

Spatial language in families' conversational reflections about museum experiences

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ABSTRACT

Prior work demonstrates the importance of spatial language use during museum experiences for children's spatial skills. The ways families talk about experiences *after* they occur is also important in the learning process. Therefore, we asked how families use spatial language in conversational reflections after experiencing exhibits and programs in a children's museum. Families ($N = 243$) with a 6- to 11-year-old child made recordings discussing experiences in a tinkering exhibit and up to two other exhibits. Families reflected on tinkering programs that were either open-ended, function-focused, or engineering-focused. In comparison to families who reflected on open-ended tinkering programs, those who reflected on engineering-focused programs used more spatial language in their reflections. Furthermore, our analysis of reflections about additional museum exhibits revealed that families used the most spatial language when reflecting on exhibits emphasizing navigation. Results suggest design features of informal learning experiences that may support spatial language in families' reflections.

Introduction

Spatial skills are used to mentally represent and transform shape, location, and path information (Newcombe and Shipley, 2015; Uttal et al., 2013). We recruit spatial skills for a variety of everyday experiences, such as arranging furniture and using maps. Additionally, spatial skills are critical for STEM learning (Bower et al., 2020; Bower et al., 2020; Casey, Nuttall, and Pezaris, 2001; Casey, Nuttall, Pezaris, and Benbow, 1995; Lubinski and Benbow, 1992; Mix, 2019; Shea, Lubinski, and Benbow, 2001; Uttal, Miller, and Newcombe, 2013; Verdine, Golinkoff, Hirsh-Pasek, and Newcombe, 2014; Wai, Lubinski, and Benbow, 2009). The role of spatial skills in STEM learning becomes particularly important in the elementary school years when children are 6- to 10-years-olds (Geer, Quinn, and Ganley, 2019; Gilligan, Flouri, and Farran, 2017; Mix et al., 2016, 2017). At this age in school, children are introduced to STEM concepts that call on spatial skills, such as geometry, graph understanding, and force and motion (Taylor and Hutton, 2013). However, spatial skills are not taught explicitly in school classrooms (National Research Council, 2006; Newcombe and Frick, 2010; Pritulsky et al., 2020). Therefore, children benefit from opportunities to engage in spatial learning through informal experiences, and children's museums are a primary example (Bustamante et al., 2020; Hassinger-

Das et al., 2020; Pochinki, Reis, Casasola, Oakes, and LoBue, 2021; Polinsky, Perez, Grehl, and McCrink, 2017).

Children's museum exhibits can support spatial skill development. Many children's museum exhibits encourage spatial experiences, such as physical manipulation of objects and navigation through novel environments. While playing in these exhibits, children may also use *spatial language* to describe and communicate with other children and adults what they are doing. Spatial language is talk that describes the features and locations of objects (Casasola, Wei, Suh, Donskoy, and Ransom, 2020; Pruden, Levine, and Huttenlocher, 2011). Spatial language in conversations with others contributes to children's spatial skill development. The more spatial language children hear, the more spatial language they use, and subsequently the better they perform on spatial skill and mathematical assessments (Casasola et al., 2020; Gilligan-Lee, Hodgkiss, Thomas, Patel, and Farran, 2021; Pruden et al., 2011). Research in museum settings suggests an association between families' use of spatial language at an exhibit and short-term spatial learning (Polinsky et al., 2017). Thus, spatial language in conversations regarding museum experiences can contribute to spatial skill development.

One potential obstacle to spatial learning from museum experiences is that the spatial language families use at museum exhibits could be tied

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to the brief hands-on experiences themselves and may not continue beyond the museum activities. Because frequent and prolonged exposure to spatial language is critical for spatial skill development (Pruden et al., 2011), it is important that families continue to use spatial language even after their museum experiences. Therefore, in this paper we report on families' use of spatial language in their *conversational reflections* shortly after experiences in a children's museum.

Conversational reflection can be defined as stepping back to think, consider, explain, remember, and make personal meaning of experiences (Haden, Cohen, Uttal, and Marcus, 2016). Reflection is foundational in modern STEM education (e.g., *Next Generation Science Standards* [NGSS Lead States, 2013]; [National Research Council, 2012]) and families often reflect together following their informal educational experiences in museum exhibits (Haden, 2010). Moreover, when the exhibit activities involve extensive hands-on and physical engagement, conversations may be limited because families are more focused on what they are doing than on what they are saying. Under these conditions, conversations shortly after museum experiences can be crucial for explicating and elaborating learning (Benjamin, Haden, and Wilkerson, 2010; Haden et al., 2014; Pagano, Haden, and Uttal, 2020).

We focus on the conversational reflections that families engage in shortly after exhibit experiences because the cognitive process of *consolidation* is critical for lasting learning (Bauer, Evren Güler, Starr, and Pathman, 2011; Haden et al., 2016; Pagano, Haden, Uttal, and Cohen, 2019). Consolidation is the step in the learning process when momentary patterns of experience are strengthened and transformed into lasting memory representations (McGaugh, 2000; Wixted, 2004). Consolidation processes can affect what transfers to long-term memory and what if any learning is retained. Thus, conversational reflection can help to promote the durability of the learning from a museum visit (Pagano et al., 2019). Furthermore, conversational reflections can also offer a vantage point for understanding initial learning outcomes (Benjamin et al., 2010; Eberbach and Crowley, 2017; Pagano et al., 2019, 2020).

The content of families' conversational reflections shortly after an exhibit experience also can serve to shed light on what families did, how they made sense of the experience, and the information they took away from it (Haden et al., 2014). Spatial language in reflections may indicate that spatial information at an exhibit was salient and memorable and could facilitate the consolidation of spatial information into families' memories of museum experiences. Thus, spatial language in reflections on exhibit experiences could be critical for revealing and extending spatial learning.

The core question of our investigation was what contributes to spatial language in families' reflections on museum experiences. Despite the relative paucity of work exploring spatial language in reflections, a growing body of research has focused on conditions that engender spatial language in families' conversations during play (e.g., Bustamante et al., 2020; Chan, Praus-Singh, and Mazzocco, 2020; Eason, Hurst, Kerr, Claessens, and Levine, 2022; Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, and Lam, 2011; Melzi, Mesalles, Caspe, and Prishker, 2022; Polinsky et al., 2017). This work suggests that the quantity of spatial language families use is tied to the design characteristics of the play experience, such as the play goals, instructions, and toys or materials. Therefore, we examined exhibit designs associated with families' spatial language in conversational reflections about museum experiences.

