Testing the Impact of a Computer Guide on Visitor Learning Behaviors at an Interactive Exhibit

(Pre-Proof Version)

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Abstract

There is a recognized need to rigorously examine the efficacy of approaches to supporting informal learning. In this study, we used a 2 x 2 factorial experimental design to test the impact of a computer guide on three proximal measures of visitor learning at an interactive math exhibit. In total, 128 families were systematically assigned to engage with the exhibit either with or without access to the supplementary computer kiosk. Visitor groups with access to the computer spent longer, on average, at the exhibit and engaged in more mathematical behaviors compared to other groups. However, based on interviews, visitors with access to the computer were less likely to fully articulate the mathematical relationships in the exhibit. These results suggest that although computer guides are a promising approach to supporting visitor engagement, they may, unless carefully designed, undermine other learning outcomes.

Keywords: interactive exhibits, free-choice learning, scaffolding, mathematics education, technology, experimental design

Testing the Impact of a Computer Guide on Visitor Learning Behaviors at an Interactive Exhibit

Although the traditional focus of education research has been schools, there is growing recognition that science, technology, engineering, and mathematics (STEM) learning occurs across a broad range of contexts, including museums, afterschool programs, the internet and other media, and family learning at home (National Research Council [NRC], 2009). Within the context of science centers, a particular area of focus has been the design of interactive exhibits to support visitor learning. Educators, exhibit designers, and researchers have explored a variety of strategies for helping to guide and deepen visitor learning and engagement and have worked to identify characteristics of successful exhibit activities (e.g., Allen, 2007; Borun et al., 1998; Humphrey & Gutwill, 2005; Serrell, 1996).

A recent example is the National Science Foundation (NSF)-funded *Access Algebra* project, led by the Oregon Museum of Science and Industry (OMSI), Portland, Oregon. *Access Algebra: Effective Strategies for Promoting Informal Math Learning* produced a 6000 square-foot traveling exhibition, called *Design Zone*, intended to engage visitors in algebraic thinking—an important type of mathematical inquiry (Kaput, Carraher, & Blanton, 2008; National Council of Teachers of Mathematics, 2000). Through front-end and formative evaluation, the *Design Zone* project team identified promising strategies for promoting algebraic thinking at the exhibits. One approach was the use of computer guides, or supplementary computer kiosks with challenge activities linked to the exhibits, to support inquiry and focus visitor attention on the mathematical aspects of the experience. Leveraging work from this project, we used an experimental design to test the impact of a computer guide on visitor learning behaviors at one activity in the exhibition, *Laser Light Show*.

Using Computer Guides to Support Visitor Engagement and Learning

In the *Laser Light Show* activity (Figure 1), visitors adjust the speed of two oscillating mirrors to control the pattern created by a laser reflecting off those mirrors. The nature of the patterns depends on the relative mirror speeds. For example, if both mirrors are oscillating at the same speed, the laser will trace a circle or an ellipse. If one mirror is oscillating at twice the speed of the other, the laser will trace a figure eight pattern, regardless of the absolute speeds of the mirrors. More complex ratios create increasingly more complex visual patterns. Using numerical readouts to quantify the speed of the mirrors, visitors investigate the mathematical relationship between the ratio of the two mirror speeds and the resulting laser pattern.

An explanatory panel to the right of the non-computers articulates this relationship and gives visitors several examples of how to make a 1:1 pattern, a 2:1 pattern, and a 3:2 pattern. In addition to this panel, the project team also created a computer guide, situated to the left of the control console, to provide visitors with a more structured way to explore the mathematical relationships in the exhibit. Each of the three challenge buttons situated below the computer screen leads visitors through several example patterns, introducing the 1:1 pattern, 2:1 pattern, and the 3:2 pattern. A fourth "free play" mode encourages further exploration. Within each challenge level, visitors are given the speed of one mirror and a target laser pattern and challenged to set the second mirror to the correct speed in order to match the given pattern. For example, in challenge level one, visitors are given the prompt, "15:?", and a picture of a circular or elliptical laser pattern. When visitors set both mirror speeds to 15, the computer screen indicates a correct answer and changes to a new challenge with the same ratio. After a short amount time, if visitors do not match the pattern, a hint appears on the screen, such as, "mirror 1 and mirror 2 should be going the same speed." After visitors complete three challenges, they are prompted to move to the next challenge level.

