Learning with Multiple Visualizations in the Science Museum

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Abstract: Science museums are intentionally designed spaces that foster visitors' understanding of scientific knowledge. Increasingly, museums are adopting digital media and technologies in the exhibits both to modernize the experience and to increase visitors' interest, engagement, and learning. This study examines how three dynamic visualizations (digital augmentation, computer simulation, and animation) support visitors' knowledge of a commonly misunderstood scientific concept, Bernoulli's Principle. Data from interviews, surveys, and tests reveal that visitors' knowledge significantly increased after engagement with multiple visualizations. Both children and adults attributed their understanding to the affordance of multiple visualizations to accommodate a range of learning styles and to offer a diverse range of types and depth of knowledge. Based on these findings, we suggest that designing for multiple visualizations in museum exhibits is a positive approach to increasing visitors' understanding of scientific knowledge.

Introduction

Informal environments such as museums play a prominent role in our nation's science education landscape. Intentionally designed to support learning about the physical and natural world around us, research has found that science museums foster engagement and interest in science, cultivate the understanding of scientific knowledge, support the growth of scientific reasoning skills, encourage reflection on science, promote engagement in scientific practices, and advance the development of science learner identities in visitors (NRC, 2009). In particular, understanding science knowledge, such as concepts, facts, models, and explanations, is an important motivation for many museum visitors including teachers bringing school groups (Kisiel, 2005) and parents bringing their families (Falk & Storksdieck, 2010). Similarly for museums as educational institutions, being able to accurately represent and successfully communicate important scientific concepts to enhance the general public's science understanding is an important institutional goal. While several studies document that museum visits enhance visitors' science knowledge understanding, assessments that measure this knowledge often demonstrate little or no positive change in science knowledge outcomes for learners (NRC, 2009).

The question of how best to support learning in science museums is often related to exhibit design. Because museums lack the direct facilitation, accountability, and rigid structure that characterize formal learning environments, supporting free-choice learning that is based on visitors' interests and motivations requires intentional design of museum objects, labels, and spaces. Increasingly, museums are adopting new digital technologies to support science learning. A growing body of literature argues that these technologies can contribute positively to visitor experiences. For example, Sandifer (2003) found that visitors tend to use technology-based exhibits more frequently and for longer periods of time than traditional exhibits, Laursen (2013) presented illustrations of children engaged in various levels of co-participation around a computer-based device, and Eberbach and Crowley (2005) found that virtual representations of objects support different kinds of learning. However, concerns have also arisen about the negative effects of technology on visitors, such as the tendency for them to interact less with other exhibits or objects (Ucko & Ellenbogen, 2008). "Ultimately, the goal of introducing new media technologies…is not only to modernize the experience and space, but to significantly improve the quality of the visitor experience, including enhancing learning outcomes" (NRC, 2009). Fundamentally, more research needs to analyze the effects of digital technologies on museum learning.

It is within this field of research that we now position our study. In this paper, we investigate how various digital technologies impact visitors' knowledge of Bernoulli's Principle, a concept often illustrated in science museums. Specifically, we examine how dynamic visualizations can support science learning. Drawing upon Ainsworth's (1999, 2006) work on multiple representations, we study how the combination of three visualizations (digital augmentation, simulation, and animation) together can afford learning of scientific concepts, facts, and principles. The research question investigated in this article is "How do multiple visualizations enhance learning in a science museum?"

Theoretical Considerations

Exhibit design is a critical feature of visitor engagement and learning. From the makeup of the individual interpretive labels to the arrangement of the exhibit elements on the museum floor, careful attention is directed towards how exhibit features might attract visitor attention and facilitate learning. In our earlier work, we investigated how scaffolding the physical design of the exhibit device might impact school children's learning. We examined how the addition of knowledge-building scaffolds and digital augmentation might enhance learning, and we discovered that knowledge-building scaffolds support cognitive learning and digital augmentation supports conceptual understanding (Wang & Yoon, 2013; Yoon & Wang, 2014; Yoon et al., 2012a, b, 2013b). Furthermore, we found that digital augmentation supports conceptual learning because it encompasses many of the same learning affordances as dynamic visualizations (Yoon & Wang, 2014). Building upon these earlier findings, this study considers how adding more dynamic visualizations might support even deeper learning during museum visits. Briefly, the device under investigation, *Bernoulli Ball,* depicts a lightweight plastic ball that is able to float in the air due to the interactions between the speed and pressure of two types of air – the normal air in the room and the air that is being blown out of a blower attached to the device. In this section, we'll first briefly discuss some of the general learning affordances of dynamic visualizations to set the framework for understanding why they can be beneficial to learners. We'll then address the three specific visualizations that were employed in this study and conclude by presenting Ainsworth's work on multiple representations to help ground our rationale for using multiple visualizations in museum learning.

