 2012) to encourage collaboration within families.

Finally, this study contributed a coding scheme based on past research in tutoring (Wood et al., 1976), classroom (Koole & Elbers, 2014; Tabak & Baumgartner, 2004), and museum contexts (Mai & Ash, 2012; Borun et al., 1996). I incorporated the scaffolding functions described by Wood and colleagues (1976) to evaluate how these functions might extend to museums as they have been extended to classrooms (Belland et al., 2013; Tharp & Gallimore, 1988). One-on-one tutoring incorporates characteristics of both formal and informal learning (Wellington, 1990). Thus, the characterization of scaffolding in tutoring might apply to formal and informal contexts. Based on the findings, the scaffolding functions described by Wood and colleagues not only apply to museums, but also characterize the kinds of support provided by family members as they participate in complex activities. While the coding scheme includes examples specific to this exhibit, it could be modified for other interactive, facilitated exhibits. It could also be tested in exhibits that are less interactive or non-facilitated. Future iterations of the coding scheme could also include kinds of talk not currently represented, such as acknowledgement (e.g., "Yeah.") and praise (e.g., "Good work!").

This investigation of museum-based scaffolding is limited by its sample size of 23 families, 17 of which indicated prior interest in compost. Future studies could include more families who are less familiar with compost. They could also study groups of visitors who are unrelated, such as adult peers. The findings are also limited by my presence as a facilitator. As a researcher, my goal was to influence families' interactions as little as possible (Block et al., 2015). However, as the facilitator, I also wanted families to have a positive experience (Adams et al., 2008). Thus, I needed to establish rapport and sustain the interest of multigenerational visitors, which resulted in providing more support than I anticipated (Adams et al., 2008; Taylor & Neill, 2008; Chak, 2001). My presence likely encouraged families to stay longer than they would have on their own, as families' visits were longer than the average of two to five minutes (Serrell, 1997; Horn et al., 2012). While my presence influenced visitors' interactions, acting as facilitator allowed me to experience their interactions firsthand and observe families' self-initiated participation in scaffolding. Future research could study scaffolding in non-facilitated exhibits to investigate how families' scaffolding changes without the presence of a facilitator.

This study has begun to address a gap in our understanding about the nature of scaffolding in museum exhibits by identifying how family members demonstrated need for support; who provided support; how support was provided; and what kinds of learning were observed. Family members provided more cognitive support than motivational support. Both parents and children adopted roles as scaffolder and scaffoldee, although children's participation as scaffolder largely depended on the presence of other children. Peers who provided scaffolding demonstrated as much learning as other children, indicating that taking on dual roles as scaffolder and scaffoldee did not hurt their learning. Finally, families most frequently demonstrated learning by interpreting and applying exhibit content, which may have been influenced by prior interest in compost. Future research can explore how families provide scaffolding in less interactive and/or non-facilitated exhibits, and also include more inductive codes for families' discourse. Future research can also investigate peers' motivation for acting as scaffolders in museum exhibits.

3.8 Conclusion

Scaffolding describes tailored support provided in a variety of learning contexts. However, much of what we understand about the characteristics and process of scaffolding is based on research in classrooms, and we have only begun to understand museum-based scaffolding. In response, I conducted a study of families' scaffolding as they interacted with a pop-up exhibit about compost. Both parents and children acted as scaffolders and scaffoldees, although the balance of these roles depended on presence of siblings or peers. Parents and children distributed the responsibility for providing support (Granott, 2005; Mai & Ash, 2012) and provided support in the same ways (e.g., reducing degrees of freedom; Wood et al., 1976). Children demonstrated more learning than parents, but this was likely influenced by the number of family members, their participation in discourse, and their physical arrangement around the exhibit (Borun, 2008). Families' tendency to interpret and apply content was likely affected by their voluntary choice to engage in complex activities about compost (Falk, 2004). This study demonstrates how we can apply a learning sciences lens to investigations of museum-based scaffolding, using prior research to inform these investigations (Hammerness et al., 2016; Paris & Ash, 2000; Schauble et al., 1997). This study also re-emphasizes the role of dialogue in supporting learning in museums, where all family members can play roles in providing support (Allen & Gutwill, 2009; Zimmerman et al., 2008).

4. Investigating Interactions Between Social and Material Scaffolds in a Pop-Up Science Exhibit

4.1 Abstract

Distributed scaffolding is an effective approach for supporting students' learning in classrooms and museums. We have begun to understand how the design of distributed scaffolds shapes students' social interactions in museums. However, we do not yet know how the design of distributed scaffolds shapes families' social interactions in museums. In response, I studied the interactions between distributed social and material scaffolds in a pop-up exhibit about compost for 23 families. Material scaffolds that afforded joint activity were incorporated into social scaffolding on an ongoing basis, reflecting the social nature of museum learning. However, material scaffolds that afforded access to information and feedback were incorporated at key moments in social scaffolding. For example, while family members referred to output from a compost simulation only after completing the simulation, this feedback was used to support joint decision-making about variables in the simulation. This study demonstrated how material scaffolds can complement support provided by family members during visits to an interactive, facilitated science exhibit. Also, inadequate support provided by material scaffolds required additional support from other social scaffolds, echoing design issues in prior research about social and material scaffolds in classrooms. Future studies can incorporate case studies to analyze these interactions in finer detail and examine their impact on visitors' learning.

4.2 Introduction

Scaffolding is a metaphor for just-in-time support that is tailored to the learner's understanding (Palincsar, 1998; Wood, Bruner, & Ross, 1976). Providing cognitive, motivational, and metacognitive support allows learners to work through complex tasks without becoming frustrated or bored (Belland, Kim, & Hannafin, 2013; Puntambekar & Kolodner, 2005;

van de Pol, Volman, & Beishuizen, 2010). Scaffolding can refer to the process of providing support, along with the entities that support this process (Pea, 2004; Stone, 1998b). For clarity, I will use *scaffolding* to describe the process and *scaffolds* to describe entities that support this process.

Originally studied in tutor-tutee interactions (Wood et al., 1976), scaffolding has since expanded to include a variety of teaching-learning contexts that emphasize responsive support (Littleton, 2013; Palincsar, 1998). One such expansion is the notion of *distributed scaffolding*. Puntambekar and Kolodner (1998, 2005) introduced distributed scaffolding to describe how students in classrooms received support from tools and activities in addition to teachers. We can describe the people providing support as *social scaffolds*, and the objects, tools, and technologies providing support as *material scaffolds*.

Material scaffolds can be designed to support certain processes, such as making design decisions (Puntambekar & Kolodner, 2005). Material scaffolds can also be designed to interact with social scaffolds. For example, a student notebook can prompt students to collaborate in groups or prepare ideas for whole-class discussions (Puntambekar & Kolodner, 2005). Individual scaffolds can address specific needs on their own or in combination (Tabak, 2004). Distributing support across multiple scaffolds created opportunities to interleave scaffolds (Tabak & Reiser, 1997) or design systems of support (Luckin, 2008). Including multiple scaffolds also allows for *fading* of support, as individual scaffolds can be removed when no longer needed (Belland, 2011; Pea, 2004).

Researchers have also begun to investigate distributed scaffolding in museums. Yoon, Elinich, Wang, Steinmeier, and Tucker (2012) found that distributed scaffolding effectively supported middle-school students' learning in an exhibit about electrical current. Yoon, Elinich, Wang, van Schooneveld, and Anderson (2013) iterated on this study by investigating specific combinations of scaffolds. While combining more scaffolds supported deeper conceptual learning, students also demonstrated fewer exploratory behaviors in the exhibit. This problem of *overformalization* (Yoon et al., 2013) indicates a need to consider both cognitive and affective outcomes in exhibits (Adams, Tran, Gupta, Creedon, & O'Hurley, 2008; Falk, 2004).

Researchers have also begun to identify how the *affordances* of scaffolds impact visitors' interactions and learning. Affordances refer to the interactions between humans, objects, and the environment, as shaped by the properties of objects and environments and humans' abilities to perceive and interact with these properties (Gibson, 1986). Affordances can be physical, allowing manipulation of a tangible object (Gibson, 1986). Affordances can also be social, allowing for interactions among humans, or symbolic, allowing for communication between humans and/or objects (Gibson, 1986; Greeno, 1994). For example, one way that exhibits afford social interaction is by arranging space to accommodate multiple people in the same exhibit (Borun, 2008; Hornecker & Stifter, 2006). Exhibits can afford communication by including text or visual representations. For example, Kim and Crowley (2010) found that signage encouraging visitors to "think like scientists" resulted in supportive interactions among family members. Signage can also communicate potential learning opportunities to visitors (Song et al., 2017).

In their study of distributed scaffolding in two exhibits, Yoon, Anderson, Park, Elinich, and Lin (2018) identified three affordances of individual scaffolds that, when provided in combination, resulted in greater learning for middle-school students. They described this combination as an instance of *synergistic scaffolding*, in which complementary scaffolds positively impact learning. Text-based scaffolds provided instructions, while an augmented reality device added information. Instructions for collaboration afforded feedback among student as they manipulated the exhibits. The combination of all three scaffolds resulted in greater learning than each scaffold on its own, indicating that the affordances of distributed scaffolds can interact to support learning (Achiam, May, & Marandino, 2014; Rowe & Bachman, 2012).

While Yoon and colleagues' (2012; 2013; 2018) studies demonstrated how distributed scaffolding could support students' learning in museums, we do not yet know how distributed scaffolding supports families' learning in museums. First, knowledge may be distributed among family members (Zimmerman, Reeve, & Bell, 2008), which they may share when interpreting exhibits (Allen & Gutwill, 2009). In addition to scaffolding provided by people, exhibits may provide support by communicating concepts and demonstrating phenomena while encouraging social interactions (Allen, 2004; Falk, Scott, Dierking, Rennie, & Jones, 2004). While there is considerable research about supportive interactions between families and exhibits (e.g., Crowley & Callanan, 1998; Crowley & Jacobs, 2002; Eberbach & Crowley, 2005; Eberbach & Crowley, 2009; Eberbach & Crowley, 2017), few studies have used distributed scaffolding as a lens for understanding families' learning in museums.

In response, I investigated how the affordances of material scaffolds in a science exhibit interacted with families' scaffolding during visits to the exhibit. In this paper, I first provide additional theoretical background that motivated this study. I then describe how I used a mixed-methods approach to understand how the affordances of material scaffolds interacted with social scaffolding provided by family members and the facilitator during families' visits. I then interpret these findings and discuss their implications.

4.3 Theoretical Background

The notion of scaffolding expanded from one-on-one instruction between a tutor and tutee (Wood et al., 1976) to describe support provided among multiple learners in a classroom (Cazden, 1979; Stone, 1998b). While scaffolding effectively supports students' learning in classrooms (van de Pol et al., 2010), providing scaffolding to multiple students is not an easy task (Tharp & Gallimore, 1998). Teachers who provide scaffolding in the classroom must be able to diagnose and respond to multiple students' needs (Brown et al.,1993; Campione, Brown, Ferrera, & Bryant, 1984; Smit, van Eerde, & Bakker, 2012).

In response, distributed scaffolding posits that the teacher need not be the sole source of support in the classroom (Puntambekar & Kolodner, 2005). First, other students can provide support by collaborating and discussing ideas (Fernández, Wegerif, Mercer, & Rojas-Drummond, 2001). When discussing ideas, students externalize their thinking and negotiate conceptual understanding with others (Fernández et al., 2001; Wertsch, 1984). Teachers can also model ways of providing support for students to practice with each other (Guk & Kellogg, 2007).

Students' learning can also be supported by a wide variety of material scaffolds, such as tools, activities, and technologies (Luckin, 2008; Puntambekar & Kolodner, 2005). For example, Puntambekar and Kolodner (2005) provided design diaries that prompted students to reflect on the design process when iterating on their designs. As another example, interleaving book readings with tutoring experiences, book club meetings, and whole-class discussions helped support preservice teachers' reflections on culturally-responsive pedagogy (Smagorinsky, Clayton, & Johnson, 2015). Tabak and Reiser (1997) demonstrated that interleaving reflective whole-class discussions with activities involving material scaffolds (e.g., software-based scaffolding) had two advantages. First, the software offloaded certain kinds of support from the teacher, allowing the teacher to provide individualized support when students asked questions as they worked on computers. Second, whole-class discussions created opportunities for teachers to diagnose common issues in students' understanding and respond accordingly. The discussions also allowed teachers to provide additional support when the software did not address students' needs (Tabak, 2004). Together, these examples show how social and material scaffolds can provide complementary support in classroom activities.

The development of technology-based scaffolding has received both praise and criticism. Technology-based scaffolds can add structure to complex tasks and problematize tasks to add context (Reiser, 2004). For example, ExplanationConstructor (Sandoval & Reiser, 2004) structured students' inquiry about and explanations of natural selection. Adaptive technologies can provide information at critical moments (e.g., Azevedo, Cromley, Moos, Greene, & Winters, 2011). However, technological scaffolds have been criticized for their inability to provide calibrated support for diverse learners (Puntambekar & Hübscher, 2005). In response, others have argued that technology-based scaffolds make learning more tractable, which serves the function of scaffolding (Quintana et al., 2004).

As a key characteristic of scaffolding, responsive support often requires social scaffolds (e.g., teachers) to add support when material scaffolds (e.g., software) fail to provide adequate support for learning (Tabak & Reiser, 1997; van de Pol et al., 2010). For example, Saye and Brush (2002) described a curriculum that included *hard scaffolding*, designed as a hypermedia environment with resources that targeted anticipated needs, and *soft scaffolding*, intended as responsive support from the teacher. Similarly, Belland, Gu, Armbrust, and Cook (2015) included computer-based scaffolds for argumentation, intended to offload some support from the teacher. While both of these studies indicated that teachers struggled to serve as more responsive scaffolds who provided individualized support, Ge and Land (2004) demonstrated that teachers could successfully provide additional support when other scaffolds (e.g., question prompts, peer collaboration) were inadequate.

These studies point to the need to consider the purposes of individual scaffolds and their relationships with other scaffolds (Belland, 2011; Belland & Drake, 2013). For example, different scaffolds might support cognitive processes, motivation to learn, or metacognitive reflection on activities (Belland, Kim, & Hannafin, 2013; Puntambekar & Kolodner, 2005).

Thus, the interactions between scaffolds can impact these processes. Tabak (2004) described three patterns of interactions among distributed scaffolds. First, *differentiated* scaffolding includes one scaffold for each need. In contrast, *redundant scaffolding* includes multiple scaffolds for each need, or the same scaffold at multiple time points. Finally, *synergistic scaffolding* describes complementary scaffolds that augment each other's support. Synergistic scaffolding suggests that the ways in which social and material scaffolds interact have implications for students' learning (Ge & Land, 2004; McNeill & Krajcik, 2009; Puntambekar, Stylianou, & Goldstein, 2007; Tabak & Reiser, 1997), and that scaffolds designed with complementary purposes may be especially beneficial for learning (Tabak, 2004).

Beyond classrooms, researchers have begun to investigate distributed scaffolding in museums. As described earlier, Yoon and colleagues (2012) found that adding scaffolds to an exhibit about electrical current resulted in greater conceptual learning for middle-school students. Yoon and colleagues (2013) later found that there was a limit to how much scaffolding could be provided while still preserving students' affective outcomes (see also DeWitt & Storksdieck, 2008; Falk, 2004). More recently, Yoon and colleagues (2018) identified three affordances of scaffolds that, when provided in combination, positively impacted students' learning. Including text-based instructions, information from an augmented reality device, and feedback from peers helped students to more deeply understand content in the exhibits.

Yoon and colleagues' (2018) study illustrates how different scaffolds in exhibits can have different affordances (Belland & Drake, 2013). Museums are particularly good contexts for investigating how the affordances of material scaffolds emerge through visitors' interactions (vom Lehn, Heath, & Hindmarsh, 2001) and reflect designers' intentions to generate particular experiences (Allen, 2004). For example, physical components afford touch and manipulation, which, in turn, can afford exploration and collaboration (Ma, Sindorf, Liao, & Frazier, 2015).

The social affordances of exhibit signage can encourage visitors (and especially families) to ask questions or adopt roles (Allen & Gutwill, 2009; Leinhardt & Crowley, 1998). The symbolic affordances of signage can help families to identify learning opportunities or engage in specific ways of thinking (Kim & Crowley, 2010; Song et al., 2017). Exhibit materials can be powerful tools for supporting different kinds of interactions, depending on their design.

Taken together, these studies indicate that distributed scaffolding can support visitors' learning, based on the affordances of the material scaffolds and their interactions with social scaffolds. However, studies of distributed scaffolding in museums have focused on middle-school students' learning (Yoon et al., 2012; Yoon et al., 2013; Yoon et al., 2018). In contrast, we have yet to understand how distributed scaffolding supports families' learning in museums. In response, I investigated the interactions between social and material scaffolds as families visited a science exhibit. I also identified ways that material scaffolds complemented support provided by social scaffolds.

4.4 Current Study

In this study, I analyzed the interactions between social and material scaffolds in an interactive, facilitated pop-up exhibit about compost. I also analyzed how the affordances of material scaffolds influenced families' scaffolding in the exhibit. My goals were to understand how material scaffolds played a role in providing scaffolding in the exhibit and to identify how support was distributed in the exhibit. My research questions were:

1. How did exhibit materials afford joint activity, access to information, and access to feedback?
2. How did family members acting as social scaffolds interact with material scaffolds in the exhibit?
3. How was support distributed among social and material scaffolds in the exhibit?

I used a mixed-methods approach to answer these questions, which included sociocultural discourse analysis and association analysis that identified how the affordances of supporting joint activity, access to information, and access to feedback were represented in families' scaffolding. These analyses helped me to better understand the interactions between material scaffolds and the people using them, who also acted as social scaffolds. For a broader picture of scaffolding, I used social network analysis to visualize the distribution of support in the exhibit. Taken together, these analyses helped me to better understand the interactions between material and social scaffolds in this exhibit.

4.5 Methods

4.5.1 Exhibit Design

I analyzed the same pop-up exhibit about compost described in my second dissertation paper, "Investigating Social Scaffolding in Families Visiting a Science Museum Exhibit." To summarize the design, the pop-up exhibit featured two activities. First, visitors could sort various items into compost, recycling, and landfill bins. This objective of this activity was to help visitors learn about organic materials that could be composted. Visitors could also simulate a compost bin by adding "green" and "brown" materials to a virtual compost bin. The objective of this activity was to help visitors learn how the carbon-nitrogen ratios of different materials impact how compost decomposes.

The exhibit activities were designed to provide certain kinds of support. These scaffolds could also afford joint activity among visitors; access to information for decision-making; and access to feedback for decision-making. I describe these scaffolds below.

Families interacting with the exhibit could receive support from social scaffolds, such as the facilitator, parents, and children. Some children provided support for other children (i.e., peer scaffolders), and one child provided support for an adult, as described in my second dissertation paper. To summarize those findings, both parents and children acted as scaffolders and scaffoldees, although parents were more likely to act as scaffolders (i.e., social scaffolds). The facilitator acted as a social scaffold by recruiting families' participation; introducing the goals of each activity; diagnosing families' prior knowledge about compost; and providing assistance as needed. Parents and children provided support primarily by reducing the degrees of freedom in the activities, which describes simplifying the number of acts required to complete the task. For example, family members might focus others' attention on one item at a time or suggest particular materials for the simulated compost bin.

Multiple exhibit components were intended to act as material scaffolds. The *Ideal Compost Guide* (see Figure B1 in Appendix B) provided self-guided instructions for the sorting activity and the simulation. This guide included an image of output from the simulation that indicated a "good" compost (i.e., fast decomposition, no odor, good air circulation, and the right temperature for microbial activity). The guide could also add information during families' decision-making processes in the simulation, as visitors could compare their results from the simulation to characteristics of "good" compost described in the guide.

I included three items that acted as real-life models of compost and compostable materials. These models consisted of a container of *decomposing flowers*, a *greens bag* (e.g., potato peels, celery greens, banana peels), and a *browns bag* (e.g., shredded newspaper). These models served as authentic, visual representations of organic materials for composting. As the qualities of compost are impacted by the carbon-nitrogen ratio of materials, the *greens bag* and *browns bag* could help visitors make decisions in the simulation. The *greens bag* represented materials with lower carbon-nitrogen ratios, while the *browns bag* represented materials with higher carbon-nitrogen ratios.

In the sorting activity, the *bins* were three large pieces of paper that represented a composting bin, a recycling bin, and a landfill bin. Each bin had a text label and image of a real bin, which provided clues to children who could not yet read. The *items* were images of organic materials that could be composted, along with non-organic materials that could be recycled and/or put in landfill. These items became scaffolds when they were used to connect families' past experiences to the exhibit.

The simulation activity included multiple scaffolds (see Figure 9). First, the *Virtual Compost Bin* represented a 1.0-liter beaker with 0.1-liter graduated markings. When visitors pressed a "simulate" button, the bin changed the green and brown materials added to the bin to a dark brown representing compost. The materials menu showed which materials were available to add in the simulation (Green, Brown 1, Brown 2, and Brown 3). The Materials Information option provided additional detail about these materials, including their carbon-nitrogen ratios. Together, I refer to these as *Materials Menu/Information*. Visitors could refer to the *Compost Mixture Data* for information about the amounts of green and brown materials in the simulation, which could be used as feedback for making decisions about additional materials. For example, if visitors saw that their virtual compost bin had a carbon-nitrogen ratio that was too low, they could add more brown materials. Visitors could also receive feedback from the *Simulation Output*, which described qualitative characteristics of the simulated compost bin (see Figure 10). This feedback described the decomposition rate (fast/ideal or slow); odor (normal or foul); air circulation (aerobic or anaerobic); and temperature range (ideal for microbes, too hot, or too cold). Finally, visitors could select the *Simulation Comments* option, which was originally designed to help middle-school students reflect on decisions. I did not intend for visitors to use this scaffold, but it was not removed from the simulation.

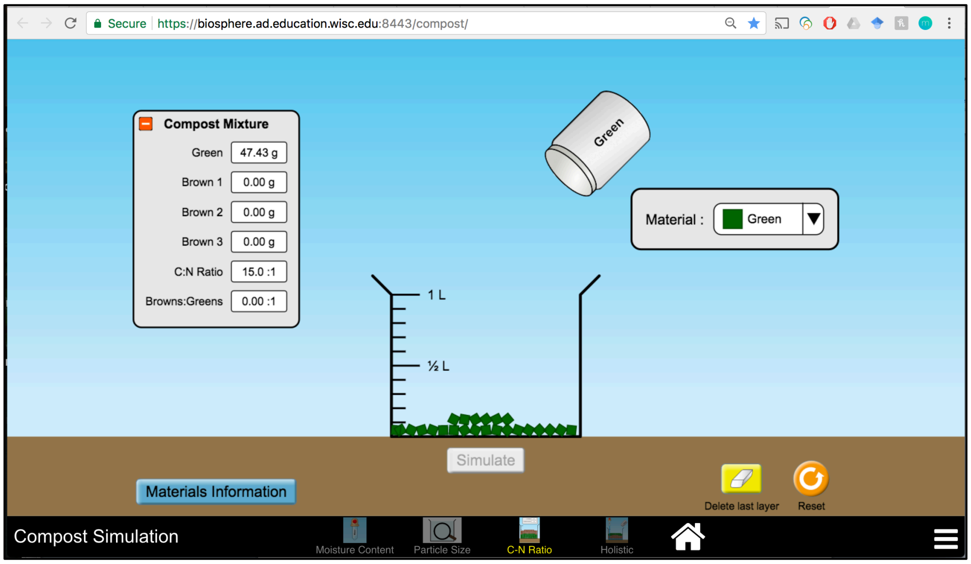

Figure 9. The compost simulation as shown before pressing the Simulate button. The *Virtual Compost Bin* is in the center of the simulation. The *Materials Menu* is to the right of the bin, with additional *Materials Information* to the bottom left. The *Compost Mixture Data* (top left) shows the amounts of materials added along with the carbon-nitrogen ration.

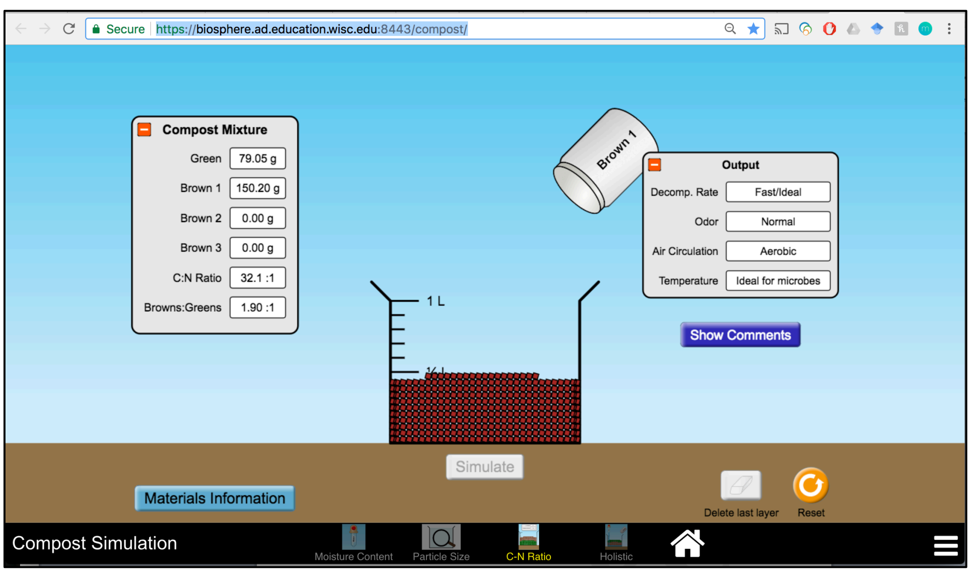

Figure 10. The compost simulation as shown after pressing the Simulate button. The *Simulation Output* (right) overlays the *Materials Menu*. The *Simulation Output* shows the characteristics of a

“good” compost bin in this screenshot. While not actively encouraged to do so, visitors could access *Simulation Comments* by clicking the Show Comments button (right).

Each material scaffold was designed to serve a purpose in supporting learning, as described above. The material scaffolds also had social and symbolic affordances that influenced families’ interactions and communication. The sorting items afforded social interaction, in that items could be passed between visitors. As visual representations, the items and bins had symbolic affordances that allowed visitors of different ages to identify objects represented by the images. The simulation included symbolic affordances in the text, numbers, shapes, and colors representing objects and concepts, which also provided information and feedback. The simulation afforded interaction and communication among visitors, as multiple visitors could discuss data and output displayed by the simulation. For symbolic affordances, the Ideal Compost Guide used text and images to provide instructions, while the real-life models acted as representations of compostable materials.

Based on the social and symbolic affordances of material scaffolds in the exhibit, I expected material scaffolds to interact with support from social scaffolds in certain ways, as demonstrated in visitors’ discourse and actions. I created three categories of social and symbolic affordances, using Yoon and colleagues’ (2018) study for guidance. I named the three categories *Supporting Joint Activity*, *Access to Information*, and *Access to Feedback*. I chose joint activity over collaboration because of the complexities involved in qualifying collaboration (Dillenbourg, 1999). These categories were incorporated into the coding scheme described below.

4.5.2 Setting, Participants, and Data Collection

This paper analyzes the same data set described in my second dissertation paper. To summarize, the pop-up exhibit was hosted at two science museums in the U.S. Midwest. I obtained visitors’ informed consent (and assent as needed) before they participated in the activities. The final sample of participants included 23 families consisting of 34 adults and 33 children. I facilitated the exhibit for 22 hours over five days and collected data of visitors' interactions with the exhibit using multiple cameras and audio records. I also collected screen capture data of visitors' actions in the simulation using Screencastify (Screencastify, 2018). Data for the final sample included 3 hours and 36 minutes of video. The mean interaction time per family was 9 minutes and 24 seconds (SD = 4 hours and 18 seconds). I transcribed visitors' discourse using video data, adding audio data when background noise was louder. I also used video data to transcribe gestures indicating joint attention (e.g., pointing, holding up items) and screen capture data to transcribe visitors' actions in the simulation. Finally, I annotated supportive turns of talk with the social and/or material scaffold providing support.

4.5.3 Data Analyses

I used a mixed-methods approach to answer my research questions about the interactions between social and material scaffolds in the exhibit and distribution of support in the exhibit. I used a combination of sociocultural discourse analysis and association analysis to identify how material scaffolds afforded joint activity, access to information, and access to feedback, as indicated by visitors' discourse and actions. I used association analysis to identify frequent co-occurrences of support from material and social scaffolds. Finally, I used social network analysis to visualize distribution of support across social and material scaffolds in the exhibit. I describe each of these methods below.

Sociocultural discourse analysis. This study builds on findings from my second dissertation paper, "Investigating Social Scaffolding in Families Visiting a Science Museum Exhibit." In this paper, I used sociocultural discourse analysis (Mercer, 2004; Derry et al., 2010) to identify how family members provided scaffolding during their interactions with this exhibit. I found that both parents and children acted as scaffolders and scaffoldees, and the balance of these roles was impacted by the presence of peers who provided scaffolding to other children. Also, family members tended to provide support by reducing degrees of freedom in the task, such as by focusing others' attention on specific items in the sorting activity.

In this study, I developed a coding scheme that represented the affordances of material scaffolds, as intended in their design. As stated earlier, I identified the social and symbolic affordances of each material scaffold. I then categorized these affordances into three codes (see Table 12), using Yoon and colleagues' (2018) study for guidance. I established inter-rater reliability (IRR) with an external rater using 20% of the data (763 turns, global Cohen's kappa = .964). Table E1 in Appendix E shows Cohen's kappa values for each code in the scheme.

Table 12

Coding Scheme for Affordances of Material Scaffolds

Code	**Description**	**Examples**
Supporting joint activity	Scaffolders or learners refer to specific material scaffolds in their talk or gestures, as part of their conversation.	Parent: [holds up item] What about a pizza box? Child: [points to recycling] Parent: Okay. Maybe we want... Do you think we want to start - What color do you wanna start with on the bottom?
Accessing information	Scaffolders or learners refer to information provided by specific material scaffolds.	Facilitator: I didn't talk about greens and browns yet but the idea is that you go to the material information. [opens Materials Information] Greens are lots of things that are fresh, have lots of moisture in them. What can you think of maybe... So you mentioned the coffee grounds, right, you said "you can compost this", so that's a good example.
Accessing feedback	Scaffolders or learners refer to feedback provided by specific material scaffolds.	Facilitator: For a really good compost, it's going to decompose quickly, it's not gonna smell too stinky. [points to Output] That's a big problem with a lot of them. Parent: [points to Output] It's still slow!

I then coded the remaining data (*N* = 3701 turns of talk) and calculated the frequency of each code. I sub-divided the frequencies of each code into three family types as described in my second dissertation paper. *No Peer* families included only one child, and thus parents, but not peers, provided scaffolding. *Peer Present* families included at least two children, with at least one child taking on the role of scaffolder of their initiative. Thus, both parents and peers provided scaffolding. *Only Peer* families also included multiple children, with at least one child acting as a peer scaffolder. However, parents in these families did not provide scaffolding. I calculated the frequency and proportion of each code for the three family types, then created charts of these findings.

Association analysis. I used association analysis to identify co-occurrences of support from social and material scaffolds in visitors' turns of talk. Association analysis uses several measures to identify associations among variables (Tan, Steinbach, Karpatne, & Kumar, 2019). To discuss these measures, I use Code A and Code B as examples of codes that might co-occur within turns of talk. The *support* for Code A is calculated by dividing the frequency of Code A by the total number of turns of talk (*N* = 3701 turns). Support can be used to find frequent co-occurrences of codes. *Confidence* calculates the frequency of co-occurrences as an association rule. If we use the association rule of {Code A, Code B} as an example, the confidence of this rule would be calculated as the number of turns in which Code A and Code B co-occur, divided by the frequency of turns in which Code A occurs. I used both support and confidence to identify co-occurrences of codes in turns of talk.

I used a broad code of *Scaffolding* to describe the kinds of support provided by social scaffolds (see Table F1 in Appendix F) for two reasons. First, families primarily provided scaffolding by reducing degrees of freedom. Thus, associations between social and material support would likely involve reducing degrees of freedom, making a more nuanced approach less helpful. Second, association analysis is sensitive to the frequency of each code, and thus sub-dividing families' scaffolding into the specific kinds of support might miss associations between social and material scaffolds. I repeated this process for the two micro-codes for demonstrating need for support (*Not Understanding* and *Help-Seeking*), as one *Need for Support* code. I also repeated this process for the two micro-codes for demonstrating learning (*Identifying and Describing* and *Interpreting and Applying*), as one *Learning* code. I applied these codes to each turn of talk.

I set up the association analysis using *Orange3*, an open-source machine learning tool (Demsar et al., 2013). The default setting for association analysis is the *apriori* algorithm, which assumes that if the association rule {Code A, Code B} is frequent, then {Code A, Code B, Code C} is also frequent (Tan et al., 2019). I identified frequent co-occurrences of codes with at least 1.0% support. I also identified association rules with at least 1.0% support at four confidence levels: 10%, 15%, 25%, and 50%. I compared the results of these analyses to understand what kind of interactions between social and/or material scaffolds occurred more frequently.

Social network analysis. In this study, I also aimed to visualize how support was distributed across social and material scaffolds in the exhibit. Social network analysis (SNA) is a methodology for analyzing relationships among entities in an interdependent network (Wasserman & Faust, 1994). SNA tools can visualize relationships among entities in the network, shown as sociograms, and reveal patterns within these sociograms (Wasserman & Faust, 1994). Sociograms show entities as *nodes* and the relationships between them as *edges*. SNA tools can also calculate the centrality of entities within the network using a variety of measures (Wasserman & Faust, 1994; Dekker, 2005). Degree centrality indicates the number of connections for each entity. Betweenness centrality indicates if a particular entity acts as a "bridge" between other entities. Also, eigenvector centrality indicates the influence of entities based on the centrality of other connected entities.

In this study, I used SNA to visualize the distribution of support among social and material scaffolds in the exhibit. As described earlier, I noted the scaffolds involved in providing support in the transcripts of visitors' talk. I then reduced this data to a sequence of support listing the social and material scaffolds involved in providing support for each turn. I created adjacency pairs to show how support shifted from one scaffold to the next in the exhibit (e.g., Facilitator → Simulation Output). I imported the adjacency pairs into Gephi (Bastian, Heymann, & Jacomy, 2009), a social network analysis tool, and created a sociogram showing distributed support in the exhibit. I also used the *NetworkX* package in Python to calculate degree centrality, betweenness centrality, and eigenvector centrality for the social and material scaffolds in the exhibit. I then compared the centrality measures of the social and material scaffolds in the exhibit.

4.6 Findings

The goals of this study were to identify how material scaffolds afforded joint activity, access to information, and access to feedback in relation to social scaffolding in the exhibit; to reveal interactions between social and material scaffolds; and to show distribution of support among social and material scaffolds. I report findings from the three methods in this section.

4.6.1 Affordances of Material Scaffolds

Using sociocultural discourse analysis, I looked for evidence of the affordances described in Table 12, which reflected the social and symbolic affordances of the material scaffolds. Figure 11 shows the frequencies of these affordances as represented in the interactions between visitors and material scaffolds. Figure 12 shows these frequencies as proportions of observed affordances for the three family types.

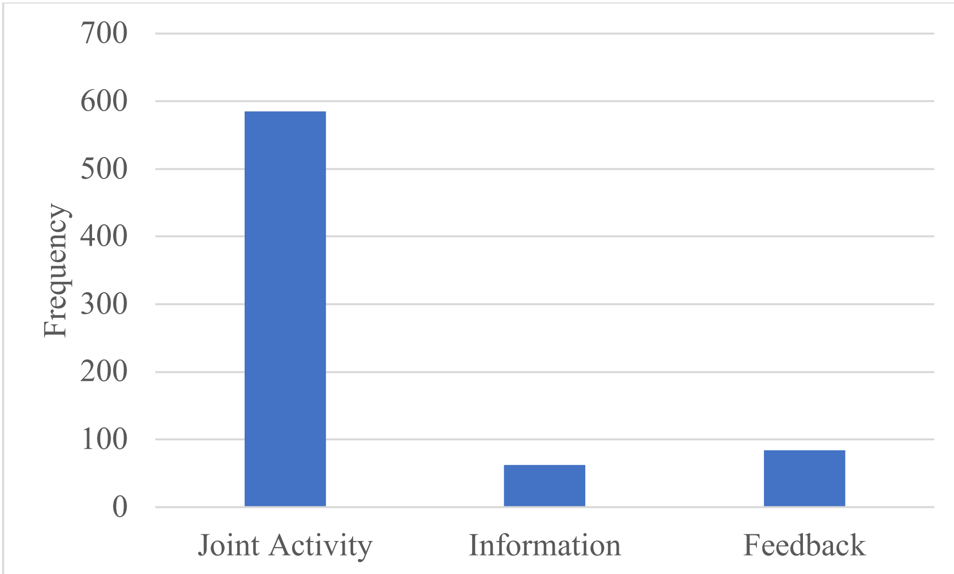

Figure 11. Total frequencies of affordances, as demonstrated in interactions between visitors and material scaffolds. These affordances reflect categories of social and symbolic affordances of the individual material scaffolds in the exhibit.

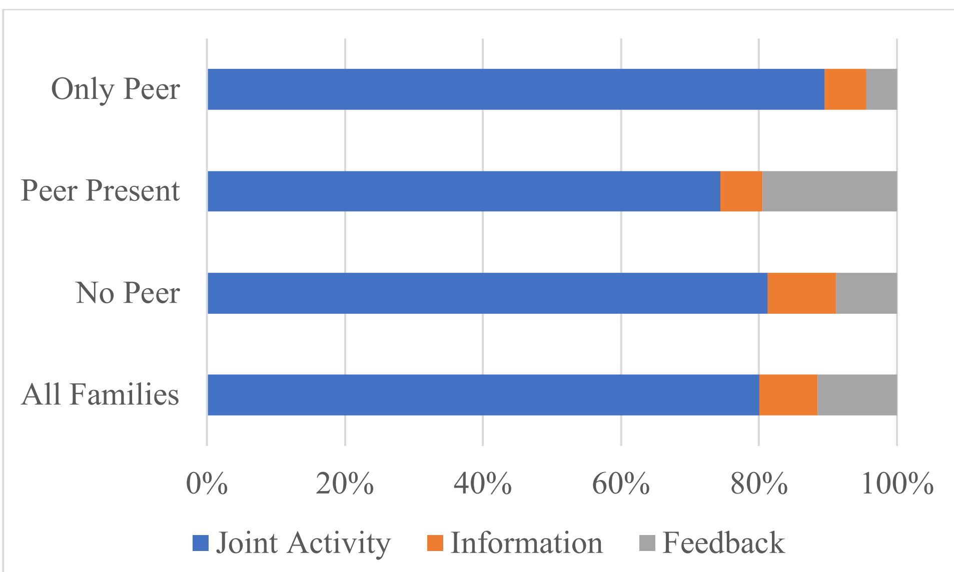

Figure 12. Proportions of each affordance, as demonstrated in interactions between visitors and material scaffolds.

Figures 11 and 12 indicated that joint activity was the most commonly observed affordance in visitors' interactions with material scaffolds. Joint activity was indicated as references to material scaffolds in visitors' discourse combined with gestures indicating bids for others' attention or instances of holding material scaffolds for others' reference. For example, Table 13 shows a brief excerpt in which a mother held up an item for her daughter to sort as a shared activity. This action helped focus the daughter's attention on one sorting item at a time, thus reducing the degrees of freedom in the task. Table 14 also shows examples of peers using material scaffolds to support their joint activity with the simulation. In Table 14, an older teen supported a younger teen's decision-making about materials. The older teen pointed to the 0.1-liter graduated markings on the virtual compost bin as she provided verbal support. Combining the social and symbolic affordances of the simulation with the older teen's verbal scaffolding allowed the younger teen to decide on the amounts of each brown material in the simulation. For clarity, I chose to include micro-codes indicating demonstrated need for support and kinds of support, but not learning, in addition to the codes in Table 1 to identify interactions between social and material scaffolds.

Table 13

Example of Joint Activity in the Sorting Activity

Speaker	Transcribed Talk and Actions	Code
Mother:	[holds up item] Meat.	Joint Activity Reducing DOF
Daughter:	[starts to point to bin but stops]	Not Understanding
Mother:	[holds item over compost bin] Here, I think. I don't really know but I'm going with it. [places item in compost]	Not Understanding

Table 14

Example of Joint Activity in the Simulation Activity

Speaker	Transcribed Talk and Actions	Code
Younger Teen:	[selects Brown 1 from Materials drop-down menu] Now, Brown 1 I'm going to fill it…[starts to add Brown 1]	
Older Teen:	Okay, so think - [points to screen]	Reducing DOF Joint Activity Information
Younger Teen:	...up three notches. Then it would be [points to notches on beaker] one, two, three, and then, oh, no, no, no. [holds hand to head]	Joint Activity Information
Older Teen:	You should maybe empty again half way and [points to increments on bin] we'll count how many there are and then you can proportion them that way.	Reducing DOF Marking Critical Features Joint Activity Information
Younger Teen:	[presses Reset button]	
Older Teen:	Okay so think. [points to increments on bin]	Reducing DOF Joint Activity Information
Younger Teen:	So there's going to be half. [points to increments on bin]	Joint Activity Information
Older Teen:	There is one, two, three, four, five. [points to increments on bin]	Reducing DOF Joint Activity Information
Younger Teen:	One, two. Okay so I want to do maybe two, wait, [points to	Joint Activity

	increments on bin] one, two, then one, two. Wait, if we do one, two, three, and then oh no. Dang it. [holds hand to head]	Information Not Understanding
Older Teen:	So, we have five rows, right?	Reducing DOF
Younger Teen:	Yes.	
Older Teen:	So Brown 1 is the easiest. So how many of these [lines] do you want to be Brown 1?	Reducing DOF
Younger Teen:	Maybe three, and then we'll do Brown 2 one, and then do Brown 3 one.	
Older Teen:	Sure. Or you could do two and then you could do two and then one. Whatever you think, either way, but I liked the way that you break that down.	Reducing DOF

The example in Table 14 also demonstrates how families accessed information provided by the material scaffolds. The older teen pointed out the 0.1-liter markings on the virtual compost bin to enhance her scaffolding of the younger teen. Table 15 also demonstrates how family members incorporated information provided by material scaffolds into their verbal scaffolding. Here, a father used the real-life models to help his son notice the differences in green and brown materials and recall a suggestion from the facilitator. The father used the material scaffolds to support their activity and recall information from earlier in their interaction, which was used to make decisions in the simulation.

Table 15

Excerpt Showing How Material Scaffolds Support Joint Activity and Add Information

Speaker	Transcribed Talk and Actions	Codes
Father:	What if you do more than two layers? So, put some brown in. Okay. Now what one could you put on top? Do you remember what she said you could mix together?	
Young Boy:	[hovers cursor over Brown 2] Yes.	
Facilitator:	[holds out greens and browns bags]	Joint Activity Information
Father:	[points to greens and browns bags]	Joint Activity Information
Father:	So, look, do you remember? You've got the brown in there [points to shredded paper bag]. What do you need to add now? [points to greens bag]	Joint Activity Information
Young Boy:	Green.	
Father:	Okay, so maybe add some green.	

The excerpt in Table 16 shows how peers used the material scaffolds to support their shared activity and discuss feedback about their simulated compost bins. Here, an older brother and younger sister (almost the same age) attempted to simulate multiple compost bins. After deciding to simulate a compost bin using only green materials, the brother used the Simulation Output to access feedback about the compost bin. To add to this feedback, the facilitator used a real-life model of decomposing flowers to show the features of an all-green compost bin.

Table 16

Excerpt Showing How Material Scaffolds Support Joint Activity and Add Feedback

Speaker	Transcribed Talk and Actions	Codes
Brother:	[selects Green] Let's try doing all green, too, and see what happens.	
Sister:	Okay. All green then. But then it will smell pretty bad, I think. Oh no. Better cover your nose.	
Brother:	[fills bin with Green] [presses Simulate button]	
Brother:	[reading from Output] Slow still?!	Joint Activity Feedback
Facilitator:	So this is actually an example, of all green. [points to compost model] These are flowers; they have been breaking down for about two months. And, if I were to open it, it would smell really bad so that's why there is tape on it.	Joint Activity Feedback
Sister:	Yes. Thank you. [laughs]	
Brother:	Please don't open it. Please don't. Nope.	

In summary, the sociocultural discourse analysis revealed that material scaffolds in the exhibit afforded social interaction among family members on a near-ongoing basis. While this is not surprising given the social nature of museum learning (Falk & Dierking, 2000), it reinforces prior design recommendations to consider how multiple visitors might interact in the same exhibit (Borun, 2008). Exhibits with inadequate space for multiple visitors can constrain opportunities for visitors to support each other's learning (Borun, 2008; Hornecker & Stifter, 2006). Compared to joint activity, material scaffolds afforded access to information and feedback less frequently (see Figure 11). Rather, material scaffolds seemed to afford access to information and/or feedback at key moments in families' scaffolding. I next used association analysis to find repeated instances of combined social and material support that would reveal key moments when material scaffolds provided information and feedback.

Association analysis identifies relatively frequent co-occurrences within data. I used association analysis to identify co-occurrences of support provided by social and material scaffolds, thus showing interactions between them. Table 17 shows the most frequent co-occurrences of codes within turns of talk, along with their support (i.e., how often they co-occurred within turns of talk). I chose a minimum support of 1.0% in these analyses, meaning that these co-occurrences were observed in at least 370 turns of talk.

Table 17

Frequent Co-Occurrences of Codes Within Turns of Talk

Frequently Co-Occurring Codes	**Support %**
Facilitator (Scaffolding) + Sorting Item (Joint Activity)	2.007
Simulation Output (Joint Activity) + Simulation Output (Feedback)	1.704
Parent (Scaffolding) + Parent (Learning)	1.237
Child (Need for Support) + Sorting Item (Joint Activity)	1.154
Facilitator (Scaffolding) + Real-Life Model (Joint Activity)	1.154

Four of the five most frequent co-occurrences indicated joint activity, echoing the findings from the discourse analysis. Two of these co-occurrences showed that sorting items were frequently used to support joint activity. Sorting items could be used to demonstrate need for support and provide support. For example, a child might ask about a particular item. In response, the facilitator might identify the item and prompt the child to sort the item in the same turn:

> Boy: What is this? [holds up image of meat]
>
> Facilitator: What about meat? What do you think?

Also, as demonstrated in Table 16, the facilitator frequently incorporated the real-life models into verbal scaffolding. The real-life models served as a focal point of discussion, thus supporting joint activity between participants.

As a material scaffold, the Simulation Output frequently afforded joint activity and feedback in the same turn of talk. Table 16 shows an example in which the older brother referred to variables in the Simulation Output ("Slow still?!") as he discussed feedback with his sister and the facilitator. This feedback was used to make shared decisions in the next simulation. Even though only one participant could control the simulation at a time, the Simulation Output was visible to multiple participants, and thus could support joint activity and discussion of feedback. I also identified co-occurrences that occurred as association rules (i.e., with a certain amount of support and confidence). I chose a minimum of 1.0% support and identified association rules with four different levels of confidence (see Table 18). To interpret Table 18, association rules with 1.0% support and 50% confidence meet two conditions. First, the association rule occurs in at least 1.0% of turns. Second, of those turns, at least 50% include this particular rule. The association rules triangulated the findings in Table 17. Again, the sorting items afforded joint activity between children needing support and the facilitator. The facilitator also frequently incorporated the real-life models into her verbal support. Finally, the Simulation Output frequently afforded joint activity and feedback in the same turn of talk.

Table 18

Association Rules with Minimum 1.0% Support in Turns of Talk

Association Rules	**Minimum Confidence**
Simulation Output (Joint Activity) + Simulation Output (Feedback)	50%
Simulation Output (Feedback) + Simulation Output (Joint Activity)	50%
Parent (Learning) + Parent (Scaffolding)	50%
Real-Life Model (Joint Activity) + Facilitator (Scaffolding)	50%
Sorting Item (Joint Activity) + Facilitator (Scaffolding)	25%
Sorting Item (Joint Activity) + Child (Need for Support)	15%
Child (Need for Support) + Sorting Item (Joint Activity)	10%
Parent (Scaffolding) + Parent (Learning)	10%

Taken together, the sociocultural discourse analysis and association analysis showed specific ways in which material scaffolds afforded joint activity, access to information, and access to feedback. Material scaffolds seemed to afford joint activity among participants on a near-ongoing basis, based on the frequency of interactions indicating joint activity. Also, material scaffolds seemed to afford access to information and feedback at key moments in participants' activities, especially activities in the simulation.

These analyses showed how the affordances of the material scaffolds encouraged social interaction among participants. The discourse analysis and association analysis revealed how and when material scaffolds afforded joint activity, access to information, and access to feedback as people acted as social scaffolds. The affordances of material scaffolds enhanced scaffolding provided by participants by adding visuals, information, or feedback to clarify or reinforce verbal support. For example, parents could use the greens and browns bags to provide hints to children selecting materials in the simulation (see Table 15). I used this data to identity themes in interactions between social and material scaffolds, which I describe in the next section.

4.6.2 Interactions Between Social and Material Scaffolds

Distributed scaffolding leverages both social and material scaffolds, and thus interactions between different scaffolds are not surprising. Analyzing these interactions, however, can help us understand how certain combinations of scaffolds may be more productive for learning in an exhibit context (Tabak, 2004). In particular, the emphasis on activities (e.g., sorting and simulating) might encourage interactions between social and material scaffolds, as this shifts the focus of the exhibit from "What am I seeing?" to "What am I doing?" (Allen, 2004).

To understand interactions between social and material scaffolds in the exhibit, I compared the intended function of each scaffold with families' actual use in the exhibit. I then used these comparisons to triangulate findings form the discourse and association analyses and qualitatively identify interactions between social and material scaffolds.

Intended vs. actual use. Table 19 describes the intended support embedded in each material scaffold (indicated as "I") and families' actual use of each material scaffold (indicated as "A"). Cells with "IA" indicate that material scaffolds were used as intended, which was true in many cases. However, cells with "I" indicate that material scaffolds were not used to provided support as intended. For example, the Ideal Compost Guide was not used as expected, which I discuss in detail below. In contrast, cells with only "A" indicate that material scaffolds were used to provide support in unanticipated ways. For example, the sorting items and bins, along with the real-life models, were used to connect exhibit content to prior experiences. In these cases, the exhibit materials served as visual anchors that could stimulate recall of past experiences with sorting, thus reifying support provided by social scaffolds.

Table 19

Intended and Actual Use of Material Scaffolds for Providing Support

Material Scaffold	**Recruit interest**	**Maintain direction**	**Reduce DOF**	**Mark critical features**	**Manage frustra-tion**	**Demon-strate**	**Revoice**	**Connect**
Ideal Compost Guide	I		I	IA			A	
Sorting items/bins			IA	IA				A
Real-life models	IA			IA				A
Virtual compost bin	IA			IA				
Materials menu/ info			IA	IA				
Compost Mixture Data				IA	A			
Simulation output				IA			A	

Interactions between social scaffolds. Based on earlier pilot studies, I expected that the parents and the facilitator would interact with each other when providing support. In particular, I expected that parents and the facilitator might provide redundant support, which could add opportunities for learners to receive support (Tabak, 2004). I found that parents and the facilitator provided redundant support when they revoiced statements or questions. This revoicing helped focus children's attention on particular activities or re-tailored support so that it was easier for children to understand, especially when the facilitator mid-judged children's understanding. As parents were more familiar with their children's abilities, they could rectify errors in the facilitator's diagnoses.

Interactions with sorting items. I found that family members interacted with sorting items and bins in ways that were unexpected, namely by using images on the items and bins to connect to past sorting experiences. Parents used items to help children recall how they would sort items at home. For example, one father asked, "What do we do with bottles at home?" As another example, two parents used the sorting items to help a four-year-old girl identify food items that could be composted. I did not anticipate that families would make connections to these items when designing the exhibit, but I consider these connections to home and other contexts to be a positive outcome.

Also, the physical nature of the sorting items allowed children to pick up items and ask for help with sorting. This act drew the family's attention to particular items, which could be followed with appropriate support from other family members or the facilitator. Parents also held up items, but this was done to focus their children's attention on a particular item. This act encouraged children to identify an item and think about where it could be sorted.
Together, the physical affordances of the sorting items appeared to facilitate families' help-seeking and help-giving.

I also noted that two families identified color-based patterns in the sorting items. Each item was placed on colored cardstock so that a visible, colorful outline surrounded each item. The color outlines served as visual clues for sorting categories of items. Raw plant items were surrounded with green outlines, while processed plant items were surrounded with blue outlines. Several "tricky" items, such as a disposable coffee cup made of plastic and paper, were surrounded by yellow or red outlines. The color outlines were intended to help families identify similar items when sorting, which could lead to discussions of what can and cannot be composted. For example, the disposable coffee cup is difficult to sort because it is made of different materials that may be recycled or composted differently based on local facilities. Again, only two families noticed the color outlines, but these families did engage in conversations about the characteristics of compostable items. These families made comparisons between items in the same category and asked questions about unexpected similarities.

Interactions with the Ideal Compost Guide. To guide families' participation in activities, I designed an Ideal Compost Guide that included brief text instructions and a visual hint for the simulation. I expected that families would need support with understanding the purpose of each activity and ways to engage in problem-solving in each activity. The guide stated the goals of each activity and suggested problem-solving strategies. While this guide was intended to support families' understanding, I found that its text format was not appealing to families because it required parents to read, interpret, and adapt instructions for others–a difficult task (Allen, 2004). In response, I provided verbal instructions in place of the guide.

When providing instructions, I communicated culturally valued ways of interacting with the sorting items and the simulation (Tabak, 2004). For example, children could technically pick up sorting items and engage in imaginative play; however, parents discouraged children's playful interactions. Parents thus created expectations for children to interact with the exhibit in specific ways. As the facilitator, I also found myself demonstrating specific ways of interacting with the exhibit, especially the simulation. For example, I demonstrated how to systematically evaluate each variable in the simulation rather than use a trial-and-error approach. This helped provide explicit guidance for interacting with the simulation (Puntambekar & Kolodner, 2005), which was necessary as the simulation was new to all families and did not include instructions (Tabak, 2004). In general, I found myself providing substantial in-the-moment support so that families could successfully interact with each activity.

Interactions with the simulation. As the facilitator, I provided the majority of support that communicated how to problem-solve with the simulation. The simulation does not include instructions or timely hints; thus, I expected to help families understand the effects of their decisions and make changes based on these effects.

The simulation was originally designed as part of a middle-school science curriculum. Students received support from a paper-and-pencil tool that included instructions and hints for the simulation. The tool also prompted students to identify and explain patterns in their data. As a result, students could make informed changes with the simulation. In the exhibit, however, I provided instructions and hints in place of the paper-and-pencil tool. To successfully build an ideal compost bin, families needed to evaluate the simulation output, identify which variables were satisfactory and which were not, and make changes based on this information. This is a challenging process for families to engage in in a relatively short period of time.

Despite these challenges, families quickly and effectively made changes to their simulated compost bins when assisted by the facilitator (myself). When providing support, I read the simulation output aloud and remarked on its characteristics. I hinted at variables that would have positive effects on the simulation output (e.g., adding a small amount of brown material to an otherwise all-green compost). By reading and evaluating simulation output aloud, I demonstrated a strategy for problem-solving with the simulation. In particular, I helped families address the following questions: What did you observe? How did your compost compare to the "ideal" compost? What variables do you need to change? How can you change them? I found that parents and children began to read and evaluate the simulation output of their own initiative after my initial demonstration. Families' self-initiated evaluation is a positive outcome in itself, as it indicated that families became less other-regulated and more self-regulated when interacting with the simulation (Tabak, 2004).

The discourse and association analyses, in combination with qualitative analysis, helped me to identify how social and material scaffolds interacted in the exhibit. However, I wanted to gain a full picture of distributed support in the exhibit. Thus, I used social network analysis to visualize how support was provided by social and material scaffolds in the exhibit.

4.6.3 Distributed Support in the Exhibit

I used social network analysis to visualize how support was distributed among social and material scaffolds in the exhibit, as shown in Figure 13. The nodes represent social and material scaffolds in the exhibit, and the edges represent how support shifted from one scaffold to the next. The thicker edges extending from parents and the facilitator indicated the majority of support in the exhibit. Also, the thicker edges connecting parents and the facilitator to the sorting items re-emphasized how social scaffolds incorporated sorting items into verbal support.

The sociogram also shows how certain social and material scaffolds provided support less frequently in the exhibit. This is triangulated by calculations of centrality measures, as shown in Table 20. As described above, the Ideal Compost Guide was not used frequently as a material scaffold, as I decided to provide support in place of the guide. While I attempted to limit my support, I found that visitors were confused by instructions in the guide. This was especially true for families with pre-school age children. Thus, I increased my support so that families with young children could still successfully participate in the activities. Also, the Simulation Comments were not used frequently, reflecting the intended design for this exhibit. The wording of these comments referred to other parts of the curriculum for which this simulation was originally designed, which could confuse other users. Visitors were not encouraged to use this particular scaffold. Finally, children rarely provided scaffolding for adults, as discussed in my second dissertation paper. There, I described how a child in one family provided support for her mother as they discussed why oranges should not be put in compost. Occurring over five turns, and only in this family, child-to-adult scaffolding was very infrequent.

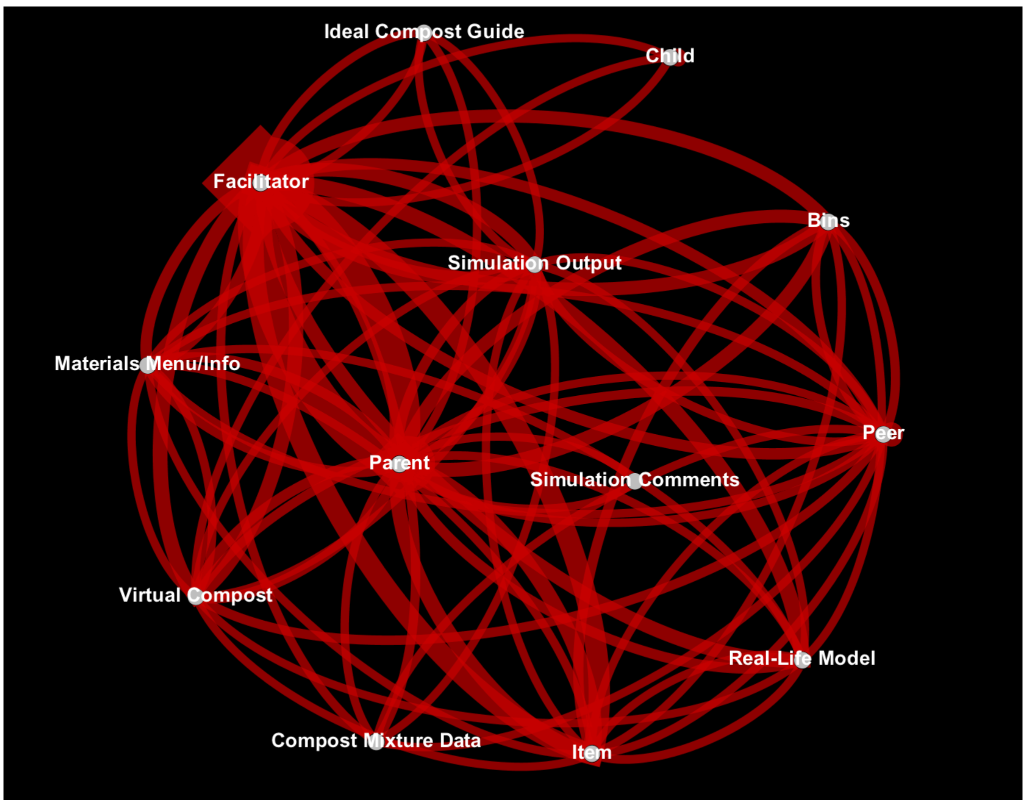

Figure 13. Sociogram of distributed support in the exhibit. Nodes represent social or material scaffolds in the exhibit, while edges indicate how scaffolding shifted from one node to another.

Table 20

Centrality Measures for Social and Material Scaffolds in the Network

Scaffold, Degree (Number)	**Scaffold, Betweenness (Bridge)**	**Scaffold, Eigenvector (Influence)**
Facilitator, 2.00	Facilitator, 0.270	Facilitator, 0.44
Parent, 1.83	Parent, 0.231	Parent, 0.43
Peer, 1.50	Simulation Output, 0.050	Peer, 0.37
Item, 1.17	Peer, 0.047	Virtual Compost Bin, 0.32
Simulation Output, 1.17	Virtual Compost Bin, 0.034	Simulation Output, 0.30
Virtual Compost Bin, 1.08	Item, 0.017	Item, 0.27
Materials Menu/Info, 1.00	Materials Menu/Info, 0.005	Real-Life Models, 0.26
Real-Life Models, 0.83	Real-Life Models, 0.003	Materials Menu/Info, 0.25
Bins, 0.75	Bins, 0.001	Bins, 0.21
Compost Mixture Data, 0.50	Compost Mixture Data, 0.000	Compost Mixture Data, 0.15
Ideal Compost Guide, 0.42	Ideal Compost Guide, 0.000	Child, 0.12
Child, 0.42	Child, 0.000	Ideal Compost Guide, 0.10
Simulation Comments, 0.17	Simulation Comments, 0.000	Simulation Comments, 0.06

The social network analysis triangulated findings from the discourse analysis and association analysis, showing that the sorting items were frequently incorporated into support provided by social scaffolds. The social network analysis also showed which social and material scaffolds provided relatively infrequent support. The Ideal Compost Guide was intended to be used with each family, but I found that the instructions were inadequate for families with younger children. Thus, I increased my support as the facilitator. The Simulation Comments were not intended to be used in the museum setting, and thus were rarely used as a material scaffold during visitors' interactions. Finally, children rarely provided support to adults. I interpret these findings in the discussion below.

4.7 Discussion

This study investigated the interactions between social and material scaffolds in an interactive, facilitated exhibit about compost. I examined how visitors' interactions with material scaffolds demonstrated affordances for supporting learning in museums (Yoon et al., 2018). Material scaffolds afforded social interaction between visitors on a regular basis, aligning with prior research about the social nature of museum learning (Falk & Dierking, 2000). Material scaffolds also afforded access to information and feedback at key moments in families' interactions. For example, while the Simulation Output was used primarily after simulating a compost bin, families incorporated this feedback in their joint decision-making about amounts of green and brown materials in the simulation. The social network analysis supported findings from the discourse analysis and association analysis, and also showed that the Ideal Compost Guide was used less often than expected. I discuss these findings below.

First, material scaffolds seemed to afford joint activity on a regular basis. This was especially true for items in the sorting activity, in which children used items for help-seeking, and the facilitator used items for help-giving. Table 13 shows a similar interaction, but with a parent providing support. One explanation for the sorting activity affording joint activity is its lower threshold for interaction, especially for younger children. Visitors of different ages could recognize the objects represented in the sorting items. In contrast, the simulation used more text and symbols, which are more abstract than the objects represented in the sorting activity (Goldstone & Son, 2005). Thus, the sorting activity seemed to afford social interaction and communication more readily than the simulation.

The frequency with which material scaffolds afforded joint activity recalls prior research about the importance of collaboration in exhibits (Allen, 2004; Falk et al., 2004; Yoon et al., 2013; Yoon et al., 2018). As with students, families also appeared to benefit from joint activity as afforded by material scaffolds (Yoon et al., 2018). To increase supportive interactions among family members, exhibit designers can consider how the design of materials and space in exhibits afford social interactions, such as scaffolding or collaboration (Borun, 2008; Gibson, 1986; Hornecker & Stifter, 2006). Future research can examine the qualities of families' joint activity for evidence of collaboration (Dillenbourg, 1999) or one-way mediation (Stone, 1998b) in this exhibit.

The analyses showed that material scaffolds afforded access to information and feedback less frequently, but the ways in which they were incorporated into social scaffolding indicated that material scaffolds were used at key moments in families' interactions. For example, the Simulation Output was only visible after completing the simulation, but it helped visitors to discuss feedback and adjust the balance of green and brown materials in their simulated compost bins. Also, when providing support, the facilitator could read feedback from the Simulation Output rather than memorize sets of compost qualities for different carbon-nitrogen ratios. Tabak (2004) described how the combination of complementary scaffolds provided greater support than each scaffold on its own. While the study described in this paper did not compare different combinations of scaffolds (e.g., Yoon et al., 2018), it indicated that material scaffolds could be used to complement support from social scaffolds in the exhibit. Items could be passed from one person to another in the sorting activity, indicating physical and social affordances (Gibson, 1986; Greeno, 1994). Data displayed in the simulation could be read and discussed by multiple visitors, indicating symbolic affordances (Gibson, 1986; Greeno, 1994). The transcript excerpts illustrated how certain material scaffolds enhanced support provided in visitors' discourse, thus interacting with social scaffolds in complementary ways.

The social network analysis revealed that the facilitator played a major role in providing support in the exhibit. This finding reflects shortcomings in the design of the distributed scaffolds, which I discuss below, as well as the ability of the human facilitator to provide adaptive support (Ge & Land, 2004). This finding echoes classroom-based research that emphasizes the need to include scaffolds that can provide individualized, responsive support, such as a teacher. Saye and Brush (2002), Belland and colleagues (2015), and Ge and Land (2004) designed curricula that included material scaffolds to support learning and offload responsibilities for support from the teacher. However, in all three studies, the authors expected teachers to respond to students' needs when material scaffolds were inadequate. Ge and Land (2004) found that teachers successfully met this requirement when needed, but Saye and Brush (2002) and Belland and colleagues (2015) found that teachers struggled to provide responsive support. In connection with these findings, future research is warranted about the kinds of exhibit activities that require human scaffolding, versus scaffolding embedded in materials. Many museum exhibits are not facilitated, which creates a demand for exhibit designers to anticipate the needs of diverse visitors (Davis, Horn, & Sherin, 2013).

These analyses also identified shortcomings in the design of the distributed scaffolding in the exhibit. The Ideal Compost Guide was intended for families to guide their participation in the exhibit. However, many families included children who were of pre-school or elementary age. As written, the instructions would have required parents to first interpret the exhibit before guiding their children (Allen, 2004). In response to this shortcoming, I provided verbal instructions for families and, in some cases, reduced the number of acts required to complete the tasks. This allowed children as young as three- and four-years-old to complete the exhibit activities. Future designs could include layers of activities for children of different age groups, along with include clear instructions that reduce support from the facilitator (Ash, 2004b). Material scaffolds other than instructions could be re-designed so that they are "immediately apprehendable" (Allen, 2004). Future research could also investigate how support is distributed among social and material scaffolds with different facilitators (e.g., Puntambekar et al., 2007), or without facilitators.

This study contributes an example of complementary interactions between social and material scaffolds in a science museum exhibit. Yoon and colleagues (2018) previously studied how the affordances of distributed scaffolds supported middle-school students' learning. This study focused on the interactions between social and material scaffolds in families' visits to a science exhibit. Material scaffolds afforded joint activity on an ongoing basis, and also afforded access to information and feedback at pivotal points in families' learning. Future research can include case studies of these interactions to show how information and feedback provided by material scaffolds supports deeper learning.

This study also demonstrated how the design of distributed scaffolds may not work as intended, especially in museums where learners represent a wide range of ages and prior knowledge (Borun, 2008; Taylor & Neill, 2008). The Ideal Compost Guide was not suited for all age ranges, and the facilitator needed to respond with additional support to meet this shortcoming. In addition to the improvements stated above, this illustrates how the design of material scaffolds is paramount to effectively supporting visitors' interactions (Allen, 2004; Borun, 2008; Falk et al., 2004). Exhibits play a central role to affording social interactions between visitors, including supportive interactions between scaffolders and scaffoldees (Allen, 2004; Gutwill, 2008; Yoon et al., 2018;). Thus, exhibit designers can use a distributed scaffolding lens to design material scaffolds that promote social interactions and complement support provided by visitors, as social scaffolds.

This study was limited by its sample of 23 families, the majority of which indicated prior interest in or experience with compost. Future studies could include families who are less familiar with compost. These studies could also include other non-school groups, such as adult peers or couples (McManus, 1987). As discussed earlier, this study was limited by my participation as the facilitator. As stated in my second dissertation paper, I faced tensions between limiting my influence on families' participation (Block et al., 2015) and wanting families to have a positive experience (Adams et al., 2008; Yoon et al., 2012). Ultimately, I provided more support than expected. Future studies could investigate changes in how social and material scaffolds interact, based on the presence of different facilitators or no facilitators.

4.8 Conclusion

Distributed scaffolding can effectively support students' learning in classrooms (Puntambekar & Kolodner, 2005; Smagorinsky et al., 2015) and museums (Yoon et al., 2012; Yoon et al., 2013; Yoon et al., 2018). We have begun to understand how the affordances of distributed, material scaffolds shape students' social interactions in museums (Yoon et al., 2018). For example, text-based instructions can help students collaborate as they interpret exhibits (Yoon et al., 2018). However, we do not yet know how the affordances of distributed, material scaffolds shape families' social interactions in museums.

In response, I studied how the affordances of material scaffolds in a pop-up exhibit about compost interacted with social scaffolding provided by members of 23 families and a facilitator (myself, as a participant-observer). I found that material scaffolds that afforded joint activity were incorporated into social scaffolding on an ongoing basis, reflecting the social nature of museum learning (Falk & Dierking, 2000). However, material scaffolds that afforded access to information and feedback were incorporated at key moments in social scaffolding. For example, while family members referred to Simulation Output only after completing the simulation, this feedback was used to support families' joint decision-making about variables in the simulation. This study demonstrated how material scaffolds can complement support provided by social scaffolds in an interactive, facilitated science exhibit. This study also demonstrated how inadequate support from material scaffolds in exhibits required additional, responsive support from other social scaffolds, echoing design issues demonstrated in prior research about social and material scaffolds in classrooms (Belland et al., 2015; Ge & Land, 2004; Saye & Brush, 2002). Future studies can use case studies to analyze these interactions in finer detail and examine their impact on the depth of families' learning.

5. Conclusion

Much of museum learning is social in nature (Falk & Dierking, 2000), which creates opportunities for exhibits to foster supportive meaning-making among visitors (Allen, 2004; Mai & Ash, 2012; Zimmerman, Reeve, & Bell, 2008). However, there is relatively little research that specifically investigates how visitors provide *scaffolding*, as a distinct notion for support. Scaffolding describes support that is tailored to the learner's understanding, as diagnosed by the person providing scaffolding, or *scaffolder* (Granott, 2005; Koole & Elbers, 2014; Palincsar, 1998). As the learner, or *scaffoldee*, demonstrates greater understanding, scaffolding can be faded, or gradually reduced (Granott, 2005; Pea, 2004). While there are many studies that investigate how people support others' learning in exhibits, only 15 articles include the terms "museum" and "scaffolding" or "scaffold" in their titles, subjects, keywords, or abstracts, as indicated by a search of EBSCOhost Education Research Complete in Oct. 2018.

Further, there is an issue of semantics regarding research about museum-based scaffolding. These semantics were a focal point in past debates over the usefulness of scaffolding as a distinct notion of support (Palincsar, 1998; Pea, 2004; Stone, 1998a). Palincsar (1998) concluded that atheoretical use of scaffolding blurred the boundaries of scaffolding (Palincsar, 1998). This issue is also connected to critique about expansions of scaffolding that describe not only the process of scaffolding, but entities that support this process (Pea, 2004; Stone, 1998b). For example, researchers have critiqued scaffolding that does not indicate adaptive responsiveness to learners' needs (Littleton, 2013; Puntambekar & Hübscher, 2005). In connection to museums, there is also critique of research that does not build upon learning theories when discussing visitors' interactions (Hammerness, Macpherson, & Gupta, 2016). While some studies do incorporate a learning science lens when investigating visitors' interactions (e.g., Ash, 2007), others do not (e.g., Yalowitz & Bronnenkant, 2008) or do so in a perfunctory way (Melber, 2007). Together, these issues about the discussion of scaffolding highlight the need to ground discussion of museum-based scaffolding in prior research (Palincsar, 1998).

To improve our understanding of museum-based scaffolding, we can also consider how exhibit materials provide support. *Distributed scaffolding* refers to support distributed across multiple educational resources (Puntambekar & Kolodner, 2005), including *social scaffolds* (e.g., visitors, staff) and *material scaffolds* (e.g., tools, technologies). Social and material scaffolds can interact in different ways, depending on how they meet learners' needs (Tabak, 2004). Combinations of scaffolds with complementary functions can be especially beneficial for supporting middle-school students' learning in exhibits (Yoon, Elinich, Wang, van Schooneveld, & Anderson, 2013). In particular, the affordances of material scaffolds influence how visitors interact with exhibits and each other (Gibson, 1986; Yoon, Anderson, Park, Elinich, & Lin, 2018). While we have begun to understand how distributed scaffolding supports students' learning in exhibits, we have yet to understand how distributed scaffolding supports families' learning in exhibits. In response to these issues, I investigated how family members provided scaffolding as they visited an interactive, facilitated pop-up exhibit about compost. I also investigated the interactions between social and material scaffolds in the exhibit.

5.1 Summary of Dissertation Studies

My dissertation first examined prior research about scaffolding and its evolution and prior research about supporting museum learning and exhibit design. I then investigated how family members participated in the process of scaffolding as social scaffolds. Finally, I analyzed how the material scaffolds in the exhibit interacted with and complemented support provided by social scaffolds. These aims are summarized by the following three sets of research questions:

1. Based on research about scaffolding and museum learning, what evidence do we have that visitors are scaffolding each other's learning, or that exhibits are scaffolding visitors' learning?
2. Concerning families' social scaffolding in the exhibit,
    a. How did family members demonstrate need for support?
    b. Who provided support?
    c. What kinds of support did family members provide?
    d. What kinds of learning did family members demonstrate?
3. Concerning the interactions between social and material scaffolds,
    a. How did exhibit materials afford joint activity, access to information, and access to feedback?
    b. How did family members acting as social scaffolds interact with material scaffolds in the exhibit?
    c. How was support distributed among social and material scaffolds in the exhibit?

I addressed the first question by reviewing prior research about scaffolding and museum learning, described in the first paper, "Supportive Interactions in Museums: The Intersection of Research About Scaffolding and Museum Learning." Here, I described the history and evolution of scaffolding as a metaphor for support. I also described how distributed scaffolding reflected how social and material scaffolds, and the interactions between them, could play roles in supporting learning, using examples of social and material scaffolds in classrooms. I then evaluated prior research about scaffolding and learning in museums for examples of social and material scaffolds in exhibits. I also discussed how families, students, and museum staff could act as social scaffolds, along with studies of material scaffolds supporting visitors' learning. The interactions between visitors and exhibit materials can be supported with distributed scaffolding, and I described Yoon and colleagues' (2012; 2013; 2018) strand of research about designing distributed scaffolding to support middle-school students' learning. I also discussed how the design of material scaffolds and their affordances can influence visitors' physical, social, and communicative interactions within exhibits. I then highlighted key issues in designing exhibits and included several recommendations from prior research. This review contributes an entry point into a more holistic understanding of scaffolding across classrooms and museums, as contextualized in prior research and history of the scaffolding metaphor. Future research can investigate which characteristics of scaffolding are situated in museum or classroom contexts, and which characteristics might generalize across contexts.

I addressed the second set of questions in a research study about social scaffolding in exhibits, described in the second paper, "Investigating Social Scaffolding in Families Visiting a Science Museum Exhibit." This study built upon the review by applying prior findings about scaffolding–namely, ways in which people can provide support–to describe visitors' supportive talk in an interactive, facilitated science exhibit. Using sociocultural discourse analysis, I developed a coding scheme based on scaffolding research in tutoring, classroom, and museum contexts to analyze data of 23 families' interactions with the exhibit. I focused on how families participated in the process of scaffolding as social scaffolds. I found that both parents and children took on dual roles as scaffolder and scaffoldee (Granott, 2005). Parents provided support to their children, echoing findings from prior research (e.g., Puchner, Rapoport, & Gaskins, 2001; Wolf & Wood, 2012). Also, some children provided support to other children when they were present. This evidence of peer scaffolding reflected research conducted in museums (Mai & Ash, 2012) and in classrooms regarding the ways in which peers provide support (e.g., Fernández, Wegerif, Mercer, & Rojas-Drummond, 2001). Peers' participation in dialogue helped others to make decisions in the exhibit (e.g., Brown et al., 1993). Peers also modeled support provided by parents, echoing Guk and Kellogg's (2007) classroom-based study. Family members' adoption of dual roles as scaffolder and scaffoldee also showed distribution of support across multiple social scaffolds, including children. This study contributed a deeper understanding of the process of scaffolding among family members and extends foundational research about scaffolding to an informal learning context with complex activities.

I addressed the third set of questions in a research study about distributed scaffolding in exhibits, described in the third paper, "Investigating Interactions Between Social and Material Scaffolds in a Pop-Up Science Exhibit." This study built upon the prior study by considering how material scaffolds played a role in providing support. Using the same data set, I analyzed how the affordances of material scaffolds encouraged social interactions between family members and enhanced support provided by family members acting as social scaffolds. I also used social network analysis to visualize the distribution of support in the exhibit. I found that material scaffolds afforded joint activity on a regular basis, aligning with prior research emphasizing the social nature of museum learning (Falk & Dierking, 2000). Also, material scaffolds afforded access to information and feedback at key moments in visitors' activities, such as when they made shared decisions about the next trial in the simulation. Material scaffolds could complement support provided by social scaffolds, such as when real-world examples of compostable materials reified support from the facilitator. Also, social scaffolds could respond to inadequacies in material scaffolds, such as when instructions were unclear. Taken together, this study contributed insights about the design of distributed scaffolding, as it showed how material scaffolds could complement support provided by family members as they interacted with a science exhibit. This study also showed how inadequate design of material scaffolds can result in a need for additional support from responsive social scaffolds. This echoes prior research about the design of school curricula and environments in which teachers were expected to provide support. Some teachers successfully addressed issues with the design of other scaffolds (e.g., Ge & Land, 2004), but other teachers struggled to provide responsive support when material scaffolds came up short (Belland, Gu, Armbrust, & Cook, 2015; Saye & Brush, 2002). In this study, the shortcomings of certain material scaffolds required greater responsive support from the facilitator. This finding reveals a common issue in designing distributed scaffolding to support learners. Yet, this finding also reveals that exhibit designers must address challenges in accommodating a wide range of ages, as represented by museum visitors, in their design of material scaffolds.

5.2 Contributions of the Dissertation

These studies contributed to the learning sciences by enhancing our understanding of scaffolding as it takes place in a science exhibit. First, the literature review bridged two bodies of research to identify how scaffolding might apply to museum contexts while preserving its essential characteristics, as described in learning sciences research. The literature review also revealed a gap in our understanding of how families participate in scaffolding, and especially distributed scaffolding, when interacting with science exhibits.

The study about families' social scaffolding showed how family members participated as scaffolders and scaffoldees when providing support in the exhibit (Granott, 2005). Peers' support of other children in exhibits is interesting in light of classroom-based research about students' support of other students (e.g., Brown et al., 1993; Fernández et al., 2001; Guk & Kellogg, 2007). Peers participated in dialogue as they interacted with the exhibit, and some peers began to provide support in this dialogue, such as by making suggestions or noting conceptual details. Together, peers could help each other to accomplish more than they could on their own. This observation echoes prior research showing how children can take on teaching roles in exhibits, thus shifting power and authority within families so that learning is more symmetrical (Mai &

Ash, 2012). Future research can investigate what motivates peers to provide scaffolding during interactions with exhibits so that exhibits can be designed to promote peer scaffolding in families' dialogue. Also, future research can investigate how parents and facilitators co-mediate children's learning, as the presence of multiple adults scaffolding individual children changes the context of traditional scaffolding yet again.

The study about distributed scaffolding in the exhibit contributes to our understanding of how distributed material scaffolds support families' learning in a science exhibit. While the material scaffolds in the exhibit were designed to support visitors in specific ways, the intended design did not always match reality. The positive outcome of this design was that material scaffolds afforded joint interaction on a regular basis, thus promoting support among social scaffolds in the exhibit. The material scaffolds also afforded access to information and feedback at key moments in activities, such as decision-making in the simulation. Taken together, the material scaffolds seemed to complement support provided by family members and the facilitator.

Despite the positive findings about the complementary interactions between scaffolds, I also observed that the design of distributed scaffolding in this exhibit came up short. Mainly, the exhibit instructions did not meet the needs of families with younger children. As a result, the intended purpose of the exhibit activities was not immediately obvious to visitors (Allen, 2004). As a result, the facilitator needed to provide additional support, especially when children could not read text or easily interpret symbols in the simulation. Overall, this study showed how material scaffolds could complement support from social scaffolds, but also require more support from social scaffolds due to shortcomings in design. Thus, social scaffolds might compensate for the inadequate design of material scaffolds (Martin, Dornfeld, Gnesdilow, & Puntambekar, 2018). This shows how the design of exhibits is paramount to affording certain kinds of social interactions, including scaffolding. Future research could investigate how material scaffolds could be re-designed to address the needs of younger children, such as by using more pictorial objects in the simulation. This research could also include feedback in the sorting activity to offload this responsibility from the facilitator. Finally, future research can investigate how family members interact with material scaffolds in less interactive and/or non-facilitated exhibits.

5.3 Limitations of the Dissertation

This study was limited by its sample size of 23 families, of which 17 indicated prior interest in or experience with compost. Replications of this study could include a more representative sample by actively recruiting families who are new to compost. Future studies could also study how these findings apply to adult groups, such as friends or couples.

The study was also limited by my participation as the facilitator. As a participant-observer in this exhibit (Allen & Crowley, 2014), I had two goals: to limit my influence on families' interactions, and to ensure that visitors had a positive experience. In response to the shortcomings of the exhibit design, I erred on the side of visitors having a positive experience (Adams et al., 2008; Taylor & Neill, 2008). Visitors seemed to stay longer than average as a result (Block et al., 2015; Serrell, 1997). Also, while my participation as the facilitator influenced families' interactions, I could directly observe how families provided support. This firsthand lens was useful when evaluating the design of this exhibit. Future research will replicate studies with different facilitators, along with non-facilitated exhibits, to compare how findings change in relation to these factors.

5.4 Final Thoughts

The studies in this dissertation contribute to our understanding of how families provide scaffolding in science exhibits. These studies also contribute to our understanding of how social and material scaffolds interact in exhibits that include distributed scaffolding in their design. The practical implications of this study concern how we design material scaffolds to complement support provided by social scaffolds in exhibits while meeting the needs of visitors of different ages. Future research can expand these findings to exhibits that are less interactive or self-guided and to non-family groups. Future research can also use a systematic approach to identify how different combinations of social and material scaffolds benefit families' learning in the exhibit. This study advances our understanding of scaffolding as a metaphor for support in museums and demonstrates a complementary relationship between social and material scaffolds in a science exhibit.

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Appendix A

Table A1

Search Results for EBSCOhost Education Research Complete (Oct. 17, 2018)

Search Terms	**Journal Article Citation**
Museum AND scaffolding	Andre, L., Durksen, T., & Volman, M. L. (2017). Museums as avenues of learning for children: A decade of research. *Learning Environments Research*, *20*(1), 47-76.
	Bamberger, Y., & Tal, T. (2007). Learning in a personal context: Levels of choice in a free choice learning environment in science and natural history museums. *Science Education*, *91*(1), 75-95.
	Eckhoff, A. (2008). The importance of art viewing experiences in early childhood visual arts: The exploration of a master art teacher's strategies for meaningful early arts experiences. *Early Childhood Education Journal*, *35*(5), 463-472.
	Erickson, M., & Ramson Hales, L. (2018). Increasing art understanding and inspiration through scaffolded inquiry. *Studies in Art Education*, *59*(2), 106-125.
	Knight, K., & Davies, R. S. (2016). Using a mobile dichotomous key iPad application as a scaffolding tool in a museum setting. *Interactive Learning Environments*, *24*(4), 814-828.
	Melber, L. M. (2007). Maternal scaffolding in two museum exhibition halls. *Curator: The Museum Journal*, *50*(3), 341-354.
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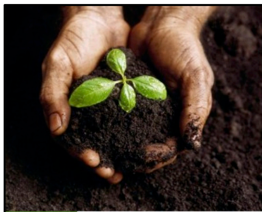
	Yoon, S. A., Elinich, K., Wang, J., Van Schooneveld, J. B., & Anderson, E. (2013). Scaffolding informal learning in science museums: How much is too much? *Science Education, 97*(6), 848-877.
Museum AND scaffold	Bowler, L., & Champagne, R. (2016). Mindful makers: Question prompts to help guide young peoples' critical technical practices in maker spaces in

	libraries, museums, and community-based youth organizations. *Library & Information Science Research*, *38*(2), 117-124.
	Marty, P. F., Mendenhall, A., Douglas, I., Southerland, S. A., Sampson, V., Kazmer, M. M., ... & Schellinger, J. (2013). The iterative design of a mobile learning application to support scientific inquiry. *Journal of Learning Design*, *6*(2), 41-66.
	Yoon, S. A., Elinich, K., Wang, J., Steinmeier, C., & Tucker, S. (2012). Using augmented reality and knowledge-building scaffolds to improve learning in a science museum. *International Journal of Computer-Supported Collaborative Learning*, *7*(4), 519-541.

Appendix B



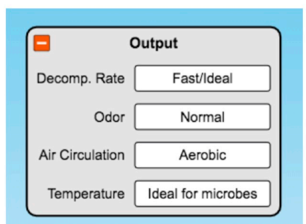
Design a "Perfect" Compost

Do you already compost? Never heard of it?
We want to know what *you* know about compost.

Try completing these challenges:

1. **Get Sorted** - Sort the materials on the board. It's okay to guess, and feel free to work as a team.

2. **Design a Compost** – Try out different combinations of **green** and **brown** materials to make a virtual compost. **Hint**: A good compost has these qualities:



3. **Sort Again!** – Sort the materials again. What would you change? What would you keep the same?

All done? Try answering these questions out loud:

- How does composting reduce waste?
- What kinds of materials can you compost?
- What's one **green** material you use at home? What about a **brown** material?

Figure B1. The *Ideal Compost Guide* provides instructions for visitors to interact with the exhibit, especially the simulation.

Appendix C

Table C1

Facilitation Script for Pop-Up Compost Exhibit

Goal	Sample Questions/Responses
Identify visitors' agenda and/or motivation for their visit	What brings you to the museum today?
Assess prior knowledge during the initial sorting activity	So, what do you know about compost? I have some materials here that I need to throw out, and I'd like you to help me sort them into the correct containers. Can you help me? Where do you think this item goes? Can you tell me why you put *[certain item]* there *[into compost/trash/recycling*]?
Facilitate observations and learning with compost models	What do you notice about the real-life compost? What's an example of a green material? What's an example of a brown material?
Facilitate exploration of the green-brown ratio in the compost simulation	Would you like to try making your own compost? I have a simulation of a compost on this tablet/laptop. You can make as many as you'd like. You can pick what materials you want here [indicates Materials button]. Just shake the shaker to add materials. You can change the materials whenever you want. When the simulate button lights up, you can press it. *As visitors are working:* What are you adding to your compost? Why are you including [material]? *If visitors use a trial-and-error approach:* Here's an example of what a "perfect" compost looks like *[indicating Ideal Compost Guide]*. Do you think you can make the perfect compost?
Assess new knowledge during the final sorting activity	Now that you know about compost, would you like to show me how you'd sort the materials again? What goes where? Why?

	What about the brown paper bag? What do you think - does it go in recycling or compost?

Appendix D

Table D1

Interrater Agreement Statistics for the Coding Scheme

				Interpretation	
Category	Code	Percentage agreement	Cohen's kappa	Landis & Koch (1977)	McHugh (2012)
Demonstrated need for support	Not understanding	99.7	.955	Almost perfect	Almost perfect
	Help-seeking	99.5	.947	Almost perfect	Almost perfect
Kinds of support	Recruiting interest	99.9	.933	Almost perfect	Almost perfect
	Maintaining direction	100.0	1.000	Almost perfect	Almost perfect
	Reducing degrees of freedom	96.2	.871	Almost perfect	Strong
	Marking critical features	97.6	.887	Almost perfect	Strong
	Managing frustration	100.0	1.000	Almost perfect	Almost perfect
	Demonstrating	99.6	.907	Almost perfect	Almost perfect
	Revoicing	99.2	.896	Almost perfect	Strong
	Making connections	99.0	.745	Substantial	Moderate
Understanding and learning	Identifying and describing	98.3	.689	Substantial	Moderate

	Interpreting and applying	97.9	.903	Almost perfect	Almost perfect

Note. Cohen's kappa for all codes combined is .892 for 20% of the data (763 turns of talk).

Appendix E

Table E1

Interrater Agreement Statistics for the Coding Scheme

Category	Code	Percentage agreement	Cohen's kappa	Interpretation: Landis & Koch (1977)	Interpretation: McHugh (2012)
Incorporating material scaffolds	Supporting joint activity	98.8	.961	Almost perfect	Almost perfect
	Adding information	100.0	1.000	Almost perfect	Almost perfect
	Adding feedback	99.7	.888	Almost perfect	Strong

Note. Cohen's kappa for all codes combined is .964 for 20% of the data (763 turns of talk).

Appendix F

Table F1

Kinds of Support Provided in Families' Social Scaffolding in the Compost Exhibit

Code	**Description**	**Examples**
Recruiting interest (Wood et al., 1976)	The scaffolder recruits the visitor's interest in the overall activity and/or parts of the activity.	Facilitator: <u>Do you want to try the virtual compost?</u> Facilitator: <u>Based on what you learned, do you want to try sorting this again?</u> Parent: Sure. [to child] <u>Do you?</u> Child: Yeah.
Maintaining direction (Wood et al., 1976)	If the visitor becomes distracted or discusses unrelated ideas, the scaffolder brings the visitor's attention back to the activity and/or the goals of the activity.	Child: [selects Brown 2] Parent: <u>Okay. What are you thinking this is gonna do, honey?</u> Child: I have ribbons at home…they look just like that. Facilitator: Yeah, just like thin strips, right? <u>So what about this pizza box?</u>
Reducing degrees of freedom (Wood et al., 1976)	The scaffolder simplifies the task by reducing the number of acts needed to complete the activity, such as by: • Clarifying what items are • Suggesting an item to sort or a material to include in the simulation • Suggesting a particular amount or ratio of materials • Reducing available options for sorting or simulating • Focusing the learner's attention on one particular item or material	Parent: [holds up item] This looks like an egg? Facilitator: <u>It's the top of a burger.</u> Parent: <u>What about uncoated paper plates? So, garbage or recycle?</u> [holds up item] Child: [points to recycling] Parent: <u>Maybe put some greens in now.</u> Child: Yeah. [selects Green] Parent: <u>So I think we want browns, but we want mostly greens? So -</u>
Marking critical features (Wood et al., 1976)	The scaffolder marks relevant features of the task in order to help the learner notice and interpret discrepancies between what they are currently doing and how they should do the activity. These could include:	Parent: <u>I think that you can't reuse the chicken bone, right?</u> So probably trash. Parent: <u>Chopsticks are usually made of wood? And wood can be...</u> Child: Composted. Parent: <u>Don't forget about the blue, okay?</u> [referring to compost]

	• Asking what makes something compostable or recyclable • Remarking on relevant options in the activity • Using information to provide relevant content • Using feedback to guide learners' thinking	Facilitator: [points to Ideal Compost Guide] For a really good compost, it's going to decompose quickly, it's not gonna smell too stinky Facilitator: But it's decomposing kind of slowly. What do you think is something you might do to make it decompose faster?
Managing frustration (Wood et al., 1976)	The scaffolder helps the learner to work through acts beyond the visitor's ability, cognitively or procedurally, if the visitor becomes frustrated or "stuck."	Parent: She can't read yet. Facilitator: I can read it for her, that's okay. Child: I can't make it work. Facilitator: Don't forget to press down and wiggle.
Demonstrating (Wood et al., 1976)	Scaffolder models how to do the activity, or think about the activity, with the implicit goal of the learner imitating these actions.	Facilitator: So, to make a compost what you're gonna do is pick which material you want, so I'm clicking here. [opens Materials menu] Parent: What do you think? Child: Like…? Parent: Like if there was a glass container in here, we probably wouldn't put it in our compost.
Revoicing (Tabak & Baumgartner, 2004)	The scaffolder revoices the learner's statements to align with content of the task *or* ability of the learner. For example, the scaffolder: • Echoes the learner's statements • Echoes support from another scaffolder • Rephrases questions or statements from another scaffolder	Child: Right there. [points to recycling] Parent: Right there. [places item in recycling] Facilitator: We're gonna say it's plastic. Parent: It's plastic. Facilitator: It would probably take a long time. Parent: Take a long time. Facilitator: We've got some crab and animal bones. Parent: It's food.
Making connections (Mai & Ash, 2012)	The scaffolder encourages connections between activities in the exhibit and prior experiences, knowledge, or contexts encountered in the visitor's personal life.	Grandma: What about your garden? Do you think the compost would help flowers in your garden? Parent: Where do we put our bottles at home?