From Living to Virtual: Learning from Museum Objects

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CATHERINE EBERBACH AND KEVIN CROWLEY

abstract **Interactive museum exhibits have increasingly placed replicated and virtual objects alongside exhibited authentic objects. Yet little is known about how these three categories of objects impact learning. This study of family learning in a botanical garden specifically focuses on how 12 parent-child family units used explanations as they engaged with three plant types: living, modeled, and virtual. Family conversations were videotaped, transcribed, and coded. Findings suggested that: 1) explanations of biological processes were more frequent than other types; 2) model and virtual plants supported more process explanations that did the living plants; 3) the model plant supported more references to school than did the living and virtual plants; and 4) the living plant supported more references to everyday experiences than did the virtual plant.**

INTRODUCTION

Interactive exhibits are increasingly popular, and one result is that replicated and virtual objects are often exhibited in museums alongside authentic objects. In the Carnegie Museum of Natural History, in Pittsburgh, Pennsylvania, for instance, children can climb into a replicated Sauropod footprint while gazing up at authentic 165 million-year-old fossil mounts. At the New York Botanical Garden in the Bronx, New York, families can classify virtual plants on a computer while children and parents nearby sort and identify living plants. At the San Francisco Museum of Modern Art, original art works surround interactive digital discovery tables. Yet little is known about how visitor engagement with authentic, replicated, and virtual museum objects impacts visitor experience. This paper explores the nature of explanation as it occurs when parents and children interact with living, model, and virtual objects. It proposes extending the definition of "authentic" to include living collections.

Catherine Eberbach (cle4@pitt.edu) is a researcher at the Center for Learning in Out of School Environments (UPCLOSE) in the Learning Research and Development Center, University of Pittsburgh, 3939 O'Hara Street, Pittsburgh, PA 15260. Kevin Crowley (crowleyk@pitt.edu) is director of UPCLOSE and associate professor, LRDC, University of Pittsburgh.

Museum professionals have historically believed that authentic objects are important and that an object's uniqueness can speak to visitors in ways that a representation cannot (Gurian 1999; Roberts 1997; Weil 1995). These beliefs face challenges as museums move away from an object-based epistemology, in which it is assumed that the display of objects is sufficient to convey an object's inherent meaning; and toward an object-based discourse, in which meaning is conveyed through the integration of object, display, and visitor narrative (Evans, Mull and Poling 2002). In this new paradigm, an object's authenticity is less essential to learning in comparison to its potential to support visitor participation. Roberts argues this is not merely a problem of privileging authenticity over participation, but it is a problem of defining what real means and what it means to experience it (1997, 86):

> Still, one cannot wonder: would the moon rocks be any less authentic without the [interpretive signage]? Certainly not from the standpoint of the rocks. From the standpoint of the viewer, however, there may be some question. For the assurance of the rock's authenticity derives not from some innate "aura" but from the indication—the sign—that they indeed came from the moon. The experience of authenticity, in other words, is based less on an inherent quality than on a sign imposed from without (Roberts 1997, 100–101).

The most common usage of the term authenticity is to describe objects that are original in nature (Evans, Mull and Poling 2002; Roberts 1997), such as dinosaur fossils and works of art.[1] Following on Roberts's observations, Leinhardt and Crowley (2002) suggest that authenticity is imparted both by the uniqueness of the object, and by a connection with the humans who give it significance. Authenticity may be conferred by an object's uniqueness in combination with its historic connection (Napoleon slept in this bed) or by an everyday object in combination with extreme age (ancient Pima pottery).

In ascribing authenticity, objects may be further subdivided according to origin. Natural objects, such as dinosaur fossils, arise from nature. "Artifactual" objects, such as original works of art, arise from intentional human activity (Evans, Mull and Poling 2002). These discussions about authenticity have been confined to objects that are nonliving.[2] Yet living collections are present in museums in the form of plants in botanical gardens and arboretums, and animals in zoos and aquariums. In such instances, the definition of authentic objects should be expanded to include the real, living plants and animals.[3] We believe this inadvertent omission limits our understanding of authentic museum objects and masks unique properties of living objects in terms of how and what visitors learn. We suggest that additional characterstics be used to define object authenticity.

For the purposes of this study, "authentic plants" are considered to be living plants regardless of their age, origin, uniqueness, or intentional human use. Of course, botanical authenticity can be defined with other criteria. For instance, a curator might consider whether or not an exhibited plant is native to its setting. When displayed in a North American desert exhibit, a Saguaro cactus is authentic; when displayed in a tropical rain forest exhibit, it seems less so. In an historical exhibition about Linnaeus, plant species available to the sixteenth-century botanist would be considered authentic, whereas modern plant cultivars may not be. Even apart from the circumstances of display, some curators might argue that only naturally-evolved plants can be authentic and that genetically-engineered plants are non-authentic.

Discussions about authenticity also typically omit virtual and digital objects, yet museums increasingly use such media to convey ideas and to construct learning experiences. This oversight is especially intriguing since the ubiquitous presence of virtual/digital media elicits uneasiness about the widespread use of digital technology and what some fear is a diminishing appreciation for real, authentic experiences and objects (Roberts 1997; Wilcove and Eisner 2000 in Evans, Mull and Poling 2002). This concern is not unique to the museum community: Some biologists also voice concern about substituting virtual objects and experiences for their authentic counterparts (Nabhan and Trimble 1994; Pyle 2002).

> Is it possible that bringing living and virtual objects into this discussion will add a critical dimension to understanding the relationship between object authenticity and visitor learning? How does an object's condition (living, model, or virtual) influence visitor engagement, conversation, and subsequent learning in museums, if at all? With little relevant empirical data, it is difficult to know what effect authentic, model, or virtual objects have on visitor learning.

Among researchers and museum observers, there is general agreement that an object's authenticity should be defined in a socio-cultural context. Learning in museums is socially mediated—meaning that visitors learn as they talk with, listen to, and observe other visitors (Allen 2002; Borun et al. 1998; Falk and Dierking 1992; Hein 1998; Leinhardt and Crowley 2002). As visitors engage with museum objects and with one another, they interpret their experiences in ways that extend their knowledge about, interest in, and personal connections to the subject matter at hand.

From the socio-cultural perspective, museum objects are important with respect to their role in supporting dialogue and learning. Leinhardt and Crowley observe that ". . . the genius of museums exists somewhere in the analysis of how unique and powerful objects support learning . . . in the form of conversations . . . that get elaborated as small clusters of individuals engage with objects" (2002, 306). As visitors talk, their observations move from simple identification to explanation and thematically organized ideas (Ash 2003; Leinhardt and Crowley 2002). This perspective aligns with Roberts's argument that the significance of museum objects lies in whether they afford opportunities for constructing visitor narratives.

Visitor conversation, then, is a critical mechanism for learning in museums; much recent research has focused here.[4] These conversations include both non-learning talk (orientation, group management) and learning talk (focusing, asking questions, labeling, making explanations). Explanation—in which visitors attempt to understand and extend an immediate experience, to cast an immediate experience in terms of cause and effect, or to connect an immediate experience to prior learning—is of particular interest to this study.[5] According to Wilson and Keil (2000) explanations result from human activity, and serve to create knowledge and to increase our understanding of phenomena. Explanations function as a vital learning tool across multiple contexts—from science labs (Dunbar 2001) to classrooms (Leinhardt 2001) to museum exhibits (Crowley and Galco 2001).

Families often generate explanations that fall short of classical definitions of explanation, especially scientific explanation (Brewer, Chinn and Samarapungavan 2000). Even so, they are powerful "just-in-time" events that bridge children's prior experience with novel concepts and experiences (Crowley, Callanan, Jipson, Galco, Topping and Shrager 2001). Parents use explanations to model patterns of learning behavior that help children focus attention, highlight evidence, ask questions, and encode information, often through a dynamic parent-child negotiation (Boland, Haden and Ornstein 2003; Callanan and Jipson 2001; Crowley, Callanan, Jipson, Galco, Topping and Shrager 2001).

This study focuses on families building explanations about pollination as they interact with authentic living plants and objects that are representations of plants (that is, model plants, virtual plants). Pollination is a key biological process that is fundamental to understanding biodiversity. At its most basic, pollination consists of moving pollen from one flower to another flower. At more complex levels, pollination reveals the intricate ecological relationship between plants and animals. Knowledge about pollination is valuable for a child appreciating such everyday events as a bee flitting from flower to flower, a gardener making decisions about which flowers attract honey bees, or policymakers debating conservation of migratory paths for agricultural pollinators (Buchmann and Nabhan 1995).

This multi-dimensionality provides fertile ground from which families can cultivate explanations—from simply identifying flower parts and pollinators, to talking about the apple in the lunchbox, to supporting explanations about form and function and evolutionary relationships. Given its accessibility in home and school environments, the topic of pollination can serve as an important platform from which families expand explanations. Finally, unlike other botanical processes that may take days, weeks, or months to be realized, pollination happens in minutes, making it suitable for interactive museum experiences.

It is no wonder, then, that pollination is prominently featured in the programs and exhibitions of botanical gardens, zoos, and natural history museums. To convey messages about pollination, these museums use a variety of objects, including authentic living plants and pollinators, three-dimensional models, and virtual simulations. Given the debate within museums about authentic objects and representational objects, we wondered whether parents and children generate different types of explanation when they interact with different object conditions. It seems plausible that the differences between authentic and representational plant objects influence visitor engagement and, in turn, visitor explanation.[6]

Living plants *in situ* allow parents and children to experience pollination in real time and scale, in complex environments with real organisms, and with full sensory immersion. But serendipity is necessary. Even with suitable environmental conditions and the presence of flowering plants and pollinators, visitors may or may not observe a naturally occurring biological event. Pollination requires patient observation; neither museums nor visitors can produce the phenomenon on demand.