Dynamic Visualizations

Dynamic visualizations, or external representations that are able to depict changes in space over time and a continuous flow of motion, have become a popular means of providing instruction in all types of learning environments (e.g., Lowe & Schnotz, 2008). There are four main affordances of dynamic visualizations that make it so attractive for learning. These include attracting learners' attention and motivation (Scheiter et al., 2009), enabling the visualization of invisible entities or processes (Hegarty, 2004), allowing objects to be viewed from different angles or viewpoints (Hegarty, 2004), and increasing interactivity and control which can facilitate comprehension (James et al., 2002 as cited in Plass et al., 2009). Collectively, these affordances significantly aid thinking.

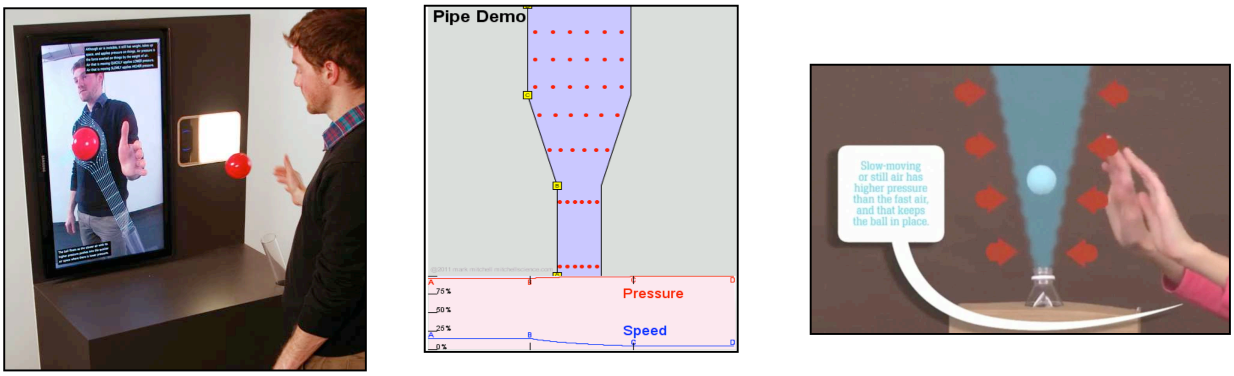

Figure 1. Three visualizations: digitally augmented device, simulation, animation.

Three dynamic visualizations were investigated in this study. The first was digital augmentation, which we previously defined as computer-generated images superimposed upon the physical environment (Yoon et al., 2012b). Although its use is relatively new within museum spaces, some studies have revealed that they can elevate visitors' interest and engagement (Hall & Bannon, 2006), support collaborative interactions (Asai et al., 2010), and garner conceptual understanding (Yoon et al., 2013b). For this study, the digital augmentation (Fig. 1) depicts the movements and pressures of the two types of airs using different colored arrows. These arrows would readjust their position depending on where the ball was. The second visualization employed was a computer simulation. Computer simulations are programs that model a simplified system or process of a real-world phenomenon and their ability to allow users to manipulate variables and observe the resulting changes makes them effective visualizations (de Jong, 2011). In science museums, they have been presented as fun games that invite visitors to explore certain aspects of a particular scientific issue (e.g., Cheng et al., 2011). The simulation in this study, depicted in Fig. 1, shows a pipe with molecules flowing through and a line graph below illustrating the speed and pressure changes of these molecules. Individuals were able to manipulate the width of the pipe and examine its effects on the pressure and speed of the flowing molecules. The last visualization employed was an animation. Animations are "pictorial display that changes its structure or other properties over time and which triggers the perception of a continuous change" (Schnotz & Lowe, 2008, p. 34). The ability to visually depict changing information, some of which are not observable is one of the greatest benefits of using animation (Rogers, 2008). In museums, animations have been used as virtual staff members that guide visitors in particular ways (Lane et al., 2011). They've also been used to convey important scientific information; consequently data has revealed that visitors respect these animations as trusted sources of information (Matuk & Uttal, 2008). The animation (Fig. 1) in this particular study demonstrates how the phenomena can be replicated at home with a blow dryer and a Ping-Pong ball. A child narrates the set-up and briefly describes the science behind how the ball floats.