Exhibit design & spatial language in conversational reflections

Tinkering exhibits

Our main research question asks how families' spatial language use during reflections varies across discussions about different types of programs designed for a tinkering exhibit. At tinkering exhibits families engage in an open-ended form of building and problem-solving involving real tools and materials (Bevan, 2017). Because tinkering is

an opportunity for families' informal learning about STEM generally, and engineering specifically (for a review see Vossoughi and Bevan, 2014), tinkering exhibits have become tremendously popular in children's museums (Letourneau, McMillan Culp, and Wells, 2021). Moreover, tinkering exhibits can feature activities that might especially foster spatial language. A primary element of tinkering is building and construction, which is a spatial activity (Jirout and Newcombe, 2015). During building activities families use spatial thinking to visualize and create novel spatial configurations (Hsi, Linn, and Bell, 1997; Ramey and Uttal, 2017). In addition, tinkering is collaborative. Families must communicate with each other to solve problems (Brahms and Werner, 2013). Given the spatial nature of tinkering, this communication necessarily involves spatial language (Ferrara et al., 2011; Ramey and Uttal, 2017).

In addition, tinkering exhibits are an ideal context for asking questions about design because the designs of these exhibits can be dynamic in that they feature different types of *tinkering programs*. Different tinkering programs vary in their designs. Design changes across tinkering programs can be made towards the goal of further advancing opportunities for families to learn about engineering while maintaining the fun and open-endedness of tinkering (Pagano et al., 2020). Two characteristics that past research shows can maintain the fun and open-endedness of tinkering while focusing families' attention on engineering content are function-focused goals and orientations provided by museum facilitation staff (Pagano et al., 2020).

Function-focused goals

Goals for tinkering can fall on a spectrum from being extremely open-ended to being considerably more planned and structured (Bevan, 2017; Pagano et al., 2019; Ramey and Uttal, 2017). Open-ended tinkering programs provide very little information regarding what the tinkering creation needs to do or look like and instead encourage families to engage and experiment with materials (e.g., "make something that does something") (Martinez and Stager, 2013; Resnick and Rosenbaum, 2013). Goals of more structured tinkering programs challenge visitors to achieve specific design goals by encouraging families to make something that functions in a particular way (e.g., make something that rolls) (Brophy, Klein, Portsmore, and Rogers, 2008; Pagano et al., 2020). These more structured programs with *function-focused goals*, seem to best promote families' engagement in engineering learning. For example, Pagano et al. (2020) reported that relative to other more open-ended programs, function-focused programs were associated with the most engineering talk by families during and after tinkering. This engineering talk included conversations about the engineering design process, such as what materials to use and whether and how to test if a creation functioned as planned. Families' increased talk about engineering indicates that function-focused goals focus families' attention on the engineering concepts at work within tinkering exhibits.

Orientations

The facilitation practices can also vary across tinkering programs (Acosta and Haden, 2022; Acosta, Polinsky, Haden, and Uttal, 2021; Letourneau et al., 2021). In some tinkering programs, museum staff might provide guidance and assistance to families on an as needed basis. In other tinkering programs, museum staff may provide *orientations* in which they convey key engineering information related to tinkering goals to families at the start of the program. For example, in a program with a function-focused goal of making something that rolls, an orientation by museum facilitation staff could highlight the engineering principle of an axle, which is needed for wheels to spin. Families engage in more STEM-related talk when they receive relevant instructions, experiences, or related content information prior to exhibit engagement (e.g., Callanan, Castañeda, Luce, and Martin, 2017; Eberbach and Crowley, 2017; Jant, Haden, Uttal, and Babcock, 2014; Willard et al., 2019). Moreover, in other work, receiving engineering information prior to making a skyscraper in a building exhibit benefited children's recall of

science and engineering information weeks later (Benjamin et al., 2010). Therefore, when tinkering programs are designed with orientations, they might better focus families' attention on the engineering and STEM concepts.

Tinkering characteristics & spatial language

Goals and facilitation practices might play an important role in the spatial language families use when reflecting on tinkering experiences. Regarding goals, spatial language during playful building activities increases when families are provided a building goal (Casey et al., 2008; Eason and Ramani, 2020; Ferrara et al., 2011). In addition, parent-child spatial talk increases when families are provided information about spatial concepts and skills prior to play (Borriello and Liben, 2018). This information does not need to instruct families to use spatial language; instead, information that highlights the activity's spatial elements bolsters spatial talk (Borriello and Liben, 2018). Furthermore, the increased STEM-related talk associated with function-focused goals and orientations provided by museum staff might indicate that families who participate in these programs are more engaged in STEM and engineering learning. Spatial skills and concepts underlie STEM principles (Gaudreau, Anggoro, and Jee, 2020; Hodgkiss, Gilligan, Tolmie, Thomas, and Farran, 2018; Ramey, Stevens, and Uttal, 2020; Ramey and Uttal, 2017). Consequently, if families are more engaged with the engineering and STEM concepts presented through tinkering activities, they may also be more engaged in spatial thinking. This focus on space may be reflected through spatial language in families' conversational reflections.

The setting

In this study, we investigated the connection between tinkering programs with different design characteristics and spatial language in reflections. Our investigation occurred through a research-to-practice partnership with Chicago Children's Museum. This partnership's goal is to conduct design-based research that increases the engineering and STEM learning opportunities in Chicago Children's Museum's tinkering exhibit, *Tinkering Lab* (Barab and Squire, 2004). Therefore, three different types of tinkering programs were featured in Tinkering Lab at different times. There were programs with open-ended tinkering activities, programs with function-focused goals (to make something that rolls or flies), and programs in which the staff facilitation and exhibit design focused on engineering, in that they featured both function-focused goals and pre-tinkering orientations. We considered how efforts to increase engineering learning opportunities through different design characteristics implemented in tinkering programs might be associated with families' spatial language use in reflections on tinkering.

Exhibits across museums

In addition to considering families' spatial language used in reflections about different programs within a tinkering exhibit, we wanted to understand how spatial language in reflections might vary across exhibit spaces that are designed for different playful opportunities. All families in this study also engaged in conversational reflections about up to two additional exhibits in the children's museum. The design of these exhibits can be characterized as emphasizing one or the other of two main categories of spatial skills – those that support object manipulation, and those that support navigating environments (Chatterjee, 2008; Newcombe, Uttal, and Sauter, 2013). Specifically, several exhibits emphasize hands-on engagement with objects and artifacts, such as building dams in a water-focused exhibit. The other set of exhibits especially encourages navigation of the environment, such as exhibits featuring large, playground-like equipment that children can explore by crawling, running, and jumping (e.g., a treehouse, a pirate ship).