Figure 1. Two Participants at the *Laser Light Show* exhibit. The computer guide is to the left of the participant sitting at the control console and the explanatory panel is to his right.

The project team's decision to add the computer guide to the activity was motivated by formative testing and prior literature, which suggested the potential for using challenges and technology to capture visitor attention, guide and scaffold exploration, and encourage deeper engagement. Although empirical evidence is limited, several researchers have argued that challenges are a promising format for supporting visitor engagement at interactive exhibits. For example, based on findings from a series of formative and summative evaluation studies conducted as part of the NSF-funded *Active Prolonged Engagement* (APE) project, Humphrey and Gutwill (2005) recommended posing challenges as a promising approach to focusing "visitors' attention on a subset of options—those required to meet the challenges—while still conveying the notion that there are many other activities to try" (p. 131). Other researchers have suggested that challenges may also help promote “mindfulness” (Screven, 1992) and encourage visitors to frame activities in a way that is more congruent with the goals of exhibit designers (Atkins, Velez, Goudy, & Dunbar, 2009).

Visitors may prefer the additional guidance that challenges can provide even when there is no noticeable impact on their learning behaviors. In an observational and interview study comparing visitor behavior at three different versions of an interactive science exhibit, Gutwill (2006) concluded that visitors in the study preferred the additional guidance of exhibit labels with both questions and suggestions, as opposed to only suggestions or only questions, even though there was no significant difference in visitor behavior across the versions.

In addition to the use of challenges, the project team also speculated that the technology-based format of the computer guide would help capture and focus visitor attention. Despite a growing interest in the use of technology in informal science education (ISE), there has been little research testing its impact and existing studies have primarily focused on usability, rather than learning (Uko & Ellenbogen, 2008). Based on a review of the literature, Uko and Ellenbogen (2008) concluded that there is some evidence that visitors use technology-based exhibits more frequently and for longer periods of time compared to other types of exhibits, perhaps because of a “technological novelty” effect. From a cognitive perspective, novel uses of technology in exhibits might help to provoke visitor interest and renew attention capacity (Bitgood, 2002), although this assertion has not been tested. Uko and Ellenbogen (2008) also speculated, based on classroom research, that technology can help support and scaffold inquiry by encouraging learners to “extend their investigations beyond simply reading exhibit labels or even beyond a one-time visit” (p. 246).

In summary, although the approaches adopted by the project team in the design of *Laser Light Show* are promising, there is little empirical evidence of the impact of technology or challenges on visitor learning and behavior at exhibits. The activity, therefore, provided a timely opportunity to test the impact of a design element combining both approaches.

Hypotheses

For the study, we chose three proximal learning indicators, or short-term outcome measures, aligned with the goals of the project team: (1) how long visitors engaged with the exhibit (engagement time), (2) the extent to which they fully explored the phenomenon embodied by the exhibit (mathematical behaviors), and (3) their ability to articulate, in their own words, the key take-home messages as intended by the project team (articulation of main messages). These measures were also chosen to represent proximal learning indicators valued by exhibit developers and designers and frequently used in the visitor studies and informal science education fields (NRC, 2009; Falk, Dierking, & Foutz, 2007). As we discuss in more detail at the conclusion of the article, the three measures, although frequently used to evaluate or study interactive exhibits, may or may not relate to long-term learning outcomes.

Building on the limited prior research described above, as well as the assumptions of the project team, we tested the following hypotheses:

- Hypothesis 1: Family groups will spend longer at the exhibit version with the computer guide compared to the version without.
- Hypothesis 2: Family groups will exhibit more mathematical behaviors at the exhibit version with the computer guide compared to the version without.

- Hypothesis 3: Adults in family groups will be better able to articulate the main messages in the exhibit after engaging with the exhibit version with the computer guide compared to the version without.

At the outset of the study, we conducted pilot observations, watching visitor groups who independently chose to engage with the activity and actively recruiting groups for testing. Because these pilot observations suggested that the computer guide might have a stronger impact on uncued families compared to cued families, we also designed the study to investigate interaction effects between cueing and experimental condition. In this report, we discuss cueing only when necessary to interpret findings related to the computer guide. Detailed analyses of interaction effects and the impact of cueing visitors will be reported in future publications.