Multiple Representations

As discussed above, whether through increasing learners' interests to continue their exploration or by making information more visible and accessible, dynamic visualizations bear much potential to support learners' comprehension of complex scientific phenomena. In this study, we hypothesize that by bringing together these individual visualizations, we'll be able to capitalize on their collective affordances to garner even deeper learning than if using them separately. We draw upon Ainsworth's work on multiple external representations (MERs) to provide some grounding on which to base this hypothesis.

MERs have been widely used in science teaching to help learners understand complex scientific concepts (Ainsworth, 1999). They typically refer to modern, multi-representational, computer-based learning environments that package together several dynamic representations such as audio, video, animations, dynamically changing graphs, diagrams, and tables and other interactive dynamic visuals (van der Meij & de Jong, 2006). Although a common justification for employing multiple representations is that they are more likely to capture a learner's interest and motivation (Ainsworth, 1999), they also provide cognitive benefits that aid in learning. Broadly, there are three main functions of multiple external representations: to complement each other, to constrain the interpretation between the visualizations, and to construct deeper understanding (Ainsworth, 1999). First, MERs can complement each other in the content of the representation or in the cognitive processes needed to interpret the representation. Concerning content, regardless of whether they express completely different information or they provide some similar redundant information, by distributing the information across several representations instead of containing all of it in a single representation, the complexity of the representation decreases. This in turn decreases the amount of cognitive load learners need to interpret the representation (Ainsworth, 1999). MERs can also support complementary processes; even if representations contain equivalent information, they can still support different inferences because of differences in their computational properties (Ainsworth, 1999). This requires that different cognitive processes are needed to interpret the information. Second, MERs can also be used to constrain the interpretation between the representations (Ainsworth, 1999). A familiar representation can be used to support the interpretation of a less familiar or more abstract representation. In this role, the familiar representation is meant to support learners' reasoning about the less familiar one. The last function of MERs is to support the construction of deeper understanding by promoting abstraction, encouraging generalizations, and in teaching the relations between representations (Ainsworth, 1999).

In this section, we've outlined how previous studies on dynamic visualizations and MERs inform our hypothesis of bringing together several dynamic visualizations to enhance learning. Because our research analyzes the use of three distinctive visualizations that operate through three different platforms, from here on out, we will use the term "multiple visualizations" (as opposed to MERs) to refer to the collective of the three distinct visualizations.

Methods

Context and Participants

This study evolved from a formerly funded large-scale National Science Foundation informal science education project in which the goal was to design, integrate, and increase the use of educational technologies, particularly digital augmentation, and to study their impact within the science museum learning experience (Yoon et al., 2012a, b, 2013a). This mixed methods quasi-experimental study extends that focus by considering how two additional technologies, a computer simulation and an animation, can supplement the previously augmented exhibit device. The participants were family groups that consisted of at least one child, between the ages of 11 and 14, and one adult. In total, 30 families with 37 children and 38 adults participated. Over 75% of the families were recruited directly off the museum floor on the day of the study. The remainder was recruited through the museum's monthly community outreach event and through emails to professional and personal contacts.

