GEOMETRY PLAYGROUND
PATHWAYS STUDY

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EXECUTIVE SUMMARY

The Geometry Playground Pathways research project explored the effects of in-school and museum-visit activities (Pathways) designed to deepen students’ field trip experiences with several geometry exhibits. The Exploratorium, a San Francisco science museum, often develops Pathways materials linked to specific exhibits to provide teachers with age-appropriate pre-, during-, and post-field trip activities tied to school curriculum and standards. Pathways are thought to support students’ field trip learning, including improving attitudes and aiding understanding of the focal topic. This particular study investigated the effects of Pathways connected to a geometry exhibition, Geometry Playground, on San Francisco elementary school students’ attitudes toward geometry and spatial reasoning abilities.

The study, originally a pre/post control group design, became a post-only control group design in order to eliminate student class time spent on outcome measures. Six paired classrooms participated, each pair consisting of two same-grade classes from the same school. Each member of the pair was randomly assigned to one of two conditions, either Pathways or Control. Student measures from all Pathways classrooms were pooled (n = 62) and compared to student responses from all Control classrooms (n = 50).

Results\(^1\) indicate:

- **Significantly higher attitudes toward geometry** for Pathways students compared to Control students.
- **Significantly higher geometry self-confidence** for Pathways students compared to Control students. Lending to discriminant validity, math self-confidence scores were found to be equivalent for the two groups.
- No significant differences between Pathways and Control students’ spatial reasoning scores.

The results of the Geometry Playground Pathways study support claims that museum-developed pre-, during, and post-visit activities can enhance the efficacy of school field trips (Griffin, 1998a). In particular, the results support the notion that such activities can lead to improved attitudes toward the focal topic (e.g., geometry), above and beyond the positive effects of field trips devoid of classroom integration. These results also suggest that integrating classroom curricula with field trip activities can enhance students’ self-confidence in a topic area rife with anxiety. Such positive attitudinal effects are related to academic success and career choice (Xin, 1999), making them a necessary focus for schools; a focus that museums are equipped and eager to support.

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\(^1\) All comparisons were made using an analysis of variance (ANOVA) and were considered significant at the p < .05 level.
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INTRODUCTION

With support from the Moore Foundation and the National Science Foundation, the Exploratorium, a San Francisco science museum, is developing a set of pre-, during-, and post-museum visit activities, *Geometry Playground Pathways*, tied to a set of geometry exhibits. These Pathways offer an easily accessible way to bridge the gap between museum and school, perhaps ameliorating some negative associations students have with school geometry and potentially enhancing the educational effectiveness of museum field trips. Exploratorium researchers recently worked with several San Francisco schools in an effort to determine the effects of these Pathways on geometry attitudes, confidence, and skills of field trip students.

ENHANCING THE EDUCATIONAL EFFECTS OF FIELD TRIPS

Museums have long been interested in improving the educational value of field trips (DeWitt & Storksdieck, 2008b). Recent research has shed light on some of the conditions associated with maximizing learning during a field trip. One important factor is students’ prior knowledge (Falk & Dierking, 1992; Feher & Rice, 1985; Griffin & Symington, 1997). When students have a basic understanding of a concept, they can use this knowledge to make sense of exhibit phenomena. (Beiers & McRobbie, 1992; Tuckey, 1992). Additionally, teachers in the US and abroad have voiced a need for more curricular integration with field trips (Anderson, Kisiel, & Storksdieck, 2006). Knowing this, many educational researchers have recommended strengthening connections between classroom curriculum and museum content (e.g., Griffin, 1998b), but few teachers succeed in identifying or supporting those connections (Rennie & McClafferty, 1995).

There are several reasons why teachers may not be able to draw strong connections between the two domains (DeWitt & Storksdieck, 2008a). Teachers may not know how to use a museum as an educational resource; some studies have shown that pre-trip instruction is most effective when the teacher is trained by museum staff (Balling & Falk, 1980 cited in Rennie & McClafferty, 1995) and when the teacher is involved in design and running of the visit program (Price & Hein, 1991). Other inhibitors for teachers include the extra time needed to prepare closely linked materials, the difficulty in finding exhibits with tailor-made programs and content (Xanthoudaki, 1998), or the complexity or accessibility of existing, museum-developed pre-, during, or post-activities (Burtynk & Combs, 2005).

To better connect the worlds of museums and schools, researchers have studied the effects of museum-developed pre- and post-visit activities on student learning. Most studies have investigated orientation or novelty-reducing activities that serve to help children familiarize themselves with the museum environment so they can learn more effectively (Balling & Falk, 1980; Griffin, 2004; Kubota & Olstad, 1991; Lucas, 2000; Wolins, Jensen, & Ulzheimer, 1992). Meanwhile, research on content-based pre- and post-visit activities is more rare. DeWitt and Osborne (2007) developed an overall museum visit framework that includes activities designed to help students integrate topics from the classroom into the museum experience. Before their visit, students chose from a list of questions to investigate during their visit to the Science Museum, London. After gathering some information during the field trip, students also used...
supplementary materials provided by DeWitt to complete a detailed class presentation about their topic. DeWitt found that the larger museum framework including these pre- and post-activities reinforced learning and promoted collaboration. To our knowledge, only one study has attempted to isolate the effects of content-linked pre-visit classroom activities. Gennaro (1981) provided eighth grade earth science teachers with four days of pre-visit instructional materials that presented both generalized concepts and specific vocabulary. These pre-visit materials were content-linked to an earth-science film called “Genesis,” which students viewed during a field trip to a science museum. Following the field trip, analysis of pre- and post-test data indicated that such pre-visit activities did increase content learning from the informal setting.

The Geometry Playground Pathways project aimed to enhance students’ field trip experience while addressing teachers’ needs for more curricular integration (Anderson et al., 2006). To that end, the Geometry Playground Pathways activities were developed to align with the San Francisco Unified School District’s Balanced Score Card, the 4th and 5th grade curriculum Scope and Sequence, and the Mathematical Content Standards for California Public Schools.

THE IMPORTANCE OF SPATIAL REASONING SKILLS AND ATTITUDES

This project attempted to help students build spatial reasoning skills, a key aspect of geometric learning and understanding. Spatial reasoning skills are “those mental skills concerned with understanding, manipulating, reorganizing, or interpreting relationships visually” (Tartre, 1990, p. 216). In practice, this means visualizing objects from multiple perspectives; rotating, flipping or inverting mental objects; recognizing spatial relationships among objects; and perceiving spaces and their properties.

Research has shown that spatial reasoning itself is a necessary skill for learning science and mathematics in general, and geometry in particular (M. T. Battista, Clements, Arnoff, Battista, & Van Auken Borrow, 1998; Ben-Chaim, Lappan, & Houang, 1989; Pallrand & Seeber, 1984; Tartre, 1990; Tracy, 1987). For example, elementary and high school students with high spatial reasoning skills are better able than those with low skills to approximate the magnitude of figures, comprehend and efficiently solve math problems, and build on prior knowledge by linking new problems to similar problems they have already encountered (Brown & Wheatley, 1989; Tartre, 1990). A similar relationship between spatial reasoning and problem solving has been found in physics (Pallrand & Seeber, 1984). Studies with children ages 3-13 have found that gender differences in spatial abilities are significantly predictive of children’s scores on math and science achievement (Tracy, 1987). In fact, there is growing evidence that spatial visualization skills are central to mathematical and scientific cognition (see Bryant & Squire, 2001; Butter, Eisenberg, Garcia, Lewis, & Nielsen, 2003; Ferguson, 1992; Mathewson, 1999; Miller, 1984), and the positive relationship between mathematics achievement and spatial reasoning has been found at all grade levels (see Fennema & Tartre, 1985 as cited in Clements & Battista, 1992). Fortunately, spatial reasoning skills can be taught (M. G. Battista, Wheatley, & Talsma, 1982; Pallrand & Seeber, 1984). The Geometry Playground Pathways study provides students with multiple hands-on opportunities to practice their spatial reasoning skills and explores whether such integrated practice can strengthen students’ spatial reasoning abilities.
Another aspect of this study focuses on students’ attitudes about mathematics, particularly geometry. Attitudes toward math are often negative, and those negative attitudes can have damaging effects on academic success and later career choices. A meta-analysis has shown that higher anxiety (including worry, lack of confidence, discomfort, dislike, and fear) is consistently and significantly related to lower classroom grades and other mathematics measures (Xin, 1999). Unlike other subjects such as language, it is acceptable to dislike and perform poorly in mathematics (Burns, 1998; Latterell, 2005; Paulos, 1988). According to the South Carolina Mathematics Framework (1993), “Mathematics is perceived by many to be difficult and demanding and is considered to be a subject in which it is socially acceptable to do poorly.” Many educational researchers believe that positive attitudes toward science and math are necessary if improvements to education are to be realized (e.g., Reynolds & Walberg, 1992; Slate & Jones, 1998). Importantly, researchers have found that negative views of mathematics and science make it less likely that students will later choose science careers (Stangor & Sechrist, 1998; Tai, Qi Liou, Maltese, & Fan, 2006).

Fortunately, experiences with mathematics in museums can give students a "safe" way to take intellectual risks, and create positive associations with this difficult subject. A variety of studies have found that field trips often lead to positive attitudes toward curricular topics (Dancu, 2005; Flexer & Borun, 1984; S. G. Paris, K. M. Yambor, & B. Wai-Ling Pacard, 1998). Other studies have found that visits to science museums are positively related to students' later interests in Science, Technology, Engineering, and Math careers (Salmi, 2001, 2002; Tai et al., 2006). In this vein, the Geometry Playground Pathways research aimed to assess the attitudinal impacts of museum-designed classroom and field trip activities, and measure the impacts on the anxiety students associate with geometry.

PURPOSE OF THE STUDY

The main goal of the Geometry Playground Pathways project was to create in-school and museum-visit activities (Pathways) and to determine whether these activities enhance students' attitudes toward geometry and spatial reasoning abilities, beyond the effects of a typical field trip visit. The Exploratorium offers Pathways for several school subjects: materials linked to specific exhibits that provide teachers age-appropriate pre- and post-field trip activities for the classroom. Pathways are thought to enhance students’ field trip experience, including aiding understanding and improving attitudes toward the focal topic. This study investigated the effects of Pathways connected to a geometry exhibition, Geometry Playground, on San Francisco elementary school students.

METHODS

PARTICIPANTS

Participants consisted of 4th and 5th grade school children and their classroom teachers. We recruited pairs of classroom teachers (same grade, same school) from an Exploratorium database of San Francisco public schools from which field trips to the Exploratorium had occurred between the years of 2006 and 2008. We randomly assigned the teachers’ classrooms to the Pathways or Control conditions; teachers (and students) were kept blind to the purpose of the study and the conditions to which they were assigned. We asked teachers to refrain from
discussing any aspects of the study until the close of the research. Teacher pairs from eight San Francisco schools were initially interested, and 12 teachers (6 pairs) from four geographically diverse schools officially enrolled in the study. Two classroom pairs were dropped due to delays in obtaining parental permissions or sharing of Pathways materials within the pair. Later analysis revealed that one Control classroom was significantly different from the other Control classrooms (and likewise for the Pathways classroom from the same pair) leading us to drop that pair from the study. Therefore, the final results are based on 112 students from six classrooms (62 Pathways students and 50 Control students) from two San Francisco schools (see Table 1).

Table 1. Research participants.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number of classrooms</th>
<th>Number of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathways</td>
<td>3</td>
<td>62</td>
</tr>
<tr>
<td>Control</td>
<td>3</td>
<td>50</td>
</tr>
</tbody>
</table>

RESEARCH DESIGN

The original study design incorporated pre- and post-assessments in Pathways and Control classrooms. Pre- and post-designs remove students’ initial differences and focus on the change for each student in each outcome. However, changes to the SFUSD classroom research governance eliminated researcher access to collect student data in the classroom, in order to preserve classroom time for coursework only. This change in access affected the research in two major ways:

1. We could only assess the students at the museum, necessitating a change to a post-only experimental design. A post-only design has less power to detect small effects.

2. Because we could not conduct follow-up assessments after the museum visit, we did not ask students to complete the follow-up Pathways activities designed to reinforce what they did at the museum. This may have reduced the size of the effects the study was originally designed to measure.

The final study was a post-only control group design (see Table 2 for a summary of the research activities). Students in the Pathways condition used two spatial reasoning activities related to the geometry curriculum before the field trip; their chaperones were given a sheet with an orientation map and a few inquiry question suggestions, to use with the students during their field trip; and each class received the typical Exploratorium field trip orientation. Control students used two non-spatial activities related to the general math curriculum prior to the field trip; and each class received the typical Exploratorium field trip orientation.

TREATMENT AND CONTROL CURRICULA

Both Pathways and Control condition classrooms used Exploratorium-developed curricular activities during the two weeks prior to their museum visit. The Pathways classroom activities were developed to relate specifically to the focal exhibition, Geometry Playground, at the museum, and emphasized spatial reasoning skills promoted at two specific exhibits. For example, one activity asked groups of four students to explore the polygons they could make by each holding onto the same loop of string and repositioning their hold on the string (see Figure 1 for an example page from this activity). Students were then asked to tape their favorite shape onto the floor to each draw that shape from four different vantage points. At the related museum

Exploratorium
exhibit, called Personal Space, students walk around on a large floor that has a set of lines projected on it from overhead (see Figure 2). The lines maintain a distance halfway between every two people (using a Voronoi algorithm); so the resulting polygons, including the number of sides and their size, depend on where people stand in relation to one another. The students move around on the floor, making a variety of different shapes together and viewing them from multiple vantage points. The Pathways activity and the exhibit help students build spatial reasoning skills, such as mental rotation. The Control classrooms used activities based on general math, but unrelated to the focal exhibition or spatial reasoning.

Figure 1. Example Pathways page. Figure 2. Personal Space exhibit.

All field trips were scheduled for non-overlapping days. On the day of the field trip, both Pathways and Control teachers were met at the museum entrance by an Exploratorium researcher and an Explainer (Explainers are college students who explain exhibits on the museum floor and conduct field trip orientations). For each group, the researcher reviewed the day’s schedule with the teacher and chaperones. Teachers and chaperones in Pathways classrooms were given a copy of the in-museum Pathways activity (they had also received this component of the Pathways in their earlier materials). This portion of the Pathways was a half-page front and back: one side provided a map of the museum, while the other provided three simple inquiry questions similar to the questions raised in the in-class Pathways activities. Control classrooms did not receive any in-museum activities. Both the Pathways and Control classrooms received an Explainer-led orientation by the same Explainer. The orientation ended at the Geometry Playground area of the museum. Students and chaperones were free to move in and out of that focal area as they wished for about an hour.
Table 2. Summary of research activities.

<table>
<thead>
<tr>
<th>Condition</th>
<th>In-class activities</th>
<th>Museum visit</th>
</tr>
</thead>
</table>
| **Pathways** | Two in-class activities were developed by the Exploratorium to:  
  • **emphasize spatial reasoning skills,**  
  • **relate specifically to the focal exhibition *Geometry Playground,* and**  
  • connect with school curriculum and standards. |  
  • Teachers and chaperones were met by a researcher at the museum entrance to review the day’s schedule.  
  • **Museum researcher supplied teachers and chaperones in-museum Pathways sheet.**  
  • Classes met at the entrance by Field Trip Explainer who conducted the typical Exploratorium Field Trip Orientation  
  • Classes dropped off at the Geometry Playground exhibition, free to move in and out of the area and explore as they pleased.  
  • 1 hour later, classes met by museum researcher and led to a classroom for assessments.  
  • Classes returned to the museum floor to explore as they pleased. |
| **Control** | Two in-class activities developed by the Exploratorium that were purposefully:  
  • unrelated to spatial reasoning skills,  
  • unrelated to the focal exhibition *Geometry Playground,*  
  • still connected to school curriculum and standards in math. |  
  • Teachers and chaperones were met by a researcher at the museum entrance to review the day’s schedule  
  • Classes met at the entrance by Field Trip Explainer who conducted the typical Exploratorium Field Trip Orientation  
  • Classes dropped off at the Geometry Playground exhibition, free to move in and out of the area and explore as they pleased.  
  • 1 hour later, classes met by museum researcher and led to a classroom for assessments.  
  • Classes returned to the museum floor to explore as they pleased. |
MEASURES

Students completed four short measures and an open-ended questionnaire immediately following their first hour in the museum:

- The Wheatly Spatial Abilities Test\(^2\) (k = 100), a standardized measure of spatial reasoning with comparative norms and high reliability. Possible scores range from zero to 100.
- An Attitude Toward Target Topic (geometry) questionnaire, adapted from an evaluation of an informal, extracurricular science program (Scott G. Paris, Kirsten M. Yambor, & Becky Wai-Ling Pacard, 1998). Possible scores range from 8 to 40.
- Two other short scales for assessing math and geometry confidence, adapted from Tapia & Marsh (2002; 2004a; 2004b). These measures tapped three sub-areas of anxiety, but were reverse scored to reflect positive feelings of confidence, rather than negative feelings of anxiety. Given the Pathways’ focus on geometry, we predicted higher scores for the Pathways group on geometry confidence, but no difference on math confidence. This latter measure was included as a check for discriminant validity. For each measure, possible scores range from 4 to 16.
- A brief open-ended questionnaire was developed to understand students’ field trip experiences. A rubric was later developed using interpretive phenomenological analysis (Smith, 1995), to code student responses for mentions of learning, geometry, and fun, and to assess the depth of their responses. As a measure of our coding scheme reliability, a second blind researcher coded 20% of students’ responses; coders’ agreement ranged from 88% to 100% on the four rubric-based codes.

RESULTS AND DISCUSSION

The results from the Geometry Playground Pathways study are encouraging, and they support claims that museum-developed pre-, during, and post-visit activities can enhance the efficacy of school field trips. Of the three areas assessed—attitudinal effects, spatial reasoning abilities, and overall exhibit experience—the main enhancement afforded by the Pathways was in the area of attitudes and geometry self-confidence. In accordance with our predictions, students in the Pathways groups had significantly higher attitude toward geometry scores (see Table 3 for details). It appears that museum-developed activities can lead to improved attitudes toward the focal topic (e.g., geometry), beyond the positive effects of field trips alone.

Similarly, Pathways students had significantly higher geometry confidence scores (see Table 3). Students’ had equivalent math confidence scores (used as a measure of discriminant validity). The addition of these specificity hypotheses, which narrow the focus to predict that we’d find a significant impact on geometry confidence scores and a non-significant impact on math confidence scores, boosts our assurance that the differences in scores are due to the Pathways and not due to other unrelated events. These results suggest that integrated curriculum and field trip activities, such as Pathways, can enhance students’ self-confidence in a curriculum area rife with anxiety.

\(^2\) (Wheatley, 1978)
As positive attitudinal effects are related to academic success and career choice (Tai et al., 2006; Xin, 1999), these findings help make the case for school involvement in field trips, and for further museum involvement in creating classroom activities that integrate museum exhibits and school curricula.

Concerning students’ spatial reasoning abilities, however, our findings were contrary to our expectations. There was not a significant difference in students’ spatial reasoning abilities scores between the Pathways and Control students (see Table 3). There are several reasons why this may be the case. First, perhaps follow-up classroom activities were needed to reap the full benefits of Pathways: follow-up Pathways were not implemented due to restrictions in student class time that prevented follow-up assessment. Price and Hein (1991) found that successful field trips begin with hands-on exploration time and follow with conceptual instruction; that is, follow-up activity is the most effective way to foster a connection. Additionally, perhaps spatial reasoning requires a longer period of intervention; other studies that have found increased spatial reasoning abilities have had a range of intervention from 6 -12 hours of instruction over the course of many weeks (Ben-Chaim, Lappan, & Houang, 1985; Casey, 2008; Spence, Yu, Feng, & Marshman, 2009). Finally, and most importantly, spatial reasoning skills are not typically taught in schools (Baenninger & Newcombe, 1995; Hamilton, Nussbaum, Kupermintz, Kerkhoven, & Snow, 1995) and are understandably highly variable from student to student. Therefore, it is likely that only a pre/post measure of change in individual ability could detect the effects of field trips and Pathways activities on students’ spatial abilities. Unfortunately, the post-only research design may not have been capable of identifying the effects of the Geometry Playground Pathways on students’ spatial reasoning.

### Table 3. Research results.

<table>
<thead>
<tr>
<th></th>
<th>Pathways Mean (SD)</th>
<th>Control mean (SD)</th>
<th>F statistic</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitude Toward Target Topic (Geometry)</td>
<td>31.69 (6.94)</td>
<td>27.64 (6.89)</td>
<td>9.51</td>
<td>.003*</td>
</tr>
<tr>
<td>Geometry Confidence</td>
<td>12.79 (2.61)</td>
<td>11.66 (2.58)</td>
<td>5.25</td>
<td>.024*</td>
</tr>
<tr>
<td>Math Confidence</td>
<td>12.21 (2.87)</td>
<td>12.62 (2.58)</td>
<td>.62</td>
<td>.433</td>
</tr>
<tr>
<td>Wheatley Spatial Reasoning Abilities Test</td>
<td>63.85 (18.59)</td>
<td>63.26 (18.93)</td>
<td>.028</td>
<td>.868</td>
</tr>
</tbody>
</table>

* significant at the p < .05 level.

Finally, we explored the students’ open-ended responses about their exhibit experience. We ran 17 chi-square analyses to determine if Pathways students were more likely to describe their exhibit experience as fun or educational, or in more depth; and to see if favored exhibits depended on Pathways connections. Only one of the analyses was significant (after applying a Bonferroni correction to account for the high number of comparisons). Pathways students were more likely to report that the exhibits reminded them of something they had seen or done before and to be able to give examples of this connection, nearly all of which were outside of the classroom ($X^2 = 9.37, p = .002$); perhaps the Pathways activities prime children to notice similar things at home, or the social activities encourage students to make connections. Given this
pattern of results, it seems that the Pathways did not provide a strong enough link to affect the students’ exhibit experience. Future studies may want to try enhancing the connection between the in-class and exhibit experience. It is also possible that this link may have been stronger had students participated in the follow-up activities that weren’t included, given the limited classroom time for assessments.

LIMITATIONS

The results of this study should be considered with awareness of the limitations to external and internal validity. The Pathways’ focus on geometry skills and abilities may limit the generalizability of the results to other Pathways that focus on other topics, or on content rather than skills and abilities. For example, perhaps a focus on skills is necessary to the enhancement of attitudes toward and confidence in a focal area. Even though we were able to collect data from six schools, the fact that the final participants were from only two San Francisco schools limits the generalizability of the results to all schools in the city. An analysis of the Districts’ school statistics reveals that these two participating schools are substantially more economically and culturally diverse than the average District representation (CA Department of Education, 2009). While the results may only generalize to students who come from lower economic or culturally diverse backgrounds, they are both important and promising given that individuals from low-socioeconomic and minority populations continually experience lower academic achievement as evidenced by grades, test scores, school completion, and education level (National Task Force on Women, 1989; Slate & Jones, 1998; Van Laar & Sidanius, 2001).

While this study was conducted with a small number of classrooms, the researchers took measures to mitigate the teacher-based effects, such as matching teachers’ classrooms by grade and school, and randomly assigning teachers into Pathways or Control groups. The post-only design limits our claims that the results are due to the Pathways and not other extraneous events. However, random assignment of classroom pairs from the same school, and the pattern of results (i.e., the inclusion of math confidence as a specificity measure) reduce the likelihood that such effects were due to any school-based or larger historical causes. This design also reduced the potential to identify changes in highly variable outcome measures, such as spatial reasoning.

IMPLICATIONS

The results of the Geometry Playground Pathways study support claims that museum-developed pre-, during, and post-visit activities can enhance the efficacy of school field trips (Griffin, 1998a). In particular, the results support the notion that such activities can lead to improved attitudes toward the focal topic (e.g., geometry), above and beyond the positive effects of field trips devoid of classroom integration. These results also suggest that integrating classroom curricula with field trip activities can enhance students’ self-confidence in a topic area rife with anxiety. Such positive attitudinal effects are related to academic success and career choice (Xin, 1999), making them a necessary focus for schools; a focus that museums are equipped and eager to support.
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