Methods

The study followed a 2 x 2 factorial experimental design, with experimental condition and cueing as the primary factors. We observed and interviewed family groups at one of two versions of the exhibit: (a) the current version, with the computer guide available to visitors (computer condition), and (b) a modified version, with the computer guide covered and only the explanatory label available (non-computer condition). Because of the design of the exhibit, it was possible to cover the computer kiosk with a graphic panel without disrupting the essential interactive elements of the activity. The graphic panel used in the non-computer condition duplicated the introductory screen shown on the computer kiosk, orienting visitors to the purpose of the activity and the mirror speed controls. All other elements of the exhibit, including the explanatory panel, were available to visitors in both conditions. Half of participant groups were actively recruited (cued) to participate in the study and half were observed without being cued (uncued).

Sampling and Recruitment

The target population for the study was families with children visiting OMSI who chose to enter the *Design Zone* exhibition. We defined families as visitor groups with at least one adult 18 or older and one child between the ages of seven and 17. The primary target audience of the *Design Zone* project was 10- to 14-year-olds with their families. For this study, the target age group was broadened in order to more fully represent the diversity of OMSI visitors and to ensure that study findings would be relevant to a broad range of museums and science centers. During project formative testing, evaluators also observed that families with children younger than 7 years old were less likely to engage in mathematical talk and behaviors.

The target sample size was 128 families, evenly distributed between the four experimental groups (32 families per condition). Assuming an alpha level of 0.05, this sample size provided acceptable power (0.80) to reliably detect medium effect sizes ($f = 0.25$) for both main effects and interactions (Faul, Erdfelder, Lang, & Buchner, 2007). We collected data on four weekends between April 16 and May 22, 2011. The data collection each day was divided into two time blocks: morning (10 AM to 1 PM) and afternoon (1:30 PM to 4:30 PM). Rotation of cueing condition was structured to ensure that each condition was equally represented for each time block and for each weekend day, Saturday and Sunday, across the data collection period. For example, if data were collected from uncued participants on Saturday morning, participants would be cued the morning of the following Saturday.

The procedures for sampling and recruitment depended on cueing condition (see below). Families in both groups were offered two free museum admission passes for participating in the study. Following Gutwill (2003), the data collector alternated between the computer and non-computer conditions, by removing or replacing the covering over the computer screen, each time data from two family groups had been collected. At the end of the observations, the data collector approached the family and asked one adult to participate in a post-interaction interview. If there was more than one adult family member, the data collector allowed the group to self select who participated in the interview. This approach was chosen based on the assumption that adults play a key role in family learning in museums (e.g., Crowley et al., 2001; Crowley & Palmquist, 2007; Fender & Crowley, 2007; Gleason & Schauble, 2000), as well as to limit the time commitment for participants.

Cued participants. For cued participants, we used a systematic random sampling approach (Bernard, 2006). The data collector drew an imaginary line in front of the entrance to the exhibition and recruited the first family in the target population that crossed the line, with child age estimated by the data collector. Families that gave verbal consent to participate were led to the exhibit. After that observation was complete, the data collector returned to the exhibition hall entrance and recruited the next family in the target audience that crossed the imaginary line. This process of systematic random sampling is common in museums and other settings where simple random sampling is difficult or impossible (Diamond, 1999). During the study, the exhibit was closed off by stanchions to minimize interruptions by other visitors. The observations began when all the members of the group were inside the stanchions and ended when the last adult left the stanchioned area. Families sometimes split up after being recruited for the study, such as when one adult took several children to the exhibit while a second adult left with other family members.

Uncued participants. By necessity, uncued families self-selected to participate in the study. A sign notifying visitors about the research was posted in front of the exhibit and all families and visitor groups were allowed to engage with the activity. Stanchions placed around the sides of the exhibit helped to discourage multiple groups from interacting with the exhibit at the same time. Although all visitor groups were allowed to interact with the activity, we only collected data from groups in the target population. Observations began when one adult and a child entered the stanchioned area together, a child joined an adult family member inside, or an adult joined a child family member inside. The observation ended when the last adult in the family group left the stanchioned area. Groups that engaged with the activity for less than 30 seconds or did not create at least one laser pattern were not included in the analysis. Groups that declined to participate in the interview were also not included.

Data Collection

We collected data through both naturalistic observation and post-interaction interviews with families. For each family, the data collector recorded the total engagement time and the mirror speeds for each laser pattern that the visitors created, as indicated by a family member pausing for at least two seconds on a pattern. At the end of the interaction, the data collector asked one adult family member two open-ended questions to elicit his or her understanding of the exhibit main messages: (a) what would you tell another visitor this exhibit is about? and (b) what do you hope the child/children in your group learned from this exhibit? We also collected demographic data, including family size, child and adult gender, age of children, frequency that the adult interviewee had visited OMSI in the last six months, and whether or not the adult had visited the *Design Zone* exhibition before.

Based on the goals of the exhibition, the primary dependent variables in the analyses were engagement time, number of mathematical behaviors, and level of articulation of exhibit main messages. For the analyses reported in this article, the primary independent variable was experimental condition. Engagement time was measured as the total time families spent at the activity from start to end of the observations. For number of mathematical behaviors, we calculated the total number of *unique* laser patterns that visitors created for seven of the most common ratios (1:1, 2:1, 1:2, 3:2, 2:3, 3:1, and 1:3). To be counted as unique, a pattern could match the simplified ratio of a previously created pattern as long as the numerator and denominator of the pattern were distinct (e.g., 20:40 and 15:30 would both be counted as unique patterns but 20:40 and 20:40 would not). We chose to focus on this subset of seven ratios with the assumption that families are more likely to intentionally choose these ratios and to understand their underlying mathematics. During pilot observations, these ratios included the vast majority of patterns created by families. Furthermore, the results of the analyses were substantively equivalent when a broader range of ratios was included (e.g., any ratio with a simplified numerator and denominator no larger than six). Two data collectors were present during the first two days of testing in order to check interrater reliability of the observational data. Interrater reliability of total number of unique patterns across the first 33 observations (25.8% of all observations) was extremely high (Pearson's correlation, $r = 0.978$). For all subsequent analyses, only data from the primary data collector were used.

Articulation of the main messages in the exhibit was determined by coding and ranking adult interviewees' combined responses to the two open-ended interview questions. Aligned with the project team's goals, coding focused on the degree to which visitors articulated the mathematical relationships embodied by the exhibit. Two of the authors developed the initial codebook, which was based on findings from pilot testing, and coded all 128 responses. The remaining author, who had not participated in the development of the initial codebook, then coded the first 58 interviews (45.3% of the total). Interrater agreement for these responses was 70.7%. After disagreements were resolved and the codebook updated, the third author coded the remaining 70 responses (54.7% of the total). Interrater agreement for the second round of coding was very high (87.1%). The final codebook defined four levels of successively more sophisticated articulations of the mathematical relationships in the exhibit: (1) no mathematical content, (2) identifying mathematical elements of the exhibit, (3) relating two mathematical elements, (4) relating three mathematical elements, and (5) generalizing relationships. If adults mentioned at least one of the mathematical elements in the exhibit, such as the speed of the mirrors or the shape of the laser pattern, their responses were coded as level 2. If the adults described a mathematical connection between these elements, their responses were coded as level 3 or 4, depending on the number of elements described. When adult visitors articulated a generalized relationship between the mathematical elements of exhibit, such as how the laser always traces a circle or an ellipse when both mirrors are oscillating at the same speed, their responses were coded as level 5.

Data analysis. All data were entered into Microsoft Excel and imported to *SPSS 18.0* for analysis using descriptive and inferential statistics. When data met the appropriate assumptions, such as normal distribution and homogeneity of variance, we used parametric statistics. In other cases, we used the equivalent nonparametric tests. All effect sizes were calculated following Field (2009). Hypothesis tests were one-tailed unless specified, using a critical value of 0.05. For categorical variables and variables with distributions that differed substantially from normal, we report the median as the measure of central tendency, with confidence intervals calculated without distributional assumptions.