Typically, research on spatial language and play examines activities involving object manipulation, such as play with blocks and puzzles (e.

g., Casey et al., 2008; Chan et al., 2020; Ferrara et al., 2011; Levine, Ratliff, Huttenlocher, and Cannon, 2012). These activities facilitate spatial language because they require children to manipulate objects, consider dimensions, and understand relative locations (Ferrara et al., 2011; Jirout and Newcombe, 2015; Verdine et al., 2014). Other types of activities that primarily involve navigation may also foster spatial language (Zosh, Fisher, Golinkoff, and Hirsh-Pasek, 2013). Activities that encourage navigation can create opportunities for spatial exploration and foster children's attention to spatial aspects of the environment (Campos et al., 2000; Oudgenoeg-Paz, Leseman, and Volman, 2015), which might be reflected in spatial talk about these experiences even after they occur. Moreover, efforts to incorporate playful learning into urban landscapes demonstrates that opportunities for children to physically navigate through environments increases spatial language in families' conversations during play (Bustamante et al., 2020; Hassinger-Das et al., 2020; Hassinger-Das, Bustamante, Hirsh-Pasek, and Golinkoff, 2018). We aimed to investigate the role of these exhibit activity types in families' spatial language use beyond exhibit walls. Therefore, we examined how spatial language in conversational reflections varied when families reflected on exhibits emphasizing object manipulation or on exhibits emphasizing navigation.

Current study

Through our partnership with Chicago Children's Museum, we leveraged museum practices to examine families' spatial language use in conversational reflections. Families self-recorded these reflections using a multi-media component at Chicago Children's Museum called *Story Hub: The Mini Movie Memory Maker*. Although all recordings were created by at least one adult and child, some families were larger, with multiple adults or children. Within museums, families learn together (Stevens, 2000; Stevens and Hall, 1998). Each family member contributes their unique knowledge and skills (Gutiérrez and Rogoff, 2003; Zimmerman, Reeve, and Bell, 2010). Moreover, tinkering experiences encourage social interactions making spatial cognition socially distributed (Ramey and Uttal, 2017). Therefore, like prior work on learning in museums (e.g., Knutson and Crowley, 2010; Povis and Crowley, 2015), we focused on the family as the unit of analysis. In these short reflections, it is valuable for adults or children to use spatial language (Pruden et al., 2011).

We asked two research questions: (1) What tinkering program design characteristics are important for families' spatial language use in reflections on tinkering exhibits? We hypothesized that tinkering programs designed with goals or facilitation practices that focus families' attention on engineering concepts would be associated with more spatial language in reflections. (2) Does spatial language in families' conversational reflections vary according to the design of the museum exhibit, either emphasizing object manipulation or physical navigation? Given work showing that both activities emphasizing object-manipulation and activities emphasizing navigation foster spatial language, we did not form a hypothesis about which type of exhibit activity would be associated with more spatial language in reflections on exhibits from across the museum. Investigating the role of design characteristic in the spatial language families use in reflections can contribute to the development of spatial learning opportunities for children.

Method

Participants

This collaborative research project was reviewed and approved by the Loyola University Chicago Institutional Review Board (LUC #2914

and #1973 “Visitors’ Narratives Recorded in Story Hub about Exhibit Experiences”). The sample included 243 English-speaking family groups who recorded a video of themselves reflecting on their exhibit experiences in Story Hub between October 2016 and September 2018.¹ All family groups had at least one adult caregiver, and from the videos we estimated that at least one child in each family group was between 6 and 11 years old. On average, there were 2.92 ($SD = 0.95$) visitors per family group (range: 2–6). Although demographic information is not collected from families in Story Hub, survey data collected by the museum from the years 2016–2018 revealed that 52.80% percent of visitors report identifying as White, 18.28% Hispanic or Latino, 11.90% African American or Black, and 14.89% Asian. The criterion for selection of the video recordings was that the family chose to record a reflection about their experiences in Tinkering Lab because tinkering was the focus of the larger project of which this study is a part. Table 1 includes the number of families who recorded reflections about each Tinkering Lab program that took place over the period of the study. Out of the 243 families in our sample, 148 recorded a conversational reflection about one ($n = 102$) or two ($n = 46$) other exhibits, in addition to Tinkering Lab. Table 2 shows the number of families who elected to also record a reflection about at least one other exhibit. Families in this sample never directly interacted with researchers and none of the families in this sample were observed at any museum exhibit.

Procedures

Story Hub

Families recorded their reflections about their exhibit experiences in the self-guided multi-media component *Story Hub: The Mini Movie Memory Maker* at Chicago Children’s Museum. Prompts presented on a touchscreen computer guide families through the reflection and recording process (see Fig. 1). First, families selected an exhibit to discuss from a display of images of the museum’s different exhibits.

Table 1

Date of each tinkering lab program, number of families who reflected on each program, and program descriptions all categorized by program type.

	Program name	Date	N	Challenge description
Open-ended tinkering programs	Make a Robot	Fall 2016	29	Build a robot sculpture with recycled materials.
	Make Something That Does Something	Winter 2017	26	Building a creation that does something without specifying what it should do/ function and no exhibit spaces designed for testing.
	Make a Monster Playground	December 2017	20	Build playground equipment for a toy finger-puppet monster to play on.
Function-focused goal programs	Make It Fly 1	December 2016	17	Build a creation that flies in a wind tunnel.
	Make It Fly 2	Spring 2017	58	Build a creation that flies in a wind tunnel or hovers at a wind table.
Engineering-focused programs	Make It Roll	Summer 2017	45	Build a vehicle that can roll down a ramp.
	Monster Ride Park	Summer 2018	48	Build a vehicle that will give a toy finger-puppet monster a ride.

¹ This sample did not share participants in common with Pagano et al. (2019).

Table 2

Number of families who reflected on each exhibit other than tinkering lab and the exhibit descriptions.

Exhibit	N	Description	Exhibit design-emphasis
Dinosaur Expedition	24	Re-creation of a Saharan paleontology expedition where children can dig for fossils.	Object manipulation
Kids Town	21	Miniature version of an urban neighborhood, including grocery store, kitchen, car wash, and a city bus.	Navigation
Kovler Family Climbing Schooner	44	Large boat whose rigging spans several floors, on which children can climb up and down.	Navigation
Play It Safe	20	Fire station, including a pole, fire truck, fire hose, and firefighting gear.	Navigation
Skyline	18	Construction site overlooking the Chicago skyline, where children build skyscrapers.	Object manipulation
Treehouse Trails	20	Enchanted forest with a fort, canoe, climbing rocks, and slide.	Navigation
Waterways	47	Running river of water canals where children create dams and fountains.	Object manipulation

Next, families choose digital (stock) photos from inside the selected exhibit to include in their video. For Tinkering Lab, where the exhibit design changed over time, the photos offered in Story Hub were updated, so that they corresponded to the program families experienced. After selecting photos, families received the standard prompt to record their reflection – “Talk together about what you did.” – which was the same prompt for reflection about all exhibits and Tinkering Lab programs. Recordings about each exhibit could last up to two minutes, and families could record reflections about as many as three exhibits. Finally, when families indicated they had completed all their recordings, they could choose to email the video to themselves as a keepsake from their visit and to give permission for the video recording to be used for research purposes.