This study follows a within-subjects, or repeated measures, design in which all of the participants engaged in both experimental conditions with the device. The study took approximately 45 minutes to complete and was held in a separate room off of the museum floor. Before families engaged with the exhibit device, parents were asked to fill out a pre-survey and children were asked to complete a pre-knowledge test and answer some pre-intervention interview questions. After this pre-intervention data was collected, families were exposed to the first condition that featured the device with just the digital augmentation visualization. Families were asked to play with the device as if they had found it on the museum floor. Once families signaled that they were finished playing and after the mid-intervention interview data was captured from children, they moved onto the second condition. The second condition featured a computer simulation and an animation in addition to the augmented device. Both the simulation and animation were presented on two netbooks at a table adjacent to the device. Again, families were asked to play with all of the tools as if they had seen it on the museum floor and to signal me when they were done. Their participation ended once parents completed their post-survey, children finished their post-knowledge test and post-intervention interview, and both children and parents answered some post-study interview questions.

Data Sources and Analysis

1. Pre- and post-surveys were administered to adults at the very beginning and end of the study. There were two parts to the surveys but for the purposes of this study, only the second part, which assesses parents' *knowledge of the phenomenon*, was analyzed. The question asks, "How do you think the ball is able to stay floating in the air without being blown away?" In the post-survey, we asked parents to review and revise their answer. A categorization manual was constructed to evaluate this question and interrater reliability was obtained on 20% of the responses by two independent researchers ($\alpha = 0.91$). The written responses were coded from "Little to No Understanding" (Level 1) to "Complete Understanding" (Level 6). Whereas in a level 1 response, the individual attributes the floating phenomenon to just the air from the blower, a level 6 response recognizes that the ball floats because the high pressure from the slow-moving room air keeps the ball in the low-pressure, fast-moving air stream. Both types of air are explicitly addressed in the highest level of understanding. Paired samples *t*-tests were conducted to determine whether parents' understanding of the phenomenon had changed after the study.
2. Children's *knowledge of the phenomenon* was also measured, but was administered via interview as opposed to a written survey. Pre-, mid-, and post-intervention interviews were conducted with children to more finely explore how their knowledge changed with each exposure to the visualization tools. In all three interviews, children were asked the same question as on parents' surveys, "How do you think the ball is able to float without being blown away?" The mid-intervention interview was administered to more finely identify differences in the learning impact between just the digital augmentation and then the multiple visualizations. The same categorization manual was used to code these verbal responses. Interrater reliability was obtained on 20% of the responses by the same independent researchers ($\alpha = 0.96$) and a one-way repeated measure ANOVA was conducted to examine how their knowledge changed between each condition.
3. Pre- and post-knowledge tests were administered to children at the very beginning and end of the study to assess children's *conceptual understanding*. Whereas the interviews measured their understanding of the exhibited phenomenon, these tests were meant to assess understanding and application of the principle to different contexts. The test consisted of 4 multiple-choice questions (2 low level recall questions and 2 application questions) that were informed by textbooks and vetted by content experts. The responses were coded as correct or incorrect and a paired samples *t*-test was administered to examine differences between overall pre- and post-knowledge scores.
4. To understand how the multiple visualizations impacted visitors personally, in the post-study interview, children and parents were asked to reflect on their interaction with all three visualizations. They were asked, "Do you think you learned more by playing with all three, or a combination of these, tools? If so, why or how did playing with these tools enhance your learning?" These responses were qualitatively mined for common themes.

Results

Adults' Knowledge of Phenomenon: Pre- and Post-Surveys

A paired samples *t*-test was performed on adults' written responses to the question "How do you think the ball was able to float in the air without being blown away?" Results indicated significant increases in their knowledge between the pre-intervention (M = 1.87, SD = 0.99) and post-intervention (M = 3.21, SD = 1.61); $t(37) = -4.97$, $p = .00$. This suggests that their engagement with the multiple visualizations in the exhibit enhanced their understanding of how the phenomenon occurred.

Children's Knowledge of Phenomenon: Children's Pre-, Mid-, and Post-Intervention Interviews

A one-way repeated measures ANOVA was conducted to compare the effects of the various visualization tools on children's understanding before any exposure to the exhibit, after the augmentation-only condition, and after the multiple visualizations condition. The results suggest that there was a significant difference in children's knowledge ($F(2,72)) = 25.399$, $p < .01$, partial $\eta^2 = 0.414$) between pre-intervention (M = 2.16, SD = 1.04), mid-intervention (M = 2.76, SD = 1.52), and post-intervention (M = 4.27, SD = 1.87). This implies that children's knowledge of the phenomenon deepened with each successive engagement with the visualizations. Furthermore, the difference between mean scores suggests that children learned most when they played with all of the visualizations.

Children's Conceptual Knowledge: Pre- and Post-Knowledge Tests

The pre- and post-knowledge tests contained two types of questions – questions about subject matter content that required simple recall of information ("What is the relationship between the speed and pressure of moving air?") and transfer questions that required application of the concept to a new situation ("What do you think will happen to the 2 hanging ping-pong balls when the boy blows air through the straw between the balls?"). A paired samples *t*-test was performed on children's test scores before and after their engagement in the mini-exhibit. Results indicated significant increases in knowledge between the pre-intervention (M = 0.84; SD = 0.83) and post-intervention (M = 1.84; SD = 1.14), $t(36) = -4.71$, $p = .00$. This similarly indicates that playing with multiple visualizations positively impacted children's conceptual knowledge of the science principles that underlie the floating ball.

Children and Adult Post-Intervention Interview about Effects of Multiple Visualization Tools

Interview responses to "Do you think you learned more by playing with all 3, or a combination, of these tools?" indicated that 100% of the families had at least one member who thought a combination was helpful while 93% of the families had every member agree that it was helpful. For example, one child remarked, "Can't just have one of it. It's not going to be enough." Parents made comments such as, "All 3 together makes it more better and easier to understand" and "I didn't understand it fully until I did all 3."

When asked to explain why or how they thought multiple visualizations supported deeper learning, two major themes emerged. First, adults and children identified that having more visualizations accommodated a greater range of learning styles. For example, one child commented "I think they're all teaching the same thing but they're all slightly different so it's kind of just what you prefer. If you prefer just listening to something, then you can do the video or if you prefer hands on, then you could do that one or kind of both *[sic]*, you could do that." Similarly parents explained, "I like when there's multiple ways…different people have different learning styles…I think maybe *[sic]* would provide a learning experience for different learning styles" and "I think because we all learn differently, the hands-on, the visual, the video....that just helps reinforce the knowledge... the person who learns most by doing or the person who learns by reading...so I think it's great, all 3, and technology today, especially for young people. I think it hit everybody". Another theme that emerged as to why engaging with multiple visualizations enhanced learning was because they offered visitors a range of types and depth of information that could be learned. Even though the visualizations all focused on the same concept, they addressed the concept from different perspectives. As one parent explains, "It's 3 different things but the same topic, same main idea on all of them...so you get to learn more about that piece of information." This affordance enabled all visitors, with varying degrees of knowledge on the topic, to gain understanding. Another parent explained, "You can go to the simulator and kind of get a more in depth look at air pressures um, maybe for kids that are ready to take it to another level of understanding...And then again, the video gave an opportunity to give kids an idea to try it on their own at home which would add another level of understanding of the experiment." This recognition that multiple visualizations could support varying depths of learning was understood to be a function of the nuanced information contained in each visualization. For example, one child explained, "I think it [enhanced learning] because it added stuff that maybe the other tools didn't have." He explains further by describing the different knowledge revealed by each tool: "Like the 3^{rd} one. The video showed you that you could make it yourself. The simulation showed that you could change the shape and change the pressure, the speed of air by doing so. And then the augmentation showed you where the air was going. I like the 3 put together." Her brother added, "Yeah because some of the things like added little details that some of the other stuff didn't have." Here, the children have recognized that each tool presents slightly different information. The interpretation is that that when these disparate pieces of information are added together, they extend learning.

Discussion and Implications

One of the many goals of science museums is to increase visitors' understanding and knowledge of scientific concepts. Through careful design of exhibit spaces, tools, and objects, exhibit developers create experiences that not only provide entertainment but that also facilitate science learning in visitors. Consequently, this project sought to investigate how incorporating visualization tools into exhibits can support children's understanding of a commonly misunderstood scientific concept, Bernoulli's Principle. Building upon the positive learning gains from our earlier research with just one visualization tool (digital augmentation) (Yoon et al., 2012b), we hypothesized in this study that the addition of more visualizations might elicit even greater learning gains.

Overall, we found that engagement with multiple visualizations in a science museum supports science knowledge understanding. Differences between pre-, mid-, and post-evaluations of how adults and children understood how the ball was able to stay floating revealed that both groups of visitors grew in their understanding of the role of invisible features involved in the phenomenon. Initially, parents' and children's conceptions reflected an "Emergent Understanding" (Level 2) of how the system worked. Only obvious features (e.g., characteristics of the ball and the air being blown from the tube) were identified as contributing factors to the system. These pre-intervention understandings are consistent with extant literature that documents robust difficulties in reasoning about air pressure. For example, Engel Clough & Driver (1985) demonstrated that children (between the ages of 12 and 16 years old) incorrectly associate pressure or force with movement. Similarly, Basca and Grotzer (2001) found that children often do not think that pressure exists when they can't easily see an effect or movement and Sere (1982) found that children (between 11 and 13 years old) could not imagine pressure without movement associated with it. Because air pressure is a non-obvious variable that cannot be sensed directly, we expected that children would have difficulties perceiving its role. That adults also held onto these naïve understandings was unexpected, though not completely unsurprising given the robust research on the persistence of preconceptions among older children and adults even after encountering experiences and models that contradict naïve understandings (NRC, 2000). Regarding children's understanding, we were encouraged to find positive results on the mid-intervention interviews after they had engaged with one visualization (digital augmentation), which confirms our previous research that certainly, the presence of the augmentation significantly enhances children's understanding (Yoon et al., 2012b). As digital augmentation embodies many of the advantageous qualities of dynamic visualizations in general (Yoon & Wang, 2014), its added benefits to learning is unsurprising. More importantly, we found pronounced knowledge gains in both groups of visitors after their engagement with the multiple visualizations. Whereas parents (in their post-surveys) attained a "Partial Understanding" (Level 3) of the phenomenon, children (in their post-intervention interviews) progressed to a "Basic Understanding" (Level 4). Conceptually, this indicates that both are shifting their understanding from purely obvious features (e.g., characteristics of the ball and the air being blown from the tube) to more imperceptible elements such as the interactions of other forces unrelated to the tube air (e.g., gravity or the normal air in the room pushing up/down) (Level 3) and to the recognition that these forces exert different amounts of pressure which affords the ball to float (Level 4). This conceptual growth was also evident, albeit to a lesser extent, in children's post-knowledge test. Other studies lend support to our positive findings. For example, van der Meij and de Jong (2006) found that students who were exposed to separate, non-linked visualizations (in a Physics unit titled "Moment") demonstrated significantly increased post-scores on questions about content knowledge and Ainsworth (2006) suggests that because multiple representations have the potential to support deeper understanding when learners integrate all of the information together, the insight achieved increases the likelihood of being transferred to new situations.

Based on a) our post-intervention interviews with adults and children and b) the differences between children's mid- and post-interview about the phenomenon, we argue that the growth in understanding is most likely due to their engagement with multiple visualizations in the second condition as opposed to the single visualization in the first condition. Our claim is well grounded in studies that have highlighted various advantages of learning with multiple representations. Consistent with Ainsworth's (1999) work, we found that our multiple visualizations support complementary cognitive processes. This advantage allows for learners who exhibit different preferences to exploit different visualizations according to their experiences, expertise, or familiarity (Ainsworth, 1999). Our excerpts revealed that both children and parents perceived the value of aligning learning preferences with tools that support these preferences. Several visitors highlighted the affordance of these visualizations to teach individuals who preferred learning through interactive experiences versus those who preferred learning through more direct means. Not only did they recognize that their family members learn differently, but that in spite of these differences, because of the various properties particular to each of the visualizations, every member was still enabled to learn. This affordance of multiple visualizations to accommodate particular learning styles is particularly beneficial, though there are some researchers that argue that successful learning with multiple visualizations is less about alignment to learning style preferences and more about expertise with particular subjects or representations (Ainsworth, 2006). While we would not disagree that learning with multiple visualizations corresponds to both the learner's command of the subject matter and how well s/he can interpret a particular type of visualization, we also want to articulate that these studies occurred in formal learning environments, vast contrasts to informal, museum spaces. Without direct facilitation from a teacher or prescribed assignments and activities to complete, museum learning is heavily contingent upon visitors' own personal choices, motivations, and preferences in deciding which exhibits to interact with (NRC, 2009). Several studies, including Borun and Dristas' (1997) piece on exhibit characteristics that facilitate multimodal learning, have explicitly addressed this relationship between exhibit design and visitor choice. Thus designing exhibits to optimize visitor learning must consider visitors' learning style preferences.