Results

Participant Description

The sample included 128 families groups, representing 387 individuals (176 adults and 211 children). There were 64 groups in both the computer and non-computer conditions. In general, groups were small, with a median of three total group members (range: 2-9) and one child per group (range: 1-7). The average child age was 9.8 (*SD* = 2.52, 95% CI = 9.32–10.20). Adult and child participants were evenly split by gender. Similarly, the gender of self-selected adult interviewees was closely split between males (52.3%) and females (47.7%). Only 14.8% of adult interviewees indicated that they had visited the *Design Zone* exhibition previously. The majority (64%) of adult interviewees indicated that they had not visited the museum in the last six months (range: 0-12 previous visits). Table 1 summarizes general family characteristics.

There were no statistically significant differences between the computer and non-computer groups based on total group size, number of children per group, proportion of female adults in each group, proportion of female children in each group, or proportion of female adult interviewees. There were statistically significant differences, however, in mean child age, proportion of adult interviewees who had previously visited the exhibit, and number of times adult interviewees reported having visited OMSI in the last six months. The mean rank for average child age within each group was higher for the computer group (*Mdn* = 10.0, 95% CI = 9.25– 11.00, range: 6.0–16.0) than for the non-computer group (*Mdn* = 9.0, 95% CI = 8.00–9.25, range: 5.5–15.5), two-tailed test, *U* = 1468.50, *p* = 0.006, *r* = -0.245. Also, a greater proportion of the non-computer group indicated that they had previously visited the exhibition (28.1%) compared to the computer group (1.6%), Fisher's exact test, p <0.001. Finally, the mean rank for reported number of OMSI visits in the last six months was higher for the non-computer group (*Mdn* = 0.0, 95% CI = 0.00–1.00, range: 0–12) than for the computer group (M = 0.0, 95% CI = 0.00–0.00, range: 0–4), two-tailed test, U = 1512.50, p = 0.003, r = -0.263. None of these demographic variables were significantly correlated with engagement time, total number of laser patterns, or level of articulation of the mathematical relationships in the exhibit.

Table 1. *Characteristics of Families Visiting the Laser Light Show Activity*

		95% CI	
Characteristic	*M* (*SD*)	LL	UL
Group size	3.02 (1.17)	2.82	3.23
No. of children	1.65 (0.94)	1.48	1.81
Average child age	9.76 (2.52)	9.32	10.20
Proportion female adults	0.47 (0.43)	0.40	0.55
Proportion female children	0.49 (0.44)	0.41	0.57
Visits in last six months	1.04 (1.97)	0.69	1.38

Note. N=128. CI = confidence interval; LL = lower limit, UL = upper limit.

Engagement Time (Hypothesis 1)

The median time families spent at the exhibit was 4.74 minutes (95% CI = 3.75-5.57), with total engagement times ranging between 0.58 and 17.85 minutes. The difference between the computer and non-computer groups was statistically significant (U = 1574.50, p = 0.023, r =

-0.178). Families in the computer group spent longer on average at the exhibit (*Mdn* = 5.57, 95% CI = 4.02-6.58) compared to the non-computer group (*Mdn* = 3.77, 95% CI = 2.85-5.17). Even uncued families spent a substantial amount of time at the exhibit. Excluding cued families, the median engagement time was 2.12 minutes (95% CI = 1.50-2.93).

Mathematical Behaviors (Hypothesis 2)

Families created an average of 7.02 unique laser patterns (*SD* = 4.564, 95% CI = 6.23-7.82) using a variety of different mathematical ratios. The total number of unique ratios created ranged between 0 and 17. Seven groups (5.5%) did not create any laser patterns using ratios included in the analysis. As with engagement time, the difference in the number of patterns created by the computer group and non-computer group was statistically significant ($t = 2.804$, $p = 0.003$, $r = 0.24$). On average visitors in the computer group created more laser patterns (*M* = 8.125, *SD* = 4.57, 95% CI = 6.98-9.27) compared to the non-computer group (*M* = 5.922, *SD* = 4.31, 95% CI = 4.84-7.00).