Three-dimensional models are striking for their amplification of scale and reduction of complexity. Visitors may focus on essential details while ignoring others that may interfere with the designer's intended educational messages. For example, a flower model that includes an ovary and ovules facilitates learning about fertilization, whereas a flower model that displays nectar guides facilitates learning about pollinator attractants. Unlike living plants, models can be taken apart and rebuilt without harmful consequences.

Likewise, virtual plant simulations have pre-determined educational messages and interaction is repeatable upon demand. They have the advantage of compressing time and showcasing biological processes that would otherwise be unobservable during a single museum visit. For example, the life cycle of a flower may require months in real time, but can happen in moments on screen. In contrast to living plants and models, virtual simulations typically highlight action at the expense of detail.

In this study we look for evidence of how families used, talked about, and learned from each kind of plant. Our focus is on families with children aged 6–9 who visited a botanical garden. The first author's experiences with planning and running botanical education and exhibitions suggested that these ages are familiar with basic botanical concepts and can use living plants, models, and virtual environments to explore pollination. Research also suggests that children of these ages can distinguish between, and learn with, authentic and representational objects (Callanan, Jipson and Soennichsen 2002; Evans, Mull and Poling 2002; Triona and Klahr 2003).

STUDY METHODS

Participants—Twelve pairs (one parent and one child each) participated in this study at Phipps Conservatory and Botanical Garden in Pittsburgh, Pennsylvania. Seventeen families with children between ages 6–9 were recruited as they entered the courtyard of the Children's Discovery Garden. *(See the color pages for the garden and model.)* Of those, 12 agreed to participate and five declined (one due to language; two due to lack of interest; two were entertaining guests). The mean child's age was 7.7 years. Females comprised seven children and nine adults. Five families described themselves as infrequent visitors (0–2 visits per year), two families as occasional visitors (3–4 visits per year), and five families as frequent visitors (5-plus visits per year).

Environment and materials—The study took place in a 144-square-foot outdoor pavilion and an adjoining 65-square-foot garden section of the Children's Discovery Garden during normal operating hours. We ran the study on fall days that were conducive for pollination with a mix of sun and clouds and temperatures in the 50s and 60s (Fahrenheit). Materials included examples of plants in three conditions: living, model, and virtual. The living plants were in bloom and of kinds that are insect-pollinated (for instance, *Physotegia* and *Buddlea*). Magnifying lenses were placed in proximity to the living flowers and incidental pollinators (bumble bees, honey bees, monarch butterflies). A large-scale flower model (a median section of a typical angiosperm flower, 18 inches long by 14 inches wide by 21 inches high) was placed on one end of a six-foot table with one butterfly puppet and one bee puppet. At the other end of the table, a 35-second, repeatable virtual animation of unspecified butterflies pollinating unspecified flowers was displayed on a Macintosh PowerBook G4 laptop. (The butterfly animation may be viewed at http://upclose.lrdc.pitt.edu/articles/multimedia/eberbach1.html.) All interpretive signs were removed from the garden prior to the start of each data collection and no interpretation was provided for any condition, beyond asking visitors to talk about pollination. In this way, data revealed what families might spontaneously say about pollination rather than how they might interpret museum-created mediation.

Design and procedure—All parent-child dyads interacted with all three plant types (authentic living, model, and virtual). The order of the plant types was counterbalanced within subjects. Parent-child dyads were instructed to participate with each plant type, taking as little or as much time as they desired, and were told that the objects would give them an opportunity to learn about pollination. The mean time for participation was 10 minutes, 29 seconds.

All parent-child dyads were observed to witness and comment on at least one act of pollination as they engaged with the living plants. Families engaged with each plant type as long as they liked.

Coding—Parent-and-child interactions were videotaped and their conversations were transcribed. The transcripts were coded along several dimensions, including types and lengths of explanation and pollination content. In this coding scheme, an explanation describes what, how, or why phenomena occur. It may or may not be scientifically accurate, and it may assume the form of a statement or a question. In the following dialogue, for instance, the parent and child build an explanation about what a virtual butterfly is doing:

> P: What are the butterflies doing, honey?
> C: They're flying.
> P: But what are they doing? They fly down and do what?
> C: They get pollen.

Contrast this conversation with the following in which a question is asked (and answered) but no explanation is generated:

> P: Do you know what that is?
> C: Yeah, it's a plant . . . a flower. Flower. Flower.

We began coding with explanation categories from prior work on family explanations in museums (see Crowley, Callanan, Jipson, Galco, Topping and Shrager 2001; Crowley and Galco 2001). However we suspected that these categories might have been influenced by the physical science content of the exhibits in the earlier studies. We were also mindful of work on student biology explanation that suggested a preference for explanations that focus on processes rather than causal relationships (Abrams, Southerland and Cummins 2001). Our final set of coding categories represented a hybrid of these prior studies and included four types of explanation: analogical, principled, causal, and process. Inter-rater agreement was at or above 85 percent for all coding categories.

