Journal of Experimental Child Psychology 246 (2024) 106000

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

The intersection of parent questions, child skills, and activity context in informal science, technology, engineering, and math learning

Valerie P. Bambha [a,*], Sarah Surrain [a], Tricia A. Zucker [a], Yusra Ahmed [a,b], Diana Leyva [c]

[a] Children's Learning Institute, The University of Texas Health Science Center at Houston, Houston, TX 77030, USA
[b] Texas Institute for Measurement, Evaluation, and Statistics, University of Houston, Houston, TX 77204, USA
[c] Department of Psychology, University of Pittsburgh, Pittsburgh, PA 15260, USA

ARTICLE INFO

Article history:
Received 15 January 2024
Revised 22 May 2024
Accepted 22 May 2024
Available online 6 July 2024

Keywords:
Informal STEM
Parent–child dyads
Preschool STEM learning
Questions

ABSTRACT

Adult verbal input occurs frequently during parent–child interactions. However, few studies have considered how parent language varies across informal STEM (science, technology, engineering, and math) activities. In this study, we examined how open and closed parent questions (a) differed across three STEM activities and (b) related to math, science, and vocabulary knowledge in their preschool-aged children. A total of 173 parents and their preschool children (M_{age} = 4 years) from lower socioeconomic households were video-recorded participating in three STEM-related activities: (a) a pretend grocery store activity, (b) a bridge-building challenge, and (c) a book read about a science topic. Parent questions were categorized as open or closed according to the presence of key question terms. Results indicate that the three activities elicited different frequencies of parent open and closed questions, with the grocery store activity containing the most open and closed questions. Children's science knowledge was predicted by the frequency and proportion of parent *open* questions during the book read. These results enhance our understanding of the role of parent questions in young children's language environments in different informal learning contexts.

* Corresponding author.
E-mail address: valerie.p.bambha@uth.tmc.edu (V.P. Bambha).

https://doi.org/10.1016/j.jecp.2024.106000

Introduction

Parents are important facilitators of informal learning activities for their children, which are instrumental in building cognitive and school readiness skills (Bermudez et al., 2023; Cohrssen & Niklas, 2019; LeFevre et al., 2009; Masek et al., 2021; Neale & Whitebread, 2019; Schatz, Suarez-Rivera, Kaplan, & Tamis-LeMonda, 2022; Suarez-Rivera, Schatz, Herzberg, & Tamis-LeMonda, 2022; Tamis-LeMonda, Kuchirko, & Song, 2014; Zucker et al., 2022). Playful parent-child interactions foster areas such as language learning, conceptual understanding, and academic interest and achievement through avenues such as *verbal input* from parents (Masek et al., 2021; Neale & Whitebread, 2019; Schatz et al., 2022; Suarez-Rivera et al., 2022; Tamis-LeMonda et al., 2014). The language parents use often depends on the activity context. For example, whereas parents often employ open-ended verbal narratives during pretend play with their children (Lillard, Pinkham, & Smith, 2010), their verbal input during object play is more likely to be characterized by labeling object features (Suarez-Rivera et al., 2022). However, little research has directly assessed how parents' verbal input varies across informal activities that target specific academic domains. Pinpointing these distinctions is necessary for understanding differences in children's exposure to key concepts and opportunities for learning.

Parent questions in informal STEM learning

The current study targeted parents' use of *questions* during informal STEM (science, technology, engineering, and math) activities with their pre-kindergarten-aged children. There is ample evidence that children benefit from inquiry-based approaches when learning new STEM concepts (e.g., Lin et al., 2021), and *questions* are the most prevalent form of verbal support that young children receive from adults in general (Deshmukh, Pentimonti, Zucker, & Curry, 2022). These questions enrich child word learning and conceptual knowledge and can be classified as *open* or *closed* according to the degree to which they elicit children's active use of language. Although definitions of open and closed questions vary (see Worley, 2015), questions that produce a more elaborated response or elicit complex cognition requiring respondents to produce their "own" answers without contextual cues are generally considered *open questions* (see Brubacher et al., 2019; Worley, 2015). These questions are expected to be more supportive of child learning than *closed questions* that elicit a constrained set of response options and can often be answered with one word (e.g., yes/no) or using information embedded in the questions (Author, 2019). For example, *wh-questions*, which tend to be open questions that encourage children to produce reflective multi-word utterances, have been found to predict child vocabulary outcomes (Cristofaro & Tamis-LeMonda, 2012; Reynolds et al., 2019; Rowe et al., 2017) and understanding of science concepts (Benjamin et al., 2010; Haden, 2010; Haden et al., 2014).

In contrast to open questions, closed questions include *yes/no, forced-choice,* and *fill-in-the-blank* (marked by rising intonation) questions that restrict the number of appropriate answers. Children consider these questions less challenging (Brubacher et al., 2019), and they are not typically raised in the literature as effective facilitators of learning because they are thought to involve a certain degree of automaticity or quizzing (Lee & Kinzie, 2012). However, it is possible that closed questions may still play a role in learning. For instance, although yes/no questions limit children to one of two responses, Tompkins et al. (2017) found that yes/no questions and constrained wh-questions during a book reading activity predicted child receptive vocabulary skills. Results such as these suggest that closed questions may also engage important cognitive processes in certain contexts. Thus, it remains unclear what type of parent questions best support child learning and under what conditions.

A precursor to disentangling the role of open and closed parent questions is to examine their relative *frequency* across distinct contexts. Although there is established evidence that parents use a combination of open and closed questions during book reads (Kim & Park, 2015; Landry et al., 2012), there is less literature about question type frequency during more purely *STEM-based* play activities. Documenting the types of questions parents ask their children during different STEM-related activities is useful for understanding how parents talk with their children across these contexts. For example, Cohen and Emmons (2017) found that preschool- and elementary school-aged children's talk during

a block-building task was directly tied to the goal of building a tower and strategies about construction. One might expect that parents' speech in this scenario would also be closely related to guiding children through a series of iterative steps and therefore might contain more clearly defined or forced-choice closed questions. Another pertinent factor to consider is the way in which the questions parents ask relate to children's *academic knowledge.* There have been mixed findings about how parent verbal input interacts with child ability and motivation (e.g., Jirout et al., 2022; Mermelshtine, 2017), and it remains unknown how parent closed and open questions during informal STEM activities interface with children's STEM and language skills.

Study design

The goal of this research was to determine how parents' verbal input, namely parents' use of open and closed questions, relates to *activity context* and to children's *math, science,* and expressive *vocabulary* knowledge. We recruited parent–child dyads from lower socioeconomic backgrounds because the larger study focused on broadening access to playful, informal STEM learning resources for children experiencing poverty (Zucker et al., 2022). To design informal learning activities that build on parents' strengths and needs, it is important to understand the types of verbal input children from different socioeconomic backgrounds receive and how this may vary across contexts. Prior work has suggested that parents with different levels of formal education may vary in the frequency and style of questioning they use with their children during naturalistic interactions (e.g., Duong, Bachman, Votruba-Drzal, & Libertus, 2021; Yu, Bonawitz, & Shafto, 2019; Leyva, Tamis-LeMonda, Jimenez-Robbins, & Malachowski, 2017). For example, Yu et al. (2019) drew on a large corpus of transcribed parent–child interactions and found that parents from middle-class backgrounds were more likely to ask their 2- to 6-year-old children pedagogical questions that supported learning than parents from working-class backgrounds. In another study analyzing parent–child interactions during book sharing, grocery store pretend play, and a magnetic puzzle activity, Duong et al. (2021) found that parents with more formal education asked their 4-year-olds more cognitively demanding questions than parents with less formal education. However, few studies have examined whether parents from lower socioeconomic backgrounds differ in their use of open and closed questions across different informal STEM activities.

All parent–child dyads completed three informal STEM activities with a clearly defined goal and set time limit: a pretend grocery store activity, a bridge-building challenge, and a science book read. We expected that the activities would elicit variability in parent verbal input, particularly in the use of open and closed questions.

Rationale for informal STEM activities in the current study

The pretend grocery store activity was adapted from the original task developed by Leyva, Reese, and Wiser (2012) and introduced opportunities for parent questions about *math-related concepts* such as number, operations, and magnitude comparisons within guided play. Math talk occurs infrequently in everyday interactions and informal learning activities with children (Hanner et al., 2019; Purpura et al., 2017). Thus, we intentionally constructed a playful context for children to think about math using money and a simple cash register. Previous research using pretend grocery shopping has led to important observations about the language input that parents provide to their children. For example, Lu et al. (2023) found that their grocery store activity elicited more math talk compared with a party preparation activity, and Duong et al. (2021) demonstrated that the use of open wh-questions during a grocery store game predicted children's expressive vocabulary. Thus, we predicted that the types of questions parents asked their children during this task would center on math-related properties (e.g., "Do we have enough money?") and relate to their children's math and expressive vocabulary knowledge.

The book read activity, in which dyads read an informational text about the life cycle of a seed and interacted with a set of plastic manipulatives, focused on *pre-literacy skills* and *science vocabulary.* The book read task was included because accumulated research shows that shared book reading acts as an important facilitator of children's science and literacy knowledge and that parents and teachers often check their children's understanding verbally (Deshmukh et al., 2019; Mol, Bus, De Jong, & Smeets,

2008; Shirefley & Leaper, 2022; Towson, Fettig, Fleury, & Abarca, 2017). We predicted that this activity would lead to higher-level reflection and discussion of scientific themes among parent–child dyads. Based on research such as Kim and Park (2015) and Landry and colleagues (2012), we also anticipated that parents would initiate these conversations through a mix of closed and open questions.

The bridge-building challenge was intended to encourage *engineering process-related thinking* and elicit talk about strategies for building their bridge and revising strategies based on evidence. The design of this activity was inspired by Marcus et al. (2021) and Pagano et al. (2020), who found that elementary school-aged children and their parents participate in more process-related talk after they complete engineering activities that require building and tinkering with materials. We anticipated that bridge building would engage parents and younger children in iterations of engineering processes and that parents would offer verbal support to help children make and test solutions. Studies such as Haden et al. (2014), which encouraged parents to ask wh-questions during tinkering, and Cohen and Emmons (2017), which observed specific construction-related talk in preschoolers building towers, suggest that dyads might be especially focused on the technical challenges of building the bridge. If so, parents would likely ask questions addressing the decisions required to design a bridge that meets the design requirements. Given that these questions may take on an open form (e.g., "How should we test whether the bridge is strong enough?") or a closed form (e.g., "Should we use sticks or blocks to build the bridge?"), we were agnostic about what type of questions would be more prevalent during this activity.

Research questions

The research questions posed by the current study were as follows:

1. Descriptively, how does parents' use of questions (e.g., frequency of open and closed questions) differ across three distinct STEM play activities?
2. For each activity, which types of parent questions (open or closed) are associated with children's concurrent expressive vocabulary, math, and science skills?

Method

All data were collected during the pretest phase of a larger study about after-school family engagement events (see Zucