

## Connecting play experiences and engineering learning in a children's museum



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### ABSTRACT

This study examined whether and to what extent children's prior play experiences might support engineering learning in museum's building construction exhibit. 277 families with 4 to 9-year-old children worked together to solve the first engineering design problem, and then children worked alone to solve the second. At the outset, some families received a demonstration of a key spatial engineering principle - bracing - that was relevant to both problems, and some were informed of the second problem before beginning the first, to increase the likelihood of knowledge transfer. More spatial play experience was associated with better family problem solving success, and when combined with the demonstration, better success by the children problem solving alone. More creative play experiences combined with the engineering demonstration to lead to greater family problem solving success. Results suggest that certain types of play experiences can help children make better use of engineering learning opportunities.

### 1. Introduction

Play is critical for young children's learning (Hirsh-Pasek, Golinkoff, Berk, & Singer, 2009) and can foster skills that are foundational in STEM - science, technology, engineering, and mathematics (e.g., Honey & Kanter, 2013). Moreover, in informal educational environments such as museums, hands-on play and conversations with adults can advance STEM learning opportunities for children (e.g., Bell, Lewenstein, Shouse, & Feder, 2009; Benjamin, Haden, & Wilkerson, 2010; Callanan & Jipson, 2001; Jant, Haden, Uttal, & Babcock, 2014; Palmquist & Crowley, 2007; Paris & Hapgood, 2002; Rigney & Callanan, 2011). Nevertheless, we know relatively little about the connections between children's play experiences at home and early informal STEM learning in museums. This issue is important because all learning involves bridging what is already known and familiar and what is new to learn (NRC, 1999). Understanding what kinds of prior play experiences can prepare children when new learning opportunities arise may also be very helpful in thinking about ways to best support children's learning across educational contexts (e.g., home and museum; home and school). In this project, we asked parents to report on the play activities their children engage in frequently at home. We examined whether and to what extent variations in play experiences, and the knowledge these experiences might engender, connect with children's engineering problem solving in a building construction exhibit in a museum.

#### 1.1. Play and learning

Piaget (1962) described play as a primary way that children interact with materials in the environment and construct knowledge about the world. Vygotsky (1967) emphasized that in play children interact with other people and can learn from them. Contemporary studies have further suggested important connections between play and children's cognitive development. For example, children who play more have better language and literacy skills (e.g., Han, Moore, Vukelich, & Buell, 2010; Weisberg, Zosh, Hirsh-Pasek, & Golinkoff, 2013), stronger executive function skills (e.g., Barker et al., 2014; Diamond & Lee, 2011), and may be more curious and creative thinkers (Hoffmann & Russ, 2016; Schulz & Bonawitz, 2007). However, debates about the evidence for linkages between play and learning (see e.g., Lillard et al., 2013; Weisberg, Hirsh-Pasek, & Golinkoff, 2013) highlight that it is important to consider both the amount and variety of different types of play that can support learning of specific kinds of skills.

#### 1.2. Engineering learning

We focus on engineering learning for a number of reasons. Engineering emphasizes STEM-relevant problem solving, including defining a problem, considering different solutions, testing hypotheses, and generalizing across examples, and these are skills that can be

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fostered through certain play activities as well. Engineering integrates science and mathematics in ways that can be accessible and interesting to young children (Haden, Cohen, Uttal, & Marcus, 2016; Sullivan, 2006). Also, like many play activities, when children participate in engineering design and problem-solving, they usually engage in a combination of object manipulation and social interaction with others (Bucciarelli, 1988; Cunningham, 2009; Haden et al., 2016; Liu & Yu, 2004; NRC, 2009). Many children and adults possess limited understanding of key engineering principles, such as structural integrity and bracing (e.g., Cunningham, Lachapelle, & Lindgren-Streicher, 2005; Davis, Ginns, & McRobbie, 2002; Gustafson, Rowell, & Rose, 2001; Knight & Cunningham, 2004; Marcus, Haden, & Uttal, 2017), but they can learn and make use of engineering-relevant information that is provided even through very brief demonstrations in a museum (Haden et al., 2016; Marcus et al., 2017). Relevant prior play experiences may further help support understanding of such demonstrations. This later point motivates us to consider potential synergistic, interactive effects of children's prior play experiences and engineering information provided at the museum on problem solving at the museum.

### 1.3. Connecting play and engineering learning

From our perspective, play that promotes spatial skills, or mentally manipulating information about objects in the environment, may be especially crucial for promoting engineering learning. For example, in *puzzle, math, and board game play*, there are opportunities to estimate, measure, balance, construct analogies, and so forth, that may be critical in advancing engineering learning (Casey & Bobb, 2003; Verdine et al., 2014). Likewise, *construction play*, such as with Legos and blocks, can increase spatial abilities while offering specific opportunities for children to engage in principles and practices of engineering. Research on block, puzzle, and board game play to date has focused on links to children's mathematical performance (Ginsburg, 2006; Jirout & Newcombe, 2015; Levine, Ratliff, Huttenlocher, & Cannon, 2012; Mix, Moore, & Holcomb, 2011; Siegler & Ramani, 2009; see Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2017, for review). However, the same spatial skills that construction, and block and puzzle play can advance may also be relevant to engineering problem solving, particularly when the problems require use of spatial engineering principles, such as diagonal bracing to stabilize a structure (NRC, 2006). Indeed, the notion of the importance of spatial knowledge for children's engineering finds further support in experimental work linking spatial skills training to engineering problem solving activities much like the ones used in this study (Gentner et al., 2016; Ramey & Uttal, 2017).

Other forms of play that do not specifically involve engineering may nevertheless bolster skills that can either directly or indirectly impact engineering learning. For example, *creative play* – including art, music and pretend and fantasy play – can promote imagination and what-if and analogous thinking, as well as symbolic representational skills (Gardiner, 2000; Reed, Hirsh-Pasek, & Golinkoff, 2012) that are inherent to the engineering design process. Some types of *technology play* can promote spatial skills, although perhaps less so than hands-on spatial play activities (e.g., puzzles, block play, construction) for young children (Newcombe, 2010; Uttal et al., 2013). Moreover, although further work is certainly needed to draw definite conclusions, a growing body of work demonstrates linkages between *physical play*, cognitive functioning and behavioral self-regulation, and academic achievement (e.g., Becker, McClelland, Loprinzi, & Trost, 2014; Diamond & Lee, 2011). This being said, associations between play and engineering learning have not been extensively examined; this is a focus of the present study.

### 1.4. Transfer of knowledge

Importantly, connections between play and learning hinge on

children understanding and representing the knowledge that play engenders in a way that makes it useable and applicable when new relevant opportunities for learning arise. Cognitive scientists refer to this as *transfer of knowledge*, and it is evident, for example, when a child uses what was learned on one problem to solve other related problems (Bransford & Schwartz, 1999; Goldstone & Son, 2005; Klahr & Chen, 2011). Psychological research suggests that transfer is often difficult or fleeting when it happens at all (Gick & Holyoak, 1983; Ross, 1989), and few studies of object manipulation and early learning have consistently found transfer to new contexts (Marcus et al., 2017; McNeil & Uttal, 2009; Uttal et al., 2013; Uttal, Liu, & DeLoache, 2006; Uttal, O'Doherty, Newland, Hand, & DeLoache, 2009). Nevertheless, Holyoak and colleagues' work with children and adults (e.g., Gick & Holyoak, 1980; Holyoak, Junn, & Billman, 1984) suggests that it is sometimes possible to prompt successful transfer by simply pointing out that what is learned in one context or problem can be used to solve the problem at hand.

We consider three aspects of transfer. First, we ask how prior play experiences at home might enhance engineering problem solving in a museum setting. Second, we investigate if certain types of play experiences help children make better use of a key engineering principle that is demonstrated to them to solve engineering problems at the museum. Third, we consider if by explicitly prompting transfer we might be more likely to observe it across the two building problems that we presented to families at the museum.

### 1.5. The current study

A focus on the linkages between play and engineering learning guided our efforts in the current study. Parents were surveyed about how often their children engaged in 12 different kinds of play experiences that spanned five domains (cf. Zosh, Fisher, Golinkoff, & Hirsh-Pasek, 2013): (1) *puzzle, board and math game play*, (2) *construction play*, (3) *creative play*, (4) *technology play*, and (5) *physical play*. Associations between these types of play and children's engineering problem solving in a children's museum were examined.

In the museum, parents and children worked together to solve the first engineering design problem, which for half of the families was to stabilize a wobbly skyscraper, and for the other half was to stabilize a wobbly bridge. The children worked alone to solve the second problem, which was to fix the structure (skyscraper or bridge) they had not worked on with their parents. Because the same engineering principle was implicated in fixing both structures – the wobbly bridge was the same structure as the wobbly skyscraper, but turned on its side – transfer of learning was relevant across the two engineering problems for all children. Half of the children and families were introduced to the second engineering problem prior to beginning the first – a condition we called *Anticipated Transfer*. The other half of the families in the *No Anticipated Transfer* condition did not learn of the second engineering problem until they had finished the first.

Another experimental manipulation involved providing some families with information about the key spatial engineering principle – bracing – prior to working on the two problems. With this we asked if certain play experiences at home would support children's understanding and use of the demonstration of bracing when solving one engineering problem with their parents and one on their own. Prior to working to solve the two engineering problems in the museum exhibit, half of the children and their families observed a demonstration of bracing. These children in the *Engineering Demonstration* condition had the chance to test how bracing stabilizes structures. The other half of the families in the *No Engineering Demonstration* condition were not provided with any engineering-related information or experiences in the museum prior to building. We examined if the demonstration alone, and/or in combination with children's play experiences, might lead to more use of the spatial engineering principle when building at the museum.

## 1.6. Hypotheses

Our analysis of the literature informed our experimental design and the formulation of the hypotheses. First, we hypothesized that children who were reported by their parents to engage more in spatial play (i.e., build more with blocks and Legos, and play more with puzzles, board, and math games) and construction play would perform better at solving both engineering problems in the museum, in comparison to their peers who were reported to engage less in these sorts of play experiences at home. Second, we hypothesized that children in the Anticipated Transfer group would do better at stabilizing the structure on their own than the children who had no knowledge of the second task beforehand. Third, we hypothesized that children who received the demonstration of the spatial engineering principle – bracing – at the museum would include more braces in their structures compared with their peers who did not receive the demonstration. Finally, we explored the potentially interactive effects between the demonstration at the museum and children's age and prior play experiences. It seemed possible that the demonstration of the spatial engineering principle at the museum might be most helpful to older children and to children who often engaged in spatial and construction play. However, our analysis of the literature further suggests that creative, technology, and physical play might also support learning from the demonstration – directly or indirectly (e.g., through advancing cognitive and self-regulation skills) – and, in turn, enhance performance on the engineering problems solving by children with their families and alone.

## 2. Method

### 2.1. Participants

The sample consisted of 277 children (143 girls;  $M_{age} = 6.72$ , range 3.7–9.96 years) and their families. Children's race was reported by all but 7 parents: 171 children (62%) were Caucasian, 31 (11%) Hispanic, 22 (7.9%) African American; 21 (7.6%) Asian, and 25 (9%) of mixed race. Most of the families, 233 (84%) in total, had at least one parent with a college degree or higher, and 161 (58%) reported family incomes of over \$100,000.

Children participated with at least one parent or legal guardian, which was a condition of our consent procedures. Inclusion criteria were that there be complete play questionnaire and engineering problem solving data. In addition to the target child – who was the oldest 4- to 9-year-old child in families of two or more children – 90 families (33%) included a second child, and 6 (2%) had three. The majority of children were accompanied by one parent (192 children, 69%), 82 (30%) children participated with a parent and one other adult (usually another parent or adult family member), and 3 (1%) participated with a parent and more than one other adult. Overall, 187 (68%) families were first time visitors to the exhibit, whereas 37 (13%) had visited once before, and 42 (19%) had visited the exhibit more than one time in the past.

### 2.2. Procedure

Participants were recruited at the entrance of the *Skyline* building construction exhibit at Chicago Children's Museum ([www.chicagochildrensmuseum.org](http://www.chicagochildrensmuseum.org)). After consenting to participate, families were randomly assigned to receive either the Engineering Demonstration or not, and to receive Anticipated Transfer Information or not. In combination, these two conditions yielded a 2 (Engineering Demonstration: yes or no)  $\times$  2 (Anticipated Transfer: yes or no) experimental design.

Families in the *Engineering Demonstration* group first visited a permanent exhibit component shown in Fig. 1. It featured a large-scale square made of wooden struts with a middle piece that could be connected either horizontally or diagonally with a metal bolt. Children



Fig. 1. Engineering demonstration station.

were first shown that the square was unstable; the square became a rhombus because angles could change even as the length of the sides remained the same. Then they were invited to connect its middle piece as a brace to stop it from wobbling. There were two positions the child could choose to attach the middle piece – horizontally or diagonally – but only the diagonal brace position stabilized the structure because it formed triangles, which are stable polygons. All families in the Engineering Demonstration group heard and saw that the square did not wobble once the piece was connected diagonally; they were shown that the diagonal brace created two triangles, and were told that triangles are the strongest shape. Families in the No Engineering Demonstration group did not visit the exhibit component (Fig. 1) prior to engaging in the engineering problem solving activities or hear any information relevant to the engineering principle of bracing.

Children and their families were asked to solve two engineering design problems: fixing a wobbly skyscraper (Fig. 2a) and a wobbly bridge (Fig. 2b) made of small-scale plastic building pieces. The order of presentation of the two structures was counterbalanced across families. Once the parents and children said they were finished with the first structure, the children worked alone to stabilize the second structure (skyscraper or bridge).

Half of the families in each demonstration group were randomly assigned to receive the *Anticipated Transfer* information or not. Just before working on the first structure (either the skyscraper or the bridge), families who received the Anticipated Transfer information were told that their children would be asked to fix a second structure immediately after the first. The children and families were shown the second wobbly structure, and the researcher demonstrated that it was wobbly. Families who did not receive the Anticipated Transfer information did not see or hear about the second structure to be fixed before working on the first problem.

Prior to starting each problem-solving activity, participants were told to “fix it and make it sturdier, stronger, so it doesn't wobble anymore.” Participants were given up to 15 min to solve each engineering problem. All the pieces normally available at the building stations could

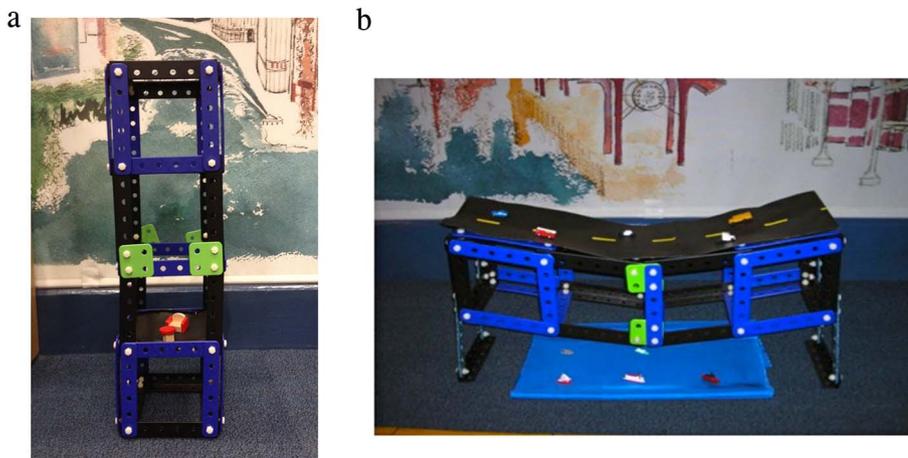


Fig. 2. a. Wobbly skyscraper engineering problem.  
b. Wobbly bridge engineering problem.

be added to the structure. The pieces could be attached using nuts and bolts and included long straight pieces (diagonal braces), shorter straight pieces (beams), straight corner pieces (girders), small square pieces (mending plates), and triangle pieces (triangle braces). All pieces except for the mending plates could be attached in a way to function as a diagonal brace. There was no limit to the number of pieces that could be added to the structures, just a limit to the amount of time to do so. In the rare event that children and families ran out of pieces at their workstation, they took pieces from one of the other two workstations, or asked a museum facilitator for more. Afterward, photos were taken of each side of each structure for subsequent coding of sturdiness of the structures.

### 2.3. Measuring play and demographic information

While the children worked to fix the second structure on their own, parents rated how often the target child engaged in 12 different types of play activities using a semantic differential scale ranging from 1 (almost never) to 7 (daily). The Appendix A provides example items from the questionnaire. The 12 activities were as follows: (1) puzzles, (2) puzzle games (e.g., mazes, dot-to-dot), (3) Legos, (4) construction (not Lego), (5) art, (6) board and card games, (7) music, (8) math games, (9) education-oriented computer/internet games, (10) video games, (11) pretend play/fantasy, (12) toys for moving arms and legs. Ratings across activities were averaged to create the five domain scores representing the extent to which children engaged in the following types of play: (1) *puzzles and board and math game play* – puzzles, puzzle games, board and card games, math games, (2) *construction play* – Legos, and construction (not Legos), (3) *creative play* – art, music, pretend play/fantasy, (4) *technology play* – education-oriented computer/internet games, video games, and (5) *physical play* – toys for moving arms and legs. A separate questionnaire asked parents to report sociodemographic information.

### 2.4. Coding

The final structures created by the families in the first engineering problem, and by the children in the second engineering problem were masked for condition (Demonstration, Anticipated Transfer) prior to coding. To index the sturdiness of each structure, the coding system involved counting the following: (1) total number of pieces – the total number of pieces added to the structure, excluding nuts and bolts; (2) total number of braces – the total number of pieces attached to the structure in such a way as to form a diagonal brace or a triangle. To establish reliability, two raters coded 20% of the photos of the final structures completed by the families and by the child(ren) alone. The inter-rater reliability (Cohen's Kappa) was 1.00 for each of the two

codes. A sturdiness ratio was computed for each problem-solving activity by dividing the total number of braces by the total pieces added to each structure. The ratio therefore reflects the extent that children and families used the engineering principle bracing: a ratio of 1.0 means that all the pieces added were braces, whereas a ratio of 0.33 means that one-third of the total pieces added braced the structure. Fig. 3a and b illustrate structures with high and low ratio scores indicating high and low sturdiness, respectively.

## 3. Results

### 3.1. Analytic plan and preliminary analyses

The main analyses involved a series of two separate linear multiple regression analyses testing associations between play and engineering problem solving. In one regression, the criterion variable was the sturdiness (ratio of braces to total pieces added) of the structure the children worked with their families to fix, and the second, the criterion variable was the sturdiness of the structure the child(ren) worked to fix alone. The standardized mean scores for each of the five play domains were tested in association with these two engineering problem solving