We also found evidence of multiple visualizations supporting complementary information. When visualizations contain partially redundant information, it enables users to exploit differences in the information, which therein supports the construction of new interpretations of the original concept (Ainsworth, 1999). In comparing the information that each visualization presented, most visitors identified that the animation taught them how to construct a similar device at home, the simulation illustrated the idea that speed and pressure is not static but rather can be manipulated, and the augmentation revealed the precise movements of the various airs involved. These pieces of information, though seemingly disparate, support the development of cognitive connections about Bernoulli's Principle when packaged together in the context of the exhibit. Visitors recognized that despite the fact that all three visualizations addressed the same concept albeit from a different angle, the variation in details afforded by each visualization complemented each other in such a way that it deepened their learning. Packaging "elements" within an exhibit to enhance conceptual coherence is not a new practice. In fact, museums frequently cluster groups of conceptually related exhibits to communicate a main concept (Falk, 1997). However, whether visitors actually discern the underlying messages and themes across connecting exhibits has received mixed reviews (Allen, 2004; Falk, 1997). Particularly with regards to illustrating abstract concepts, visitors often have more difficulty perceiving connections and themes between related exhibits (Allen, 2004). To ameliorate this complexity, researchers and exhibit designers have called for more critical consideration to be paid to all levels of exhibit design, from small-scale user design functions to larger-scale decisions about the layout and orientation of the physical environment (Allen, 2004). In addition to incorporating explicit labels that describe the main message of an exhibit (Falk, 1997), we suggest that employing multiple visualizations that contain partially redundant information in various formats may also be an effective way to support conceptual understanding.

Much research has been devoted to understanding how museums can design for a range of learning experiences from general exhibit designs that attend to a variety of learning styles and levels of knowledge (Broun & Dristas, 1997) to addressing specific design features that influence science knowledge understanding such as labeling (Falk, 1997) and interactivity (Allen, 2004). With the advent of digital technologies in museum spaces, studies of how they impact science learning are still emerging. While some have raised the concern that technology can reduce visitors' interactions with exhibit objects or other visitors (Ucko & Ellenbogen, 2008), our study not only supports the few that have found benefits of technology on visitor learning (e.g., Asai et al., 2010; Cheng et al., 2011; Sandifer, 2003) but also suggests that designing for multiple visualizations within a mini-exhibit setup may garner deeper knowledge understanding.

Limitations

While these results strongly demonstrate evidence of increased learning with multiple visualizations, we recognize that this study is not without its limitations and challenges, some of which admittedly will have impacted the positive findings. The first limitation concerns the design of the research study. While there are several benefits to conducting a within-subjects study, one disadvantage is the potential for order effects to negatively impact the data. In this study, children were asked, "How do you think the ball is able to float without being blown away?" 3 times. The successive repetition of this question may have cued participants to pay more attention to the information in visualizations than if they had encountered them on the museum floor. Second, the study occurred in a location separate from the main museum floor – half in one of the design studio and the other half in an office-like space. These environments greatly contrast a typical museum environment where the scene is often chaotic, loud, and distracting with multiple activities going on at the same time. However, we view this as a "first study" and best-case scenario of what could occur. Families had the entire exhibit to themselves, the environment was void of typical museum distractions, and they could spend as long as they wanted. To understand how this mini exhibit would fare on the actual museum floor would require further research. Finally, some may argue that increased learning resulted more from the repetition of seeing 3 visualizations rather than from the actual information presented by the visualizations themselves. We actually consider this to be an integral advantage of having multiple visualizations. Several children commented in their interviews that it was helpful to have this reiteration as it lent "more proof and understanding rather than just one" and that "since you have all 3 that are kind of similar, you can review over and over again which inputted *[sic]* in your head." Simply having multiple visualizations served to reinforce a particularly difficult concept that children and adults alike, struggle with. Thus, the presence of redundant information should not be considered a casual accessory to be minimized but instead, as an asset that can improve learning.

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