Articulation of Mathematical Relationships (Hypothesis 3)

Just under half (46.1%) of all adult interviewees discussed a relationship between at least two mathematical variables when describing the main message of the exhibit (levels 3, 4, or 5). Adults were most likely to be coded as identifying at least one mathematical element in the exhibit (50%; level 2), such as the mirror speeds or the laser patterns. The median coding level for the entire sample was 2.0. Although the difference in mean rank between the computer and non-computer groups was statistically significant (two-tailed test, $U = 1441.50$, $p = 0.002$, $r = -0.279$), the direction of the relationship was contrary to our expectations. Interviewees from the non-computer group were more likely to articulate the mathematical relationships in the exhibit at a higher level (*Mdn* = 3.0) compared to the computer group (*Mdn* = 2.0). In the non-computer group, 59.4% of adult interviewees discussed a relationship between at least two mathematical variables in the exhibit (coding level 3 or higher), compared to 32.8% of interviewees in the computer group.

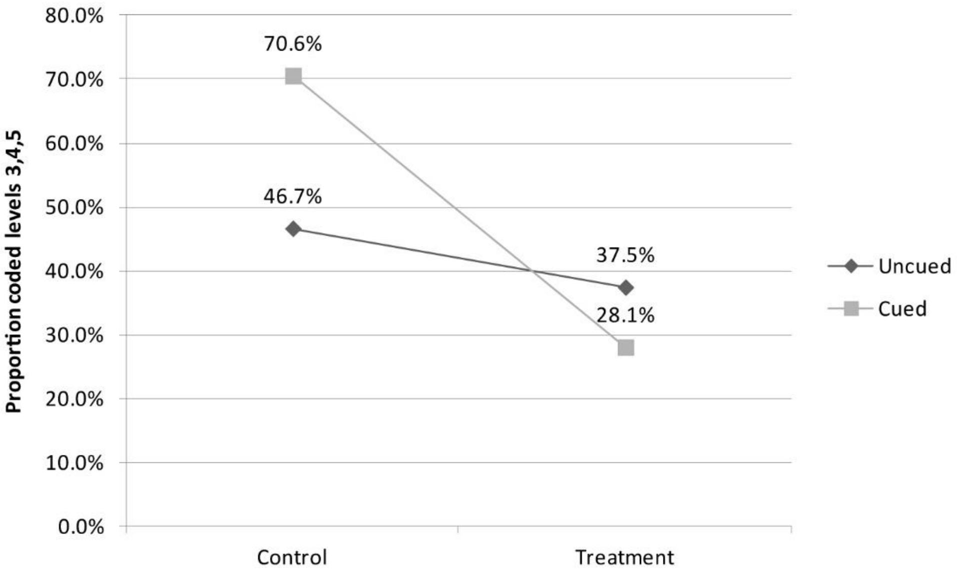

Figure 2. Percent of adult interviewees who discussed a relationship between at least two mathematical variables in the exhibit (levels 3, 4, or 5), by cueing and experimental condition. The difference between the computer and non-computer groups was statistically significant for cued families (two-tailed test, U = 305.00, p = 0.001, r = -0.410, N = 66) but not for uncued families (two-tailed test, U = 416.50, p = 0.326, r = -0.125, N = 62).

Further analysis revealed that there was an interaction between level of articulation of the mathematical relationships and whether or not participants were cued or uncued. For uncued families, the difference in mean rank between the computer (*Mdn* = 2.0) and the non-computer group (*Mdn* = 2.0) was not statistically significant (two-tailed test, *U* = 416.50, *p* = 0.326, *r* = -0.125). In contrast, there was a large and statistically significant difference between the computer and non-computer groups for cued families (two-tailed test, $U = 305.00$, $p = 0.001$, $r = -0.410$), such that participants in the non-computer group were coded at a higher level on average (*Mdn* = 3.0) compared to participants in the computer group (*Mdn* = 2.0). This interaction is shown in Figure 2.

Discussion

For the *Laser Light Show* activity, the *Access Algebra* project team used a computer guide to promote deeper visitor engagement and algebraic thinking. Capitalizing on this work, we tested the impact of the guide using three proximal measures of visitor learning. The results supported both hypotheses 1 and 2. On average, visitor groups who had access to the computer guide spent longer at the exhibit and engaged in more mathematical learning behaviors compared to those who did not. Although effect sizes for differences in engagement time and mathematical behaviors were small to medium ($r < 0.25$), the impacts were substantial relative to the length of a typical interaction at a museum exhibit. The difference in average engagement time between the non-computer group and the computer group represented a 23% increase. Similarly, the difference in average number of learning behaviors between the non-computer and computer group represented a 37% increase. These effects are striking given the wide range of backgrounds, knowledge levels, prior experiences, and demographics represented by science center visitors.

In contrast to hypotheses 1 and 2, hypothesis 3 was not supported. For uncued families, visitors in the non-computer group articulated the mathematical relationships in the exhibit at about the same level on average compared to visitors in the computer group. Surprisingly, for cued families, visitors in the non-computer group articulated the mathematical relationships in the exhibit at a higher level on average compared to visitors in the computer group. In general, therefore, it appeared that the addition of the computer guide encouraged family groups to spend longer at the exhibit and explore the mathematical phenomenon more fully but had no effect on, or in some cases interfered with, their ability to articulate the mathematical relationships underlying the activity.

Although we did not directly test which elements of the computer guide influenced visitor behavior and learning, we can speculate based on findings from prior research. An important aspect of the computer guide was the posing of challenges to motivate and help structure visitor engagement. As described above, prior research has indicated that challenges are an effective approach to fostering active, prolonged engagement at museum exhibits (Gutwill, 2006; Humphrey & Gutwill, 2005). From a sociocultural perspective, challenges also represent a potential scaffolding tool for individuals within a group facilitating learning for others. For example, research has documented that parents use signage to support family learning (Ash, 2002, 2003, 2004a, 2004b; Rowe, 2005). As a form of scaffolding, challenges may help foster experiences within visitors’ zones of proximal development (Quintana et al., 2004; Wood, 2001).

More generally, the presentation of the challenges using a computer kiosk may have supported visitor engagement. This format takes advantage of the potential attracting power of technology and the opportunity for more dynamic presentation and feedback (Uko & Ellenbogen, 2008). The impact of technology may explain why Gutwill (2006) found that visitors preferred a “questions and suggestions” label compared to other signage at an interactive exhibit but did not, in contrast to the present study, observe measurable differences in visitor learning behaviors elicited by the different label formats. Although the “questions and suggestions” label format is similar to the challenges presented in the *Laser Light Show* exhibit, the more compelling format and dynamic scaffolding provided by the computer guide in this study may be more likely than static exhibit labels to promote prolonged engagement.

The attraction of the computer guide might also help explain the unexpected finding that visitors in the computer group were just as likely or, in the case of cued visitors, less likely to articulate the mathematical relationships in the exhibit at a higher level compared to the non-computer group. Although communicating the nature of the mathematical relationships was a primary goal of the project team, only the printed explanatory label, situated to the right of the activity controls, included a clear and concise statement of the main message: “The laser pattern depends on the relationship (ratio) between the speed of mirror 1 and the speed of mirror 2.” By being encouraged to focus on the computer guide, visitors in the computer condition may have been less likely to read the explanatory panel and, therefore, less likely to have exposure to the simple and accessible summary of the mathematics. This effect may have been particular pronounced for cued families because, we speculate, this group was more diligent about reading the explanatory panel in the absence of the computer.

The presence of the computer guide also may have limited social learning or reframed the purpose of the activity for visitors. Based on qualitative research, Heath, Vom Lehn, and Osborne (2005) highlighted how computer-based exhibits, and especially computer kiosks designed for single users, can limit social interaction. If adults were less likely to become actively involved in the activity when the computer guide was present, they would have had more trouble describing the mathematical relationships in the exhibit during the interviews. The computer guide may also have reframed the activity for visitors, focusing more of their attention on the achievement of the challenges themselves rather than the exploration of the mathematics. Atkins, Velez, Goudy, and Dunbar (2009), for example, found that the introduction of an exhibit label to an interactive science exhibit could dramatically shift the nature and focus of visitor interactions.

Implications

The results of this study provide empirical evidence for the potentially powerful impact that scaffolding tools, such as computer guides, can have on visitor behavior and learning. Given the brief amount of time visitors typically spend at an exhibit, identifying design elements that can reliably increase engagement times and the degree to which visitors fully explore the phenomenon of the exhibit by 20 to 40% is not trivial. As museums and science centers take on more ambitious educational goals, such as engaging visitors in mathematical and scientific inquiry or fostering conversations around the nature science, finding strategies for extending and deepening visitor engagement becomes more critical. The computer guide tested in this study also holds promise for enhancing existing exhibits. Without the computer kiosk, the *Laser Light Show* activity is similar to many open-ended, phenomenon-based exhibits at science centers across the country. Adding technology-based scaffolding tools to these types of exhibits may be a relatively cost-effective way for science centers to enhance the visitor experience.