Exhibit experiences for conversational reflections

Tinkering Lab

All families in this project made a recording of a conversational reflection about their tinkering experiences. The Tinkering Lab exhibit is a large workshop space with various tools and materials that families can use to make creations. Over the two-year course of data collection, seven different tinkering programs were introduced into the exhibit, as part of a larger design-based research project aimed at advancing engineering learning opportunities through tinkering. Based on knowledge from research and practice, and our observations of families play, we iteratively co-designed changes to the goal structure and facilitation practices of each program. Three types of programs were offered for families in Tinkering Lab: (1) open-ended tinkering programs, (2) function-focused goal programs, and (3) engineering-focused programs. Table 1 provides a description of each program and categorizes each program by type.

Open-ended tinkering programs. Open-ended tinkering programs included goals that encouraged making something without defining what the creation should do. During these programs, museum facilitation staff supported visitors on an as needed basis throughout their tinkering experience.

Function-focused goal programs. Function-focused programs were designed to encourage making something that functioned in a certain way (e.g., rolls, flies) and included exhibit features (e.g., ramps, wind tunnels) to test the creations functionality. In these programs, museum facilitation staff introduced visitors to the tinkering goals and supported visitors on an as needed basis throughout their tinkering experience.

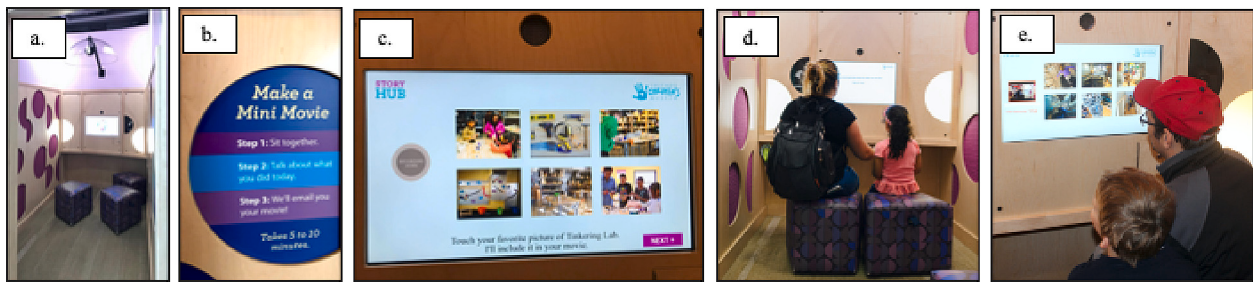


Fig. 1. Photographs of different elements of story hub exhibit.

Note. (a.) The inside of Story Hub. (b.) Recording and reflection instructions on the wall inside Story Hub. (c.) Digital prompt on Story Hub's touchscreen computer for families to choose stock exhibit images for their recording. (d.) A family recording a reflection inside Story Hub. (e.) A family choosing images for a reflection on Climbing Schooner.

Engineering-focused programs. Engineering-focused programs encouraged making something that functioned in a certain way and included exhibit features for testing creation functionality. When museum facilitation staff introduced families to the program goal before they began tinkering, they also provided a brief orientation. Orientations provided information about engineering principles and practices (e.g., wheels and axles, testing one's design) that could support building and creating. These orientations also included spatial information (e.g., relations between size, shape). For example, for the Make it Roll and Monster Ride Park programs, facilitators explained to visitors that vehicles roll best when the wheels on opposite sides of the same axle are the same size and shape. The orientations were brief and unscripted. Because facilitation staff (not researchers) provided the orientations as part of museum practice, facilitators explained the engineering principles and practices using their natural style. Therefore, across families, orientations likely varied. In this study, we did not observe the orientations and cannot describe the extent of variation in content families received.²

Exhibits from across the museum

As part of the Story Hub activity, families could record conversational reflections about up to two more exhibits in addition to Tinkering Lab. Table 2 includes descriptions of these exhibits, and Fig. 2 provides photographs of these exhibits. All exhibits from across the museum were designed for children's free play. Visits to these exhibits neither include explicitly provided goals nor orientations from museum facilitation staff. In this study, we broadly characterized these exhibits as either emphasizing object manipulation and exploration of physical materials or encouraging navigation of the physical environment. Therefore, in Story Hub recordings families could have included up to two reflections on exhibits that emphasized object manipulation, up to two reflections on exhibits that emphasized navigation, reflections on both exhibit types, or reflections on none of these exhibits in addition to Tinkering Lab in their Story Hub recordings.

Coding

The conversational reflection videos recorded in *Story Hub* were transcribed verbatim using the Computerized Language Analysis (CLAN) program from CHILDES (MacWhinney, 2000). The spatial language coding of these transcripts then proceeded in three steps. First, the Keyword and Line command (kwal) in CLAN used a list of spatial words generated from the Cannon, Levine, and Huttenlocher (2007) spatial language coding manual to identify spatial words spoken during

families' conversational reflections. The CLAN output identified the spatial word and the transcript line in which the spatial word appeared. Second, based on the context of the transcript line, the researchers evaluated whether the word was used in a spatial manner. For example, the word 'top' is spatial only when it describes a location or direction; a coder would identify the word 'top' as spatial in the sentence, "You put the pipe cleaners on top", but would not identify it as spatial in the sentence, "I used a top for a cup". Third, words identified as spatial were further coded into one of eight categories: *spatial dimensions* (e.g., big, short, thin), *shapes* (e.g., circle, triangle, pyramid), *locations and directions* (e.g., on, under, sideways), *orientations and transformations* (e.g., upside down, turn, flip), *continuous amount* (e.g., piece, half, inch), *deictics* (e.g., here, there, where), *spatial features and properties* (e.g., side, curve, angle), and *patterns* (e.g., next, before, repeat).

To capture the frequency of spatial language within the transcripts, tallies were computed on the following: the total number of individual spatial words, the total number of each spatial word type, and the number of types of spatial words used by families in their reflections on each exhibit. Interrater reliability was calculated based on 20% of the transcripts, with Cohen's kappa = 0.87 (range: 0.80–0.92).