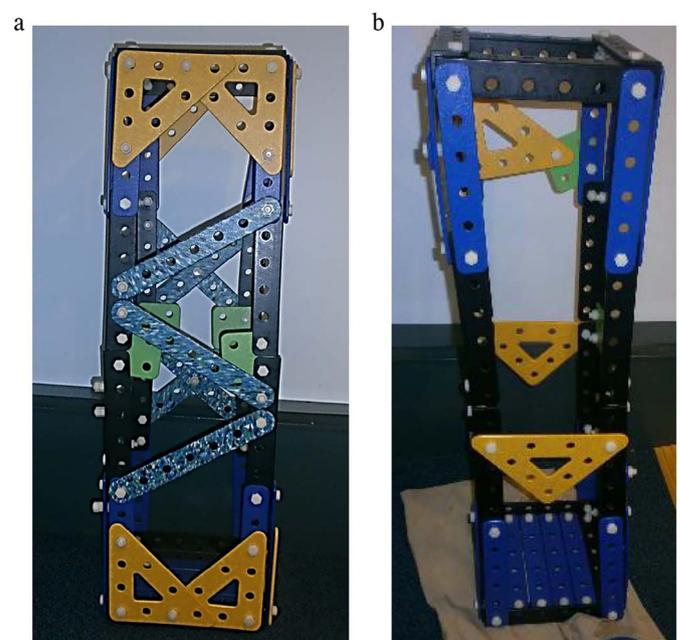


Fig. 3. a. A structure with a high ratio of braces to total pieces – high sturdiness score.  
b. A structure with a low ratio of braces to total pieces – low sturdiness score.

**Table 1**  
Bivariate correlation matrix between potential predictors of family and children's engineering problem sturdiness score.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Child age		0.09	0.41**	−0.06	−0.11	0.11	0.23**	0.22**	−0.11	0.15*	0.26**	0.03	−0.04	0.21**
2 Number of visits			0.04	0.10	−0.05	0.14*	0.11	0.16*	−0.08	0.14*	0.02	0.01	−0.03	0.11
3 Number of children				−0.07	−0.10	0.04	0.16**	0.14*	0.06	0.11	0.13*	0.15*	−0.06	0.08
4 Parental education					0.51**	−0.01	0.02	−0.09	0.05	0.05	−0.13*	−0.04	0.17**	0.02
5 Family income						−0.09	−0.11	−0.04	0.12	0.10	−0.05	0.07	0.21**	0.06
6 Time spent on first problem							0.26**	−0.10	−0.10	0.08	−0.12	−0.02	−0.01	0.11
7 Time spent on second problem								0.10	0.02	0.06	−0.02	−0.03	0.02	0.20**
8 Puzzle, board and math games play									0.33**	0.31**	0.36**	0.23**	0.13*	0.20**
9 Creative play										0.05	0.09	0.17**	0.13*	0.04
10 Construction play											0.06	0.13*	0.13*	0.11
11 Technological play												0.06	−0.04	0.05
12 Physical play													0.08	0.12*
13 Sturdiness score for family engineering														0.40**
14 Sturdiness score for children's engineering														

Note:  
\* Indicate statistically significant correlations,  $p < 0.05$ .  
\*\* Indicate statistically significant correlations,  $p < 0.01$ .

outcomes. The mean raw scores and standard deviations for each of the five play domains were as follows: (1) puzzle, board and math game play,  $M = 4.36$ ,  $SD = 1.22$ , (2) construction play,  $M = 4.32$ ,  $SD = 1.70$ , (3) creative play,  $M = 5.28$ ,  $SD = 1.23$ , (4) technology play,  $M = 4.24$ ,  $SD = 1.68$ , and (5) physical play,  $M = 5.78$ ,  $SD = 1.48$ .

Table 1 shows bivariate correlations, which were computed as a preliminary step to identify predictor variables to include in the models. With regard to the sociodemographic measures, parental education and income were correlated with the family problem solving sturdiness ratio ( $r_s > 0.17$ ,  $p_s < 0.05$ ), but income and parent education were also highly intercorrelated,  $r = 0.51$ ,  $p < 0.001$ . We selected parental education for inclusion in both sets of regressions, although including income instead did not change the pattern of results.

Time spent on the problem-solving activities was also considered as a potential predictor. Time spent averaged 13.89 (range 7–19) minutes, and 12.76 (range 2–25) for family and child engineering problem solving activities, respectively. The amount of time spent on the task did not differ between the Engineering Demonstration or no Demonstration groups for the family ( $M = 13.94$ ,  $SD = 2.00$ ,  $M = 13.88$ ,  $SD = 2.29$ , respectively) or child problem solving activities ( $M = 13.14$ ,  $SD = 2.89$ ,  $M = 12.46$ ,  $SD = 4.01$ , respectively),  $F_s < 2.42$ ,  $p_s > 0.12$ , nor between the Anticipated Transfer and No Anticipated Transfer group for the family ( $M = 13.77$ ,  $SD = 2.04$ ,  $M = 14.03$ ,  $SD = 2.27$ , respectively) or the children's problem solving ( $M = 12.70$ ,  $SD = 3.19$ ,  $M = 12.92$ ,  $SD = 3.82$ , respectively),  $F_s < 1.00$ ,  $p_s > 0.32$ . Time spent was not correlated with sturdiness for the family problem solving task, but it was correlated with the sturdiness of the structure the children worked to stabilize alone,  $r = 0.20$ ,  $p < 0.01$ . Time spent problem solving was also correlated with age of the target child,  $r = 0.23$ ,  $p < 0.001$ , but when age of the child was controlled for, the correlation between children's problem solving alone and time spent on task was no longer statistically significant. Due to the apparent multicollinearity, age of the child, not time spent on task, was included in the regression analyses.

Sex of the child, number of children in the family, and number of prior visits to the exhibit were considered as possible predictors. They were not significantly related to either problem solving outcome (see Table 1) and were not included in further analyses.

The main analyses were further aimed to test effects of the anticipated transfer information, engineering demonstration, the combination of these, and which structure was being fixed (skyscraper, bridge). Because age could affect children's understanding and use of the demonstration and transfer instructions, we included anticipated transfer by age of the child interaction and demonstration by age of the child

interaction in the analyses. Further, we explored whether children with different play experiences might benefit differently from the engineering demonstration. This was tested by entering each play experience by demonstration interaction term to predict the two sturdiness outcomes when the children worked with their families and when the children worked alone.

In the analyses of the sturdiness of the structure the child(ren) fixed alone, the sturdiness of the first (family) structure was included in this model. Initially, all potential associations were tested in each model. Then, variables found to not be statistically significant predictors of the outcomes were removed one-by-one to yield the final models presented in this report. This allowed our final results to include only variables that were uniquely related to the outcomes (Pedhazur & Schmelkin, 1991), and at the same time reduced issues related to multicollinearity (Tabachnick & Fidell, 2001).

### 3.2. Main analyses

#### 3.2.1. Family problem solving

On average, families added 9.9 (range 0–36,  $SD = 0.36$ ) pieces and, on average, 5 (range 0–20,  $SD = 4.45$ ) of them functioned to brace the structure. The sturdiness ratio of the structure the children fixed with their families averaged 0.49 (range 0.00–1.00,  $SD = 0.36$ ), indicating that overall about half the pieces added to the structure were braces. The linear regression for the sturdiness of the structure that children fixed with their families yielded  $R^2 = 0.24$ ,  $F(6, 260) = 14.62$ ,  $p < 0.001$ . The top portion of Table 2 displays the significant predictor variables. Families who worked on the skyscraper averaged a 0.18 higher sturdiness ratio than those families who worked on the bridge, after accounting for the other factors. Parental education was also significantly positively associated with the sturdiness of the structures children fixed with their families, with an average increase of 0.17 in the sturdiness ratio for every increment in parental education. Consistent with our hypotheses, the engineering demonstration helped families to incorporate more braces to total pieces in their structures. After controlling for the other variables in the model, families who received the demonstration averaged a 0.40 increase in their sturdiness ratio compared with families who did not receive the demonstration.

When engaged in engineering problem solving with their families, and controlling for the other predictor variables, children who were reported to play more puzzle, board and math games averaged a 0.15 higher sturdiness score, compared with children who engaged in these play activities less. This result provides partial support for our hypothesis, demonstrating that puzzle, board and math game play activities can advance children's engineering problem solving as measured

**Table 2**  
Linear regression models predicting engineering problem solving (sturdiness) by the family and the child alone.

Predictor variables	Sturdiness score for family engineering $\beta$
<b>Background variables</b>	
Parental education	0.17
<b>Instructions at the museum</b>	
Demonstration (yes, no)	0.40
Type of structure	−0.18
<b>Play</b>	
Puzzle, board & math games play	0.15
Creative play	−0.35
Creative play × demonstration	0.41
Predictor variables	Sturdiness score for children's engineering $\beta$
<b>Instructions at the museum</b>	
Type of structure	−0.16
Age of child × demonstration	0.32
<b>Play</b>	
Puzzle, board & math games play × demonstration	0.17
Family problem solving sturdiness score	0.28

Note: All reported  $\beta$  values are significant  $p < 0.05$ .

here. However, contrary to our hypotheses, children's construction play was not related to sturdiness of the structure in the family problem solving task.

Children reported to engage frequently in creative play averaged a 0.35 lower ratio score than families with children reported to engage less frequently in these sorts of play activities. However, the significant creative play by demonstration interaction indicates that children higher on creative play who also received the engineering demonstration had, on average, a 0.41 increase in the sturdiness of their structures when solving the engineering problem with their families. Therefore, the engineering information in the demonstration was especially helpful to families with children who came to the engineering learning activity with more creative play experiences.

### 3.2.2. Children's problem solving alone

Children working alone added 6 pieces (range 0–19,  $SD = 4.00$ ) to the structure on average, of which 1.74 (range 0–16,  $SD = 2.86$ ) were braces. The sturdiness ratio outcome when the child(ren) worked alone averaged 0.24 (range 0.00–1.00,  $SD = 0.35$ ), indicating that about a quarter of the pieces they added served to brace the structure. The linear regression analyses predicting sturdiness of structures the child (ren) fixed alone yielded  $R^2 = 0.30$ ,  $F(4, 265) = 30.18$ ,  $p < 0.001$ . As shown in Table 2, controlling for the other predictors, the children's performance alone increased 0.28 for each unit increase in the sturdiness of the first structure children fixed with their families. Children who worked on the skyscraper averaged a 0.16 higher sturdiness ratio than children who worked on the bridge, after accounting for the other factors. Older children also seemed to make better use of the demonstration information, as evidenced by the age × demonstration interaction. Among children in the demonstration group, for every one year change in the target child's age, the sturdiness scores when the children worked alone increased on average by 0.32.

The significant spatial play by demonstration effect indicated that children with more spatial play experience who received the key engineering information at the museum were most successful on the engineering problem solving task when working on their own. More specifically, children who were reported by their parents to more frequently engage in puzzle, board, and math game play who also received

the engineering demonstration saw, on average, a 0.17 increase in their sturdiness score relative to their peers. No other play experiences either singly or in combination with the demonstration predicted the sturdiness of the structures children fixed on their own.

## 4. Discussion

Developmental and learning scientists and educators draw connections between play and learning, and so do companies marketing play activities for children. This study contributes relevant information about play experiences that are associated with engineering problem solving as observed in a children's museum. Providing families at the museum with information about a key spatial engineering principle combined with the children's prior play experiences to advance engineering problem solving outcomes.

### 4.1. Play and engineering learning

Certain types of play experiences at home were linked to engineering problem solving performance in the museum. Children's frequent play with puzzles, board, and math games was positively associated with their performance stabilizing the first structure while working with their families. Additionally, relative to peers who engage in less frequent play with puzzles, board and math games, children who engaged often in these sorts of play activities benefited more from a demonstration of a key engineering principle when they later worked to fix the second structure alone. The children with this combined play experience and knowledge made the structures they were working to fix sturdier by incorporating more braces relative to the total number of pieces added to their structures.

Play may have helped the children understand and represent the knowledge play engenders in a way that made it useable and relatable when presented with new learning opportunities in the museum (Gentner et al., 2016; see Siegler & Ramani, 2009, for a related argument). For example, children's play experiences with puzzles, board, and math games may have promoted spatial skills that helped them to internally represent spatial relations and use these to organize their approach to stabilizing the structures. These children's play experiences also combined synergistically with the demonstration of the key engineering principle at the museum to advance their solving an engineering problem on their own. Prior play experiences with puzzles, board, and math games may have helped the children to encode the spatial engineering principle during the demonstration, and furthered their storage, retrieval, and transfer of knowledge when working on the second engineering problem on their own.

Another important set of findings involved children's prior creative play experiences. On the first problem solving activity that the children performed with their families, frequent engagement in creative play was negatively related to sturdiness of the resulting structures. However, the engineering demonstration boosted performance in the family problem solving activity most for children who came to it with the most art, music, and pretend play experience. These children and families evidence dramatically higher use of bracing to make their structures sturdier relative to others without such experiences. Of course, it is certainly the case that children with more creative play experiences had more room for improvement. Another explanation for why they may have benefited from the demonstration pertains to work showing children with more artistic and imaginative play experiences may have better patterning abilities (Kidd et al., 2013; Reed et al., 2012). These children may have noticed the patterns of shapes and sizes present in the demonstration in relation to the structures they were trying to stabilize in the engineering problems. Alternatively, it could be that the social skills involved in creative play were responsible for the improvement, and that children with more creative play experience were better able to pay attention or to self-regulate during the demonstration (Berk, Mann, & Ogan, 2006). Therefore, while their

creative play experiences did not lend direct advantages for stabilizing the structures, children's creative play experiences may have helped them make sense of or pay attention to the demonstration and apply it to the engineering problems. Teasing apart these explanations, nonetheless, is not possible with our data and would require further investigation.

Contrary to the expectations, prior play experiences involving building and construction at home were not uniquely related to children's engineering problem solving. The relevance of prior building experiences at home may have been less, or less obvious to children and families when working with the novel materials in the exhibit, making transfer of knowledge difficult. It remains important to consider how play experiences children have with building construction activities at home may directly and indirectly support skills for engineering learning opportunities in museums and schools. Such efforts should include observations of play and learning across home and museum contexts.

In addition to a consideration of play preferences, we examined a range of demographic factors that may have affected problem solving outcomes. Prior work has found that parental education is associated with differences in children's performance in formal (White, 1982) and informal educational settings (Tenenbaum & Callanan, 2008). Consistent with this, parents' reported education level in our study was related to the sturdiness of the resulting structures in the problem-solving activity children performed with their families. Child age did not have an effect on the outcome of the family problem solving. However, older children who received the demonstration achieved sturdier structures when working on their own, suggesting older children were more able than younger children to understand and use the information the demonstration conveyed. Both parent education and child age are likely markers for prior knowledge and experiences that may have supported problem solving, including more play experiences. Moreover, a growing number of studies suggest that the ways parents engage with their children in engineering problem-solving is affected by what families know and have experienced (e.g., Benjamin et al., 2010; Haden et al., 2014). Parents' perceptions of their children's prior knowledge can also dramatically affect the ways they engage their children in exhibits (e.g., Palmquist & Crowley, 2007).

#### 4.2. Learning and transfer in the museum

We also asked whether calling attention to the potential of transfer of knowledge across building problems at the outset of problem solving might lead to better outcomes when children went on to solve the second problem alone. The anticipated transfer instructions were intended to focus children and families on the linkages across problem solving activities, which prior work in education and learning sciences would suggest could lead to successful transfer (Bell et al., 2009; Dugan, Stevens, & Mehus, 2010; Engle, 2006). Representing knowledge in a way that makes it portable and relatable across problems may be very challenging, particularly when that knowledge is acquired through engagement with attractive, novel objects like those available for use in this museum exhibit (Jant et al., 2014). Nevertheless, the experience children had problem solving with their families initially was positively associated with the children's performance in solving the second engineering problem on their own. Although, this could to some extent be interpreted as the summative effect of the predictors that were related to success on the family engineering problem solving, it also speaks to the fact that children could use the experience gained during the family engineering to help them solve a similar problem on their own. How parents could facilitate this kind of transfer during problem solving and how different instructions could affect both children's and parents' behaviors could be addressed in future research.

Furthermore, transfer is multidimensional, and can vary in degree or range of transfer across problems, contexts, and time (Barnett & Ceci, 2002). In fact, in this study, participants braced the skyscraper more than the bridge, even when it was the second structure to be fixed by

the children alone. This suggests that the bridge presented a more difficult transfer problem than the skyscraper, even when the differences across the two problems were superficial.

#### 4.3. Limitations

Our conclusions are limited by several aspects of the work. Our measures of children's play experiences at home were based on parental report. Were we to have observational data for a fine-grained analysis of children's play activities at home, we could measure the extent and quality of parent involvement. Such an effort would identify mechanisms supporting linkages between play and engineering learning (Hirsh-Pasek et al., 2009; Weisberg et al., 2013). Our work cannot address, for example, how some types of play may lend themselves more to caregivers' co-playing along with children, and lead to linguistic interactions that may involve more spatial words being used by caregivers and children themselves (e.g., Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, & Lam, 2011; Hirsh-Pasek et al., 2009; Ramani, Zippert, Schweitzer, & Pan, 2014). Our work is also limited to the outcomes of the problem-solving activity, without a detailed analysis of the parent-child interactions when solving the first engineering problem. In addition, there are cultural differences in how families understand links between play and learning that were not captured in this study (e.g., Gaskins, 2008). Previous work along these lines (see also e.g., Siegel, Esterly, Callanan, Wright, & Navarro, 2007; Tenenbaum & Callanan, 2008) strongly suggests that consideration of cultural and other family background characteristics can dramatically add to understanding the ways the knowledge and experiences families bring to a museum can impact learning in the museum. Finally, we recognize the correlational nature of our work, and one can imagine quasi- and experimental/training studies that might further advance understanding of how hands-on play experiences can impact opportunities for future engineering learning.

#### 4.4. Implications for informal education

The connections between play and engineering learning need further consideration as parents and educators look for ways to encourage children's early interest and understanding in STEM domains. This study provides useful information about when and how prior play experiences can help children make sense of novel engineering problem solving activities in informal educational contexts. The results suggest that providing information about key principles or concepts related to the activities presented in museum can support learning in exhibits. In this study, we used a permanent exhibit display to demonstrate a key engineering principle, and showed that the display helped support families' engineering problem solving and the problem solving of older children. The demonstration especially helped children who came to the exhibit with play experiences that emphasized art, music, and pretend play to implement the engineering principle to stabilize wobbly structures while working with their families. The demonstration also helped children who may have come to the exhibit with more spatial and STEM-related knowledge to perform the second engineering problem-solving activity on their own. Therefore, museums and other informal settings need not shy away from, and indeed, should consider designing exhibits in ways where key principles and practices of engineering and science are presented in albeit playful ways to visitors to enhance STEM learning opportunities in exhibits.

The results strongly indicate that learning that happens using integrated displays and exhibit components is not purely didactic. Children and families could not just copy the engineering principle as illustrated in the demonstration. Moreover, the interactive effects of the demonstration and children's play experiences would seem to indicate that the demonstration helped to harness prior knowledge children and families brought to the exhibit, and enabled transfer of this knowledge to the tasks at hand. This is an especially intriguing finding when one

thinks about potential applications for museum practice: emphasizing designing exhibit activities and environments in ways that help children and families bring what they know to the fore when learning in museums. Open-endedness of the activity in the museum is important to support multiple points of entry for children and families who come to the exhibit with varied prior experiences. This seems to be a motivation for the expansion of tinkering and making activities as engineering learning opportunities in educational settings broadly (Honey & Kanter, 2013). Continued efforts to address how play and learning can connect in a museum can increase theoretical understandings of conditions that

can promote STEM-related learning while at the same time informing museum practice.

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**Appendix A**

<p><b>1. Puzzles</b></p> 	<p>Almost Never    1    2    3    4    5    6    7    Daily</p>
<p><b>4. Construction (not Lego)</b></p> 	<p>Almost Never    1    2    3    4    5    6    7    Daily</p>
<p><b>5. Art</b></p> 	<p>Almost Never    1    2    3    4    5    6    7    Daily</p>
<p><b>6. Music</b></p> 	<p>Almost Never    1    2    3    4    5    6    7    Daily</p>

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