In this coding scheme, *analogical explanations* are those in which one thing is like something else. Target and source analogs can be identified or inferred, such as "the butterfly sips nectar with its straw-like thing." In this example, the parent links how bees disperse pollen to how the family pet disperses dirt:

> P: Do they? You know what? They get stuff on their . . . when they do that, they touch all these things [P points to stamen].
>
> C: And they get pollen.
>
> P: And they get pollen. You knew the word. How about that? They get it on their feet and then they rub it over there. One of these parts are boys and one of these parts are girls. And the bees put . . . [P moves stamen near bee puppet] you know they kind of track it through the house, you know, like Darby does with the mud? [C nods head yes.] And puts it all inside.

Principled explanations are those in which families either literally or conceptually refer to an organizing scientific principle such as evolution, form and function, or genetics. Here, as a mother and son interact with the model, the mother explains unobservable processes at work:

> P: But something else has to happen for an apple to turn . . . for a flower, for a flower to become an apple. And that is, that something . . . that this is only—that the seed in here?
>
> C: Uhhuh.
>
> P: . . . isn't complete. It is actually only half of the genetic material of the plant. And it needs more genetic material. It needs to be pollinated. . . .

Causal explanations are those in which X causes Y, or X needs Y to do Z. These can be in past, present, or future contexts. In this example at the living plants, the parent explains a causal relationship between pollination and seeds:

> P: If it was pollinated, it'll get a seed. And look. . . .
>
> C: Yeah. There's the seed!
>
> P: Yeah, that right. It is the seed. Look at that. Pretty cool. So somehow that plant must have gotten pollinated.

Process explanations comprised the fourth explanation category and were defined as accounts of unfolding or sequential events that did not cast one event as a cause and one as an effect, and in which X does Y, or X becomes Y. Following are examples of each:

> [X does Y] P: Oh look at that. It went down in. Do you see it? So then he takes the pollen and it gets stuck on him and then he goes and he lands on another flower and another flower. That's how pollen gets spread, right?

Examples of process explanations in which X becomes Y typically described pollinator or flower life cycles, as the following exchange illustrates:

> P: And when the flower dies this [ovary] is left, and it has a bunch of seeds in it.
> C: Cool.
> P: Get it?
> C: And it grows another flower.
> P: And it grows another flower. That's right.

Process explanations were subdivided into "what" and "how" categories. In the "what" category, parents and children literally explain what is happening, as the previous examples show. In the "how" process explanations, families explain how phenomena happen without mentioning specific causal mechanisms, nor referring to results, nor why something is happening. This coding is distinct from how Callanan, Shrager, and Moore (1995) identified causal explanations using terms such as "how" and "why" to herald causal explanations. The distinction is subtle but is important to the biological explanations in these parent and child conversations. Following is an example of a "how" process explanation to illustrate this distinction:

> P: How do they get it? With what?
> C: With their . . . [puts fingers up to her mouth and mimics butterfly tongue]
> P: With their tongue.

Notice that the "how" process explanation describes how the pollinator gets nectar, rather than what might result from getting the nectar, why the plant needs the pollinator, or why the pollinator gets nectar. Contrast this example with a causal explanation that not only describes what is happening, but more critically, explains the result of moving pollen:

> P: And then he leaves some because the pollen is how the plants make new seeds. So they like to share their pollen.

In addition to categories of explanation, the content was coded for whether or not it directly related to pollination and for accuracy. Content that directly related to pollination included mentioning such terms as nectar, pollen, stamen, as well as specific pollinators in reference to flowers or some part of flowers, such as, "A bee gets pollen." Content that was non-pollination-related included references to pollinator life cycles or behavior not related to moving pollen, such as, "The bee won't hurt you if you stand still." A botanical educator and a botanist coded all explanations as being accurate or inaccurate. Some explanations lacked adequate information and were coded as unknowable. For example, "The bee eats pollen" would be true if it were a honey bee, but incorrect if it were a bumblebee. A total of nine explanations (six percent) comprised this category and were excluded from analysis.

RESULTS

The analysis begins by examining how families used different types of explanation. Then we explore explanatory content for focus on pollination, accuracy, and reference to everyday, informal, and formal learning experiences.

Family explanations—One of our expectations was that parents and children would use different kinds of explanations. Process explanations (62 percent) made up the largest segment of explanation types with 88 counts. Causal explanations (20 percent) included only 29 counts. Analogical explanations (12 percent) included 17 counts. Finally, principled explanations (6 percent) comprised the smallest segment of explanation types with nine counts. Of these comparisons, families generated significantly more process explanations than all other explanation types.[7] In addition, conversations included significantly more causal than principled explanations. All other comparisons were not above chance.

Whether parents and children used different types of explanations when interacting with authentic living plants, model plants, and virtual plants was of specific interest to this study. We expected that the unique affordances of each plant type would support specific types of explanation. Thus, dynamic pollinator activity in concert with the challenges of observing anatomic detail of both the living and virtual plants should support more process explanations. In contrast, the model plant's enlarged scale, anatomical detail, and hands-on design should support more causal connections. Surprisingly, the model and virtual plants supported significantly more process explanations than did the living plants (see figure 1 for a comparison of explanation types across plant types).[8]

It was possible that although families used fewer process explanations at the living plants, their explanations may have used more words and thus may have been richer and deeper. If so, one might expect to see larger word counts within explanations. Analysis suggested a pattern consistent with the frequencies of process explanations.[9] Families used significantly more words with the model and virtual plants than with the living plants to generate process explanations. As much as word count is indicative of quality, the model and virtual plants again outperformed living plants.

It was also possible that families stayed longer at the model and virtual plants and

Figure 1. Frequencies of explanation types across plant types and within plant types.

so had more time to produce more process explanations. However, analysis across plant types found no effect for time.[10]

So far, the model and virtual plants supported significantly more process explanations than did the living plants. We wondered whether these differences would persist with regard to the finer categorization of "what" and "how" process explanations. We found that families used significantly more "what" process explanations at the model and virtual plants than at the living plants, but used similar numbers of "how" explanations at each plant type.[11] "What" process explanations were qualitatively similar regardless of whether generated at the model, virtual, or living plants, as the following examples suggest. A parent and child explain what the butterfly is doing at the virtual plant:

> P: So what are they doing?
> C: Well, they're just collecting pollen.

At the living plant, a parent and child explain what the bee does:

> P: Well. Okay, come over here and look at the bee and tell me what the bee is doing. Whoops!
> C: Collecting pollen.
> P: Uhhuh. And then what does it do when it goes to the next one?
> C: Collects more pollen.

These across-plant-type comparisons suggest that process explanations were more likely to be observed with model and virtual plants than with living plants. Moreover, the model and virtual plants supported longer process explanations and more "what" process explanations than did the living plant.

We turn now to analyzing the profile of explanation use within each plant type. Specifically, we wondered whether, within each plant type, families were significantly more likely to use process, casual, analogical, or principled explanations. Analysis revealed significant differences within each plant type.[12] Of particular interest, the model plant and virtual plant each supported significantly more process than causal explanations, as well as significantly more process than analogical explanations. In contrast, the living plant supported similar frequencies of process and causal explanations, as well as process and analogical explanations (see figure 1 for a comparison of explanation types within plant types). This suggests that families used process, causal, and analogical explanations differently with the model and virtual plants than they did with the living plants.

Content and out-of-museum experiences—We were interested in the extent to which family explanations included pollination content. Each explanation was coded for whether or not it directly referred to pollination. We wondered whether the inclusion of butterflies laying eggs in the virtual plant program and the environmental complexity of the living plants might divert explanations away from pollination. Overall, 78 percent of explanations were pollination related and 22 percent were not pollination related.[13] All plant types supported pollination-related explanations.

We were also curious about the extent to which each plant type supported accurate or inaccurate explanations about pollination. Overall, 71 percent of explanations were accurate and 29 percent inaccurate. Analysis suggested that all plant types afforded similar opportunities for accurate and inaccurate explanations.[14] Generally, families understood the basic definition of pollination, as this explanation at the living plant reveals:

> P: But see the uh . . . and when they do they and they touch the pollen, okay? They fly, they fly to another flower and they do the same thing.

However, families typically voiced misconceptions about why pollination occurs, as suggested by this exchange at the virtual plant:

> P: Look at that! See! What does it tell us something about those little butterflies?
> C: What?
> P: They get their food from pollen.

Parents and children referred to other shared experiences as they interacted with each plant type, effectively reinforcing the observation that personal identity, prior experience, and knowledge influence the shared construction of knowledge. We coded these out-of-museum references into three categories: formal (for instance, school); informal (movies, TV, museums); and everyday (home, pets, gardening). Regardless of the type of plant they were discussing, families referred to everyday experiences an average of 0.5 times, formal experiences an average of 0.3 times, and informal experiences an average of 0.2 times per object.

We found significance for formal references, meaning that families mentioned school experiences significantly more when interacting with the model than when interacting with living plants or virtual plants.[15] There was also marginal significance for plant type in relation to everyday references, which suggested that something interesting might be happening.[16] When the comparison of everyday references was limited to the living plant and virtual plant, we found that the living plant supported significantly more everyday references than did the virtual plant.

Typically, when making references to school, families recalled the names of plant parts and plant processes. In some cases, parents attempted to gauge their child's general knowledge about pollination, as suggested by the following example:

> P: Okay, here's number one. Do you remember what these are called? Have you had that in school yet?
> C: Stem.

Parents also revealed their own experiences of studying pollination in school:

> P: One of these is the stamen and one is the style. I can't remember which is which.
> C: Why not? Why not?
> P: It's been too long.
> C: Why has it been too long?
> P: I took botany in college years and years and years ago.
> C: Oh.
> P: About 20 years ago.

In addition to identification of plant parts, everyday references seemed to extend and contextualize a family's understanding of natural phenomena. Here a child reasons about the role of bees in his own backyard garden:

> C: Yeah. But the reason why I did good with the watermelon is because we had a tree that had, like, bees.
> P: What tree was that?
> C: You know those trees with the, like, yellow flowers?
> P: Yeah?
> C: Those.

DISCUSSION

This study focused on the ways that families use explanation with authentic living plants and representational model and virtual plants. Four types of explanation were identified: process; causal; analogical; and principled. Four main findings emerged. First, process explanations were significantly more frequent than other types of explanation. Second, the model and virtual plants often functioned similarly to one another but differently from living plants. Third, the model plant supported more connections to school than connections to everyday or informal contexts. Fourth, the living plant supported more connections to everyday experiences than did the virtual plant. In our discussion we consider the nature of process explanations, the affordances of authentic living, model, and virtual objects, and finally the implications for use of living, model, and virtual objects in museums.

Process explanations reflect authentic discipline-specific activity in biology—One of the most striking findings of this study was the widespread use of process explanations whether families engaged with authentic, model, or virtual plants. Process explanations are especially salient to the discipline of biology and to field and evolutionary biology in particular (Gould 2002; Richards 1992; Rudolph and Stewart 1998). Unlike researchers who use experimental models of science, researchers working in these biological realms generate descriptions of natural phenomena to explain ecological and evolutionary relationships. Similarly, studies of classrooms suggest that students construct explanations of biological processes (behavior, growth, and so on) rather than causal mechanisms (Abrams, Southerland and Cummins 2001; Lehrer, Schauble and Petrosino 2001).

Our finding that families also favor process explanations in the botanical garden suggests that they may be rehearsing the disciplinary discourse of field biologists, teachers, and students. For example, in the following exchange a parent and child closely observe a pollinator's actions at a living flower, and describe its behavior:

> P: Um, he's collecting nectar and then he's gonna get pollen in his hairy little legs. Check out his legs.
> C: Uhhum.
> P: So he collects some pollen.
> C: He puts in the spot under his leg. It's kinda like . . .
> P: And then when he comes over here—come on, bee, do it for me. When he comes over here and lands and then he leaves some.

In this exchange, the parent and child closely observe and describe the bee's behavior ("he's collecting nectar") and anatomy ("hairy little legs," "in the spot under its leg") as they build an explanation about pollination. Similar to some biologists, they generate play-by-play descriptions that highlight what is important ("when he comes over here and then he leaves some") and thereby create accounts that deepen their understanding of the phenomena.

The overall point is not that families are natural field biologists—scientific fieldwork takes years of methodological and content training. Yet families, classrooms, and scientists sometimes start their conversations with observations of some natural phenomena, introduce shared systematic points of reference, and agree on the essential process that is at work in a specific system (Lehrer, Schauble and Petrosino 2001; Simon 2001). Families may observe, introduce, and agree on different things than trained biologists, but both sets of investigations make sense of systems by building from shared observation.

This is a different view of family conversation in museums than is suggested by most prior work. Much of what we know about families learning science in museums is based on the use of interactive exhibits that primarily support an experimentally-based view of what it is to do science (see Allen 1997; Borun 1990; Crowley and Galco 2001). Relatively few studies have focused on biological exhibits and explanations (but see Ash 2003; Ash 2002), and even fewer have included the living objects themselves (see Borun et al. 1998). To the extent that evaluation and research continue to be interpreted to suggest that doing informal science means the same thing in a science center, natural history museum, zoo, aquarium, or botanical garden, we may be masking the nature of the disciplines that are interpreted in these museums. In turn, we may inadvertently support the inaccurate notion that all science is experimental, hands-on, and dedicated to the construction of strong causal accounts (Futuyma 1998).

Differences among living, model, and virtual plants—The study was designed to explore whether parents and children generated different explanations as they engaged with the plants that were authentic living, model, and virtual. Our findings suggest that the objects did indeed provide different affordances with regard to family explanation. In several cases, the model and virtual plants functioned similarly to one another and differently from the living plants. For example, the model and virtual plants were associated with longer and more frequent process explanations than were living plants. Model and virtual plants supported more "what" process explanations than did living plants. Finally, model and virtual plants each supported significantly more process than causal or analogical explanations, whereas we found no difference between the frequency of process, causal, and analogical explanations with living plants.

This might have been expected if we consider that both the model plant and the virtual plants function as models of biological systems. In science education, model-based reasoning is considered in terms of how different representations of natural systems scaffold particular kinds of exploration (Lehrer, Schauble and Petrosino 2001; White 1993). By their nature as abstract representations of real objects, models lose immediate access to the real content, so that families engage with models differently and generate different explanations than they might with real objects. If this account is accurate, a model's amplified scale, reduced complexity, and ability to be "replayed" may explain why the model and virtual plants supported more process explanations than did the living plants. This abstraction—whether three-dimensional or two-dimensional—allows families to scaffold, extend, and revise explanation by focusing on specific features and relationships and ignoring others.

There is an alternative explanation about why the model and virtual plants functioned like one another and differently from living plants. It seems plausible that living plants and pollinators, situated in complex, dynamic environments, do a lot of the work of explanation and require fewer verbal explanations to understand naturally occurring events, whereas the model and virtual plants give away nothing for free and require parents and children to do a lot more work to build explanations

Compare typical conversations at the model, virtual, and living plants. First, consider that families must create the pollination event, describe their own actions, and explain the pollination process while interacting with the model plant:

C: These . . . this here [picks up bee puppet and positions near stamen] . . .
P: Hmm. And then what does it do?
C: It goes up to the pollen. It goes up here. It takes up the pollen and . . .
P: He lifts it off right there?
C: No! It gets stuck on his leg.
P: Oh!
C: And the ones that don't, he leaves them there.
P: Oh!
C: And he . . . and pretend that his tongue is there and reaches in and gets the nectar. Slurp!
P: Like that?
C: Uhhuh.

Although the virtual plants do not necessitate that families create the pollination event, families must fill in and explain the missing or difficult-to-identify details to understand the event:

P: What are those red things here? [P points to screen.]
C: Ah, I think they get the pollen, or how much pollen.
P: Well, let's see what happens. It seems that . . . .
C: Every time they suck on one . . .
P: Yeah?
C: . . . that loses some pollen, so it has a red dot.

In contrast, families might simply observe pollination as it occurs at the living plants, and with a pollination event unfolding before their eyes, use fewer and shorter verbal explanations to understand the event.

P: [Both observe bee.] What's the bee doing?
C: Sucking up pollen and nectar.

We see these interactions with living plants as similar to Rogoff's notion of intent participation, which posits that talk need not carry the full burden of shared learning when parents and children engage with authentic objects and experiences (2003). Rather—as we observed with parent and child explanations at the living plants—talk annotates rich activity.

Implications for museum learning—It seems that knowing more about the relationship between explanation and the affordances of authentic and representational objects may enable developers to design or choose objects appropriate to the learning goals, the desirability of linking to other experiences, and the availability of resources. With regard to the objects used in this study, botanical gardens could expect to support a lot of family explanation from living plants and pollinators without investing in expensive models and virtual programs. However the use of interactive model and virtual plants may enhance explanation in ways that living plants may not.

Visitor experience with museum objects occurs in the context of visitor identities and motives, as well as prior knowledge and experience (Falk and Dierking 1992; Hein 1998; Leinhardt, Crowley and Knutson 2003). One challenge of museums is to tap into a visitor's prior knowledge and experience to facilitate learning. Because analogical reasoning involves using what you already know about the world to reason about what you do not yet know (see Goswami 1996), it may be a powerful bridge between a visitor's prior knowledge and the learning goals of science exhibits. For example, observe how one parent and child used prior experience to understand moving pollen from flower to flower:

> C: I think, I think they move it from plant to plant.
> P: Yeah? Well, what's so great about that?
> C: Well. Then the pollen from one plant that's good can go . . . . Well, it's like that blood thing.
> P: What blood thing?
> C: You know. You know when we saw that blood truck? For blood testing or something?
> P: Uhhuh.
> C: You take the blood out and things. You take the blood out of someone.
> P: Yeah?
> C: And then you put it in another person.
> P: Ahhhhh.
> C: I think it may be like that.
> P: I see. So you think the pollen from one plant . . .
> C: Yeah.
> P: . . . goes to another plant.

This example illustrates how analogical reasoning may enrich and personalize explanations, and how referring to prior experiences is important to understanding novel experiences. In this study, families referred to formal, informal, and everyday experiences as they interacted with the living, model, and virtual plants throughout their conversations. References to school experiences emphasized recall of names and assessment of a child's level of understanding. Perhaps the particular model used in this study was familiar to children and parents from past school experiences. A different model might connect families to other kinds of prior experiences.

It seems especially striking that the tone and intent of everyday and informal references seemed so different from school references. Even when naming plants, parents and children used these opportunities to extend the observation, make a comparison, or build an explanation, as the following everyday reference illustrates:

> P: Those are like our zinnias, huh? Does that look like the one in your room? [P points to flowers. C looks closely.] Why do you think the leaves are like that?

In the following conversation, the mother uses a prior shared informal learning experience to deepen the child's understanding at the model:

> P: Yeah. And if they . . . if they manage to get the pollen on there, then it goes down and pollinates. Remember reading that book about corn?
> C: Yeah.
> P: And remember how every little strand of corn silk . . .
> C: Yeah.
> P: . . . was actually a tube that the pollen had to come into . . .
> C: Yeah.
> P: . . . and would make one kernel of corn?
> C: Yeah.

What is the import of this? Good practice often necessitates knowing exactly how the informal experience in museums links to, builds upon, supports, and foreshadows experiences in everyday and classroom settings (Crowley and Jacobs 2002; Resnick 1987). We believe researchers ought to be able to give exhibit and program developers reliable information that supports links between shared family experiences, target objects, and experiences available at museums.

Conclusion: The complexity of authenticity—This study was a first step to understanding the relationship between object authenticity and visitor learning. The findings should not be taken to be conclusive. Future studies should include larger sample sizes, a broader group of objects and experiences that capture a more complete range of museum experiences, and additional conceptualizations and assessments of visitor activity and learning.

We think future work should continue to unpack the complex meanings of authenticity while also taking into consideration its relationship to learning. This work should connect notions of authenticity in museums to the broader education and learning literature, where authenticity is considered in terms of disciplinary practice (AAAS 1993; Chinn and Malhotra 2002), learning environments (Arts, Gijselaers and Segers 2002; Resnick 1987), assessment (Newman 1991), and personal/cultural context (Gutierez, Baquedana-Lopez and Tejeda 1999). A more comprehensive exploration of authenticity may further articulate the unique contributions of museum objects to learning and help museums create more powerful and authentic learning experiences.

NOTES

1. What it means to be original in the context of digital media is debatable. Gurian (1999) suggests it is the image that is original rather than the product.
2. Gurian (1999) refers to living collections for a discussion about museum accreditation but does not include living objects in reference to authenticity.
3. Some botanical gardens support herbariums, which are libraries of non-living, pressed plants. Typically used by scholars, herbarium objects are occasionally publicly exhibited. However, we consider living plants to be the defining feature of botanical gardens.
4. See Borun et al. 1998; Crowley and Jacobs 2002; Crowley, Callanan, Jipson, Galco, Topping and Shrager 2001; Falk and Dierking 2000; Hein 1998; Leinhardt, Crowley and Knutson 2003.
5. We acknowledge the continuing debate about what constitutes an explanation. Although cause and effect may be considered a criterion by some (Callanan, Moore and Shrager 1995; Leinhardt and Knutson 2004), such a narrow lens may be less meaningful in everyday and non-scientific contexts (Keil and Wilson 2000).
6. Donald Norman defines affordance as “the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used” (1988, 9).
7. A one-way repeated measures ANOVA suggested significant differences in the frequencies of these explanations, $F(1.9, 20.6) = 56.80$, $p < .05$. In analyses throughout this study, where the sphericity assumption is violated, we used the Geisser-Greenhouse correction so that each F-test is evaluated against more stringent criterion (Huck 2000).
8. A one-way repeated measures ANOVA for each explanation-type across plant conditions found significance only for the frequencies of process explanations across conditions $F(2, 22) = 8.43$, $p < .05$. Living plants ($M = 1.33$, $SE = .41$) supported significantly fewer process explanations than the model ($M = 3.25$, $SE = .31$) and virtual plants ($M = 2.75$, $SE = .49$) according to a Bonferroni post-hoc comparison.
9. A one-way repeated measures ANOVA for word count of each explanation type across plant conditions suggested only a significant difference in the word count of process explanations, $F(2, 22) = 5.72$, $p < .05$. Families used significantly fewer words to generate process explanations with living plants ($M = 54$, $SE = 15$) than with the model ($M = 140$, $SE = 22$) and virtual plants ($M = 88$, $SE = 24$), according to a Bonferroni post-hoc comparison.
10. A one-way repeated measures ANOVA for time across conditions found no effect for time, $F(2, 22) = .89$, $p > .05$.
11. We did a repeated measures one-way ANOVA for each type of process explanation

across plant conditions and found significance only for “what” process explanations, F(2, 22) = 7.71, p < .05. A Bonferroni post-hoc comparison revealed that families used significantly more “what” process explanations at the model (M = 2.67, SE = .26) and virtual plants (M = 2.67, SE =.48) than at the living plants (M = 1.08, SE = .38).

12. A one-way repeated measures ANOVA for explanation type within each plant condition revealed significance for all conditions: living plant, F(3, 33) = 6.52, p < .05, model, F(3, 33) = 49.53, p < .05, and virtual, F(1.3 14) = 28.80, p < .05. Follow up Bonferroni comparisons indicated specific differences.
13. No significance was found from a one-way repeated measures ANOVA with pollination referencing across conditions, F(2, 22) = .50, p > .05, and another for non-pollination referencing revealed no significance, F(2, 22) = .02, p > .05.
14. A one-way repeated measures ANOVA on accurate explanations across conditions revealed no significance, F(2, 22) = 1.22, p. > .05. Likewise, a one-way repeated measures ANOVA with inaccurate explanations across conditions, F(1.4, 15) = 3.73, p. > .05, showed no significance.
15. A one-way repeated measures ANOVA for each of these categories across conditions revealed significance for formal references, F(1.2, 13.4) = 11.31, p < .05. Families mentioned school experiences (M = .75, SE = .22) when interacting with the model significantly more than when interacting with living plants (M = .08, SE = .08) or virtual plants (M = 0, SE = 0).
16. A one-way repeated measures ANOVA for everyday references across all conditions revealed marginal significance, F(2, 22) = 3.37, p = .053. A follow-up Bonferroni comparison was also marginally significant. A one-way repeated measures ANOVA for everyday references across living plant and virtual plant conditions suggested significance, F(1,11) = 7.86, p < .05

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