Results

We focus first on the spatial language families used in their reflections about their experiences in the museum's Tinkering Lab. Then we consider the spatial language used in additional conversational reflections recorded by these same families about other exhibits they had visited. Data were analyzed using Jamovi (The jamovi project, 2022).

Spatial language in families' conversational reflections about tinkering

Table 3 presents descriptive statistics of the spatial language families used in their conversational reflections about their experiences tinkering. There was large variability in the number of total words and spatial words families used in these post-tinkering reflections. On average, families used 129 total words ($SD = 67.30$) with a range from 27 to 337 words. Relative to total words, spatial words were rare. On average families used 6.05 spatial words ($SD = 4.92$) with a range of 0 to 25. As shown in Fig. 3, some families used relatively few spatial words in their post-tinkering reflections, while others used substantially more. Furthermore, although we coded for 8 different types of spatial words, on average families only used 2.21 spatial word types ($SD = 1.03$) in their reflections about tinkering experiences.

Our first research question asked whether and how families' spatial language in conversational reflections about tinkering experiences varied with the structure of the program goals and facilitation strategies available in each of the three types of tinkering programs: (1) open-ended tinkering programs, (2) function-focused goal programs, and (3) engineering-focused programs. Each tinkering program was grouped into one of these three different types. Table 4 presents the descriptive

² Prior work on Tinkering Lab shows that variations in the content of provided orientations is associated with whether families reference these orientations while tinkering (Aldrich et al., 2022), which can impact STEM-related talk in reflections on tinkering experiences (Acosta and Haden, 2022).



Fig. 2. Photographs of exhibits from across the museum.

Table 3

Means and (standard deviations) of the frequencies of spatial words and each type of spatial word used during families' reflections on tinkering lab.

Tinkering Lab spatial words	Frequencies	Minimum	Maximum
Total spatial words	6.05 (4.92)	0	25
Deictics	0.88 (1.40)	0	10
Continuous amounts	0.50 (1.03)	0	7
Locations & directions	3.98 (3.26)	0	19
Orientations & transformations	0.09 (0.56)	0	6
Patterns	0.00 (0.06)	0	1
Shapes	0.02 (0.18)	0	2
Spatial dimensions	0.45 (0.99)	0	11
Spatial features	0.11 (0.44)	0	3
Types of spatial words used	2.21 (1.03)	1	5

Table 4

Means and standard deviations of the quantity of spatial words in families' post-tinkering reflections by program and program Type.

Program type	Program	Quantity spatial words		
		M	SD	Range
Open-ended tinkering		5.73	4.49	0–21
	Make a Robot	4.66	4.34	0–21
	Make Something That Does Something	6.46	5.38	0–20
	Make a Monster Playground	6.35	3.13	0–11
Function-focused		5.16	4.72	0–24
	Make It Fly 1	7.88	5.15	1–21
	Make It Fly 2	4.36	4.32	0–24
Engineering-focused		7.02	5.26	0–25
	Make It Roll	8.07	5.88	1–25
	Monster Ride Park	6.04	4.46	0–19

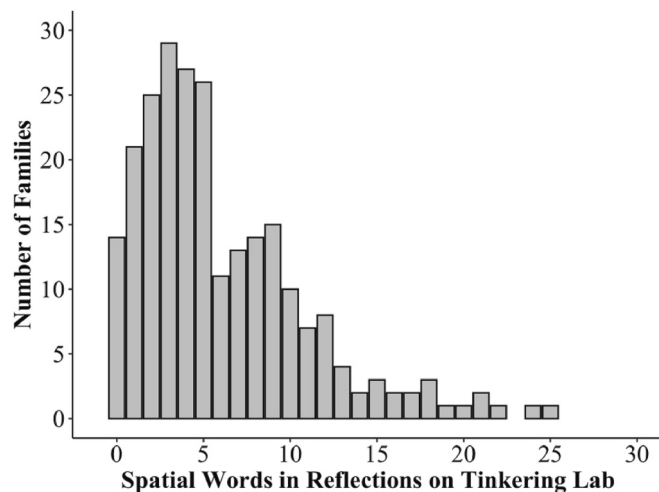


Fig. 3. Distribution of the number of spatial words used by families when reflecting on tinkering lab.

statistics of the spatial language used by families in their post-tinkering reflections by program and program type. To test whether program type was associated with spatial language in families' post-tinkering reflections, we conducted a negative binomial regression analysis. Negative binomial regressions are appropriate for our spatial language data because they can be used to model positively skewed count data that is overly dispersed (e.g., the variance is greater than the mean) (Green, 2021; for a related paper using negative binomial regression see Eason et al., 2022). We modeled the number of spatial words³ used by families in their reflections as a function of the programs on which they reflected. The open-ended tinkering program type served as the reference category against which function-focused goal programs and engineering-focused programs were compared. To account for variation across family groups, the model included the total number of words families spoke in these reflections, the number of family members in the group, and the number of exhibits about which families reflected in their Story Hub recordings as control variables. All results show the unique contribution of each variable, controlling for all other variables in the model.

The results of the full model are displayed in Table 5. Families who reflected on engineering-focused programs used more spatial words than those families who reflected on open-ended tinkering programs, $SE = 0.10$, incidence rate ratio (IRR) = 1.23, $p = .034$. In contrast, there was

³ To examine whether the effect tinkering program type was driven by families repeating spatial terms, we conducted this same analysis with the number of unique spatial words as the dependent variable. Across the two analyses the pattern of significant results was nearly the same, suggesting the effect was not driven by repeated words. The only difference was that when the dependent variable was the number of unique spatial terms, families who reflected on engineering-focused programs used more unique spatial terms than families who reflected on function-focused goal programs ($p = .01$).

Table 5

Negative binomial regression coefficients and program type factors predicting spatial language in reflections on tinkering lab.

Variable	<i>b</i>	<i>SE</i>	<i>p</i>	IRR [95% CI]
Intercept	1.66**	0.042	<0.001	5.27 [4.85, 5.72]
Engineering-focused	0.21*	0.10	0.034	1.23 [1.02, 1.49]
Function-focused goals	−0.00002	0.11	0.10	1.000 [0.81, 1.23]
Number of family members	0.04	0.04	0.31	1.04 [0.96, 1.13]
Number of exhibits	−0.02	0.06	0.78	0.98 [0.88, 1.10]
Total words spoken	0.01**	0.00005	<0.001	1.01 [1.006, 1.01]

Note. IRR = incidence rate ratio, which is the exponential unstandardized regression coefficient; CI = confidence interval; ** $p < .001$; * $p < .05$.

not a difference between the spatial language used by families reflecting on function-focused goal programs and open-ended tinkering programs, $SE = 0.11$, $IRR = 1.00$, $p = .10$. To compare the spatial language used by families who reflected on function-focused goal programs and engineering-focused programs, we conducted a post-hoc test with Bonferroni adjustments. The spatial language used by families who reflected on function-focused goal programs was not different from those families who reflected on engineering-focused programs, $SE = 0.12$, $IRR = 1.23$, $p = .11$.

Spatial language in families' conversational reflections about additional exhibits

In addition to Tinkering Lab, families could have reflected on up to two of seven exhibits from across the museum. Our second research question asked how spatial language in conversational reflections were influenced by these non-tinkering exhibits, which encourage either object manipulation or navigation (see Table 2). We therefore examined spatial language use in entire Story Hub recordings, as opposed to in solely Tinkering Lab specific reflections. These recordings included reflections on Tinkering Lab and additional exhibits from across the museum; of interest was whether the quantity of spatial language in recordings would vary depending on the types of non-tinkering exhibits on which families reflected.

On average, within entire recordings families used 220 total words ($SD = 136$; Range: 29–898). There was also considerable variability in the number of spatial words families used in these recordings. On average families' entire recordings included 12.1 spatial words ($SD = 9.22$) with a range of 0 to 57. As shown in Fig. 4, some families used

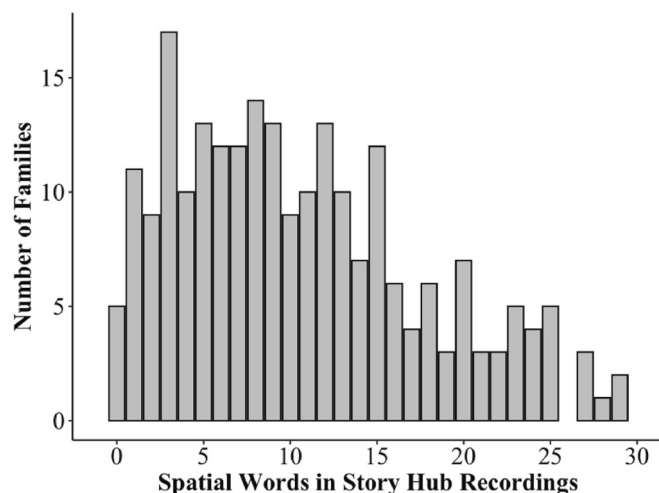


Fig. 4. Distribution of the number of spatial words used by families in complete story hub recordings.

relatively few spatial words across their reflections about different exhibits, while others used substantially more. Also, on average families only used 2.79 spatial word types ($SD = 1.03$) in their entire recordings, with a range of 1 to 6.

We conducted a negative binomial regression to investigate whether spatial language in entire recordings varied depending on the design emphasis of the non-tinkering exhibits on which families reflected. We modeled the number of spatial words used by families in their entire recordings⁴ as a function of the combination of the types of exhibits families discussed in addition to Tinkering Lab. There were four combinations: (1) reflections on only exhibits that emphasized object-manipulation, (2) reflections on only exhibits that emphasized navigation, (3) reflections on one object manipulation exhibit and on one navigation exhibit, and (4) no reflections in addition to the one on Tinkering Lab. The no additional reflections group served as the reference category against which only object-manipulation exhibit reflections, only navigation exhibit reflections, and reflections on both types of exhibits were compared. To account for variations across families, we included the total number of words families spoke in their recordings, the number of family members in each group, and the number of exhibits families discussed as control variables. All results show the unique contribution of each variable, controlling for all other variables in the model.

The results of the negative binomial regression are displayed in Table 6. Families who only reflected on navigation exhibits used more spatial language in their Story Hub recordings than families who only reflected on Tinkering Lab, $SE = 0.15$, $IRR = 1.39$, $p = .03$. In contrast, there were no differences in the amount of spatial language used by families who only reflected on Tinkering Lab and those who also reflected on object-manipulation exhibits, $SE = 0.15$, $IRR = 1.05$, $p = .74$, or on both object-manipulation and navigation exhibits, $SE = 0.07$, $IRR = 1.07$. Post-hoc tests with Bonferroni adjustments revealed that families whose non-tinkering reflections were on only navigation exhibits used more spatial language than families' whose non-tinkering reflections were only on object-manipulation exhibits, $SE = 0.07$, $IRR = 0.76$, $p = .01$. No other comparisons were significant, p 's > 0.35 . These results indicate that families who in addition to Tinkering Lab only reflected on navigation exhibits used more spatial language in their conversational reflections than families who did not include any additional reflections or reflected on any object-manipulation-focused

Table 6

Negative binomial regression coefficients predicting spatial language in complete story hub recordings.

Variable	<i>b</i>	<i>SE</i>	<i>p</i>	IRR [95% CI]
Intercept	2.32**	0.05	<0.001	10.2 [9.31, 11.19]
Only object-manipulation exhibits	0.05	0.15	0.74	1.05 [0.78, 1.42]
Only navigation exhibits	0.33*	0.15	0.03	1.39 [1.03, 1.89]
Both types of exhibits	0.07	0.24	0.77	1.07 [0.66, 1.73]
Number of exhibits	0.11	0.11	0.35	1.11 [0.89, 1.39]
Number of family members	0.004	0.03	0.90	1.00 [0.94, 1.07]
Total words spoken	0.004**	0.00003	<0.001	1.004 [1.003, 1.004]

Note. IRR = incidence rate ratio, which is the exponential unstandardized regression coefficient; CI = confidence interval.; ** $p < .001$; * $p < .05$.

⁴ To examine whether the effect of including reflections on different types of exhibits was driven by families repeating the same spatial terms throughout their Story Hub recordings, we conducted this same analysis with the number of unique spatial terms in recordings as the dependent variable. Across the two analyses the pattern of significant results was the same, suggesting that the effect was not driven by repeated words

exhibits.

Discussion

We analyzed conversational reflections about exhibit visits that families recorded in a multi-media platform at Chicago Children's Museum. We were interested in the ways that families' conversational reflections shortly after visiting exhibits might include spatial language and what they could tell us about program and exhibit design that supported spatial learning. Our analyses of families' self-recorded reflections revealed program types and exhibit activities that are associated with spatial language in conversational reflections. The most spatial language in families' conversational reflections was observed when (1) tinkering programs explicitly focused on engineering, by including both goals and facilitations practices that highlighted STEM concepts, and (2) exhibits encouraged physical navigation through environments. Taken together, our focus on families' conversational reflections about museum experiences uncovered features of museum programs and exhibit design that can advance informal spatial learning opportunities for children.

Spatial language in reflections

The current study contributes to literature on play and spatial language by revealing characteristics of playful experiences that extend families' use of spatial language beyond the play experience itself. Research has primarily examined the types of playful experiences that can engender spatial language in families' conversations during play (e. g., Chan et al., 2020; Eason et al., 2022; Melzi et al., 2022; Polinsky et al., 2017). However, conversations about experiences after they occur can further support the learning process of consolidation and retrieval, which can lead to lasting learning (Camilleri, Leichtman, and Pillemer, 2021; Haden, 2010; Haden et al., 2014; Leichtman et al., 2017; Pagano et al., 2019, 2020). Spatial language in conversational reflections may contribute to children's comprehension and recall of spatial information from informal learning experiences. Moreover, conversational reflections can provide a natural assessment of what children take away from these experiences (Acosta et al., 2021; Ocular et al., 2022; Pagano et al., 2019; Sobel, Stricker, and Weisberg, 2022). Our analysis further suggests that spatial language in conversational reflections can provide important diagnostic information about how variations in exhibit programs and museum exhibit design links with spatial language and opportunities for spatial learning.

Exhibit design & spatial language use in reflections

Tinkering programs

Our first research question asked about the tinkering program design characteristics that may be important for families' use of spatial language when reflecting on tinkering exhibits. We predicted that tinkering programs designed with goals or facilitation practices that focus families' attention on engineering concepts would be associated with more spatial language in reflections. However, we found that only families who reflected on engineering-focused programs that featured function-focused goals and pre-tinkering orientations used more spatial language in reflections than families who reflected on open-ended tinkering programs. In addition, there was no difference in the spatial language between families who reflected on function-focused goal programs and engineering-focused programs. These findings suggest that the implementation of both goals and facilitation practices that focus families' attention on engineering concepts is most important for spatial language in reflections on tinkering programs.

One possible explanation for why the implementation of both function-focused goals and orientations was so important for spatial language in reflections is that engineering-focused programs best engage families in engineering concepts and practices. Function-focused goals

engage families in the engineering practice of testing and iterating (Marcus, Acosta, Tôugu, Uttal, and Haden, 2021) and orientations explicate engineering principles (Acosta et al., 2021). Spatial thinking and skills underlie these engineering principles and practices (Uttal, Miller, and Newcombe, 2013). Therefore, if engineering-focused programs with function-focused goals and orientations engage families in engineering more than other programs, families may use more spatial language in reflections. This explanation follows prior research suggesting that children used spatial reasoning when they engaged in making solutions to challenging engineering problems (Ramey et al., 2020).

One question is why programs with only function-focused goals were not associated with reflections that had higher quantities of spatial language. This finding was surprising given research showing that function-focused programs can engender families' conversations about the engineering process during and after tinkering (Pagano et al., 2020). In contrast to engineering process talk, spatial language describes object manipulations, which underlie engineering (Ramey and Uttal, 2017). Consequently, spatial language in reflections may be best supported when tinkering programs are designed with more than one element that highlights engineering practices and concepts. Therefore, in this study families had the most opportunities to use spatial language in reflections when they discussed tinkering programs with both goals and facilitation practices focused on engineering.

The following example demonstrates how engaging with both the engineering principles and practices highlighted by the function-focused goals and orientations created opportunities for families to use spatial language when they reflected on Tinkering Lab. The family is reflecting on the Make It Roll program, an engineering-focused program that included both a function-focused goal and orientation providing engineering information. Throughout the conversation the child uses spatial language to describe engineering-related elements of their tinkering experience that were highlighted by the orientation and were central to the function-focused goal (spatial language is in **bold**):

CHILD: So I built mine out of discs and then I put the sticks **on** the **bottom** and then put wheels and then I put pipe cleaners to hold them **together**.

ADULT: It was smart.

CHILD: And then I went **over** to the ramp and put it **down** and then it **turned** so I decided maybe I could put a stick to keep it going in the right **direction**, but it still **turned**.

ADULT: It looked great.

In this reflection, the child used spatial words to describe how they built the axle for their creation, by putting sticks on the bottom. Axles were a concept emphasized by the pre-tinkering orientation provided by the museum's facilitation staff. Additionally, the child used spatial language to discuss how their creation functioned, "put it down and then it turned". Testing creations was a practice highlighted by the function-focused goal. Therefore, this reflection demonstrates how the emphasis on engineering provided through both the goal for tinkering and staff facilitation led to a program design that resulted in increased spatial language use when families reflected on their experiences.

Future work should consider whether more spatial language in reflections is indicative of more spatial talk when families are engaging in exhibits and museum programs. Although we did not observe families during their exhibit experiences in this study (families recorded themselves in Story Hub), other work finds that families' conversational reflections are affected by both museum programming and the conversations families have during exhibit experiences (Acosta et al., 2021; Pagano et al., 2020). Moreover, research on parent-child conversations in museums demonstrates a connection between a focus on spatial concepts during an exhibit program with spatial attention shortly after (Gentner et al., 2016). Therefore, the use of more than one engineering-focused design characteristic may lead to more spatial attention and spatial talk during tinkering, which may lead to more spatial language in reflections on engineering-focused programs after

the experience has concluded.

Additional museum exhibits

Our second research question asked how spatial language in families' conversational reflections varied depending on whether families reflected on museum exhibits from across the museum that emphasized object-manipulation or navigation activities. Answering this question provided insight into the role of exhibit-level factors in families' learning from museum experiences (Caporaso et al., 2022). Families who in addition to Tinkering Lab reflected exclusively on exhibits that emphasized navigation used more spatial language in their Story Hub recordings than families who only reflected on Tinkering Lab or who reflected on at least one object manipulation exhibit. Families who reflected on exhibits designed with a focus on navigation may have used more spatial language across all their exhibit reflections, or they may have used more spatial language when they specifically reflected on navigation-focused exhibits. In either case, our findings demonstrate that when families choose to reflect on a navigation-based exhibit they seem to focus more on spatial information in at least one conversational reflection, and subsequently use more spatial language.

Playful experiences that engage children in navigation may facilitate spatial language in reflections by creating opportunities for spatial exploration, including children's movement and navigation through space. Spatial exploration can support children's attention towards spatial aspects of the environment (Campos et al., 2000; Oudgenoeg-Paz et al., 2015). Consequently, this increased spatial attention at exhibits that foster navigation may engender spatial language in families' conversational reflections. Given the value of spatially rich conversations for children's spatial skill development (Pruden et al., 2011), recognizing experiences – such as play encouraging navigation – that naturally lend themselves to everyday spatial conversations is important.

In contrast, we found that reflecting on exhibits that emphasized object-manipulation was not associated with the use of spatial language. Past research on parent-child interactions during playful experiences demonstrates that some object manipulation activities do not readily engender spatial language. For example, Chan et al. (2020) found that block play activities better supported spatial talk between parents and children than another object manipulation activity involving kitchen set play. Furthermore, Ferrara et al. (2011) demonstrated that object manipulation activities best support parent-child spatial language when these activities include specific goals on how to play with the objects, which these exhibits did not include. Therefore, object manipulation activities may best support spatial language during play and in reflections under specific conditions that may not currently be met by these museum exhibits.

An additional factor that could impact the amount of spatial language families use in reflections is the role of parents during distinct types of playful experiences. In general, during play experiences that emphasize navigation, such as the Climbing Schooner, children tend to lead the play while their parent or caregiver observes from the sidelines. Due to this dynamic, when families reflect together on navigation-focused play, children may spend more time describing the experience, which engenders spatial language. The following example of a families' reflection on Climbing Schooner illustrates how parents' questions about what children did during play within the exhibit may naturally lend themselves to answers, and subsequent questions, that include spatial language (spatial language is in **bold**):

ADULT: What did you do **in** the climbing schooner?

CHILD: We climbed and we um let's see we went **in** the secret playground.

ADULT: Did you climb **to** the very **top**? Did you climb **over** a bridge?

CHILD: Well, I climbed **over** a bridge too but there was also a little thing **there** and then we climbed **through** this little tunnel and then we went **into** the **big** thing **over there** too and we got to go **up** a thing to get to that thing and to get to that thing that goes **up** the **big** thing we had to

do another thing.

Spatial words were a crucial element of this child's description of the navigation-focused exhibit and how they played within it. The child's description of their time at the exhibit was informative, given that the parent was not able to climb through the exhibit with them. Consequently, the parent-child dynamic created by activities designed with a focus on navigation may naturally lend itself towards reflections that are rich in spatial language, and in this study may have facilitated greater quantities of spatial language in Story Hub recordings. Alternatively, the way parents and children engage during activities emphasizing object-manipulation may not create the same types of spatially rich conversations. Given the many factors that could influence how exhibit design characteristics foster spatial language in conversational reflections, future work must examine the connection between how families use spatial language both during and after play.

Limitations and future directions

This study informs our understanding of how design characteristics can support families' spatial language use beyond exhibit walls. A methodological strength of this paper was our use of an existing multimedia museum platform at Chicago Children's Museum, Story Hub. By examining families' self-recorded conversational reflections, we could examine factors that are associated with families' spatial language in reflections without disrupting the natural flow of museum visits. Simultaneously, some limitations emerged from the naturalistic nature of our work.

One limitation is that we did not observe families during their interactions at the exhibits and could not explore connections between spatial language during *and* after exhibit experiences with the same group of families. Prior research demonstrates a relation between parents' and children's use of STEM-related language as events unfold with their use of STEM-related language in conversational reflections after the event (Benjamin et al., 2010; Haden et al., 2014; Marcus, Haden, and Uttal, 2018). Exploring this relation regarding spatial language is an important next step for research on designing informal activities for spatial language and is one that we are beginning to pursue.

Additionally, the tinkering programs also varied on several dimensions. Our design-based research is premised on the idea of studying authentic museum practices and iterating across programs to provide increasingly effective STEM learning opportunities for children. Although through this methodology we uncovered program types associated with spatial language in reflection, we are limited in what we can say about the elements of these types of programs that specifically caused the differences we observed.

Finally, some prior studies suggest that demographic characteristics, such as child gender, are associated with spatial skills (Coyle and Liben, 2020; Levine, Huttenlocher, Taylor, and Langrock, 1999; Linn and Petersen, 1985; Newcombe, 1982; Polinsky et al., 2017). However, the current study cannot speak to how potential demographic differences in spatial skills might contribute to families' conversational reflections because the museum does not request this information from visitors to Story Hub. Investigating the interaction between family background characteristics and the spatial language used when families reflect together is an important focus for future research.

Implications for informal education

More broadly, our results have important implications for practice in informal learning settings. First, designed areas for reflections, such as the Story Hub exhibit, can extend conversations involving spatial language beyond an initial playful experience. These opportunities for reflections may be particularly valuable when parents and children are together but not talking, or when the exhibit is too small for adults (e.g., the Climbing Schooner), as may be the case at playful activities that engage children in navigation. Moreover, children may benefit most

from reflection opportunities when the playful experience is relatively novel (e.g., exploring engineering principles and practices), as reflection supports discussion and explanation of information that might not have been fully understood as the experience unfolded. Therefore, to enhance learning generally, and spatial learning specifically, museums and other informal learning settings should continue to create designed spaces for families to engage in conversational reflections.

Second, our results suggest conditions of informal learning activities that may promote spatial language in conversational reflections. For example, some elements might work best when used together, such as structured play goals and pre-play orientations because they focus families' attention on spatial aspects. Our findings show that the combination of structured goals and pre-play orientations that do not explicitly focus on space but reveal general spatial information or problems, can support spatial language in reflections. Combinations of design characteristics can be readily implemented within informal learning settings. Another condition of playful activities that may support spatial language in reflections is a design encouraging navigation of the play environment. Including these conditions in continued efforts to design informal learning spaces may contribute to advancing children's spatial learning.

Finally, efforts to promote children's exposure to spatial language, even after the conclusion of a playful activity, are important because this exposure can foster children's spatial skill development (Casasola et al., 2020; Ferrara et al., 2011; Pruden et al., 2011). Although spatial skills are not taught in formal education (Newcombe and Frick, 2010), spatial abilities are predictive of children's achievement in STEM subjects (Mix, 2019; Uttal, Miller, and Newcombe, 2013; Verdine et al., 2014; Wai et al., 2009). Thus, creating opportunities for families to use spatial language in reflections on informal experiences can be a valuable way to support children's spatial and STEM learning.

CRedit authorship contribution statement

Naomi Polinsky: Conceptualization, Investigation, Formal analysis, Writing – original draft. **Lauren C. Pagano:** Conceptualization, Methodology, Investigation, Writing – review & editing. **Diana I. Acosta:** Conceptualization, Investigation, Writing – review & editing. **Catherine A. Haden:** Supervision, Writing – review & editing, Resources, Funding acquisition. **David H. Uttal:** Supervision, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

None.

Data availability

Data will be made available on request.

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