Despite the promise of the computer guide, however, study findings also highlight the need to think carefully about the trade-offs of such scaffolding tools and their alignment with project goals. Although it is not clear from the data why families in the computer group were just as likely or less likely to articulate the mathematical relationships at a higher level compared to the non-computer group, prior research suggests that the presence of the computer kiosk may have decreased the likelihood that families attended to messages in the printed signage, inhibited engagement by adult family members, or reframed the purpose of the activity. At the very least, designers should take care that the focus of the scaffolding tool aligns with the learning goals of the exhibit. This includes ensuring that key messages are embedded within the scaffolding tools, in addition to any other printed signage. The results of the study also highlight the potential "tension that can arise between designing exhibits to support scientific content versus scientific inquiry processes" (Allen, 2004, p. S26). Scaffolding tools that afford the former goal may not be well suited for supporting the latter. Because the context and goals of each exhibit are unique, formative testing will always be critical for determining how scaffolding tools such as computer guides will impact visitor learning and behavior at a specific exhibit.

Limitations and Future Research

In the *Active Prolonged Engagement* project, the developers and researchers tested a variety of exhibits, measured their impact on visitor engagement, and then speculated on the characteristics of those exhibits that contributed to the research findings (Humphrey & Gutwill, 2005). The current study extends this work by testing the impact of a specific exhibit element and providing practitioners with strong empirical evidence of its effect on three proximal measures of visitor learning. Further research is needed to identify how specific aspects of the computer guide influence visitor learning behaviors. This research can contribute to the ongoing refinement of our understanding of exhibit design through successively more focused intervention studies. In addition, researchers should consider collecting more detailed data on visitor talk and behavior in order to better understand the advantages and trade-offs of using a computer interface to scaffold visitor engagement and the mechanisms by which computers influence behavior and learning.

In this investigation, we adopted three proximal measures of visitor learning often used by evaluators to assess the effectiveness of interactive exhibits and by researchers to study learning and behavior in ISE settings. An important challenge for the field is to understand how measures of learning behaviors documented in this study relate to long-term outcome measures, such as improved conceptual understanding of mathematical relationships, development of mathematical inquiry skills, or increased interest in mathematics. The relationship may be complex, with different proximal measures relating to different long-term outcomes. For example, engagement time may be a better indicator of the potential for long-term interest development, while number of exhibit behaviors may support the development and transfer of mathematical inquiry skills. As in this study, a lack of correlation between different outcome measures does not necessarily undermine the validity of those measures. For example, in an investigation of family interactions at 25 different children's museum exhibits, Sanford (2010) found that engagement time, learning behaviors, and family conversations all provided unique and different indicators of the family learning experience.

Museums still have much to learn about designing effective scaffolding tools. Researchers and practitioners should look to other fields, such as formal education or media design, to begin to build a theoretical understanding of how scaffolding supports learning in ISE settings. Quintana and colleagues (2004), for example, proposed a framework for designing effective scaffolding that highlighted the importance of supporting sense making, process management, and articulation and reflection. As the use of technology in exhibits becomes more common, designers can explore ways to provide more dynamic and responsive scaffolding, including the ability to decrease assistance as participants gain experience and competence (Azevedo, Cromley, & Seibert, 2004; Wood, 2001). In a social learning context, such as a family visit to a science center, it is also important to acknowledge that families bring with them an array of learning strategies (Astor-Jack, Whaley, Dierking, Perry, & Garibay, 2007; Dierking & Falk, 1994; Ellenbogen, Luke, & Dierking, 2007; NRC, 2009) and that scaffolding tools provided by an institution may or may not be used as intended. Acknowledging that human beings continue to be much more sophisticated supporters of learning than existing technologies (Wood, 2001), scaffolding tools should be designed to support and enhance, rather than replace, the social dynamics of group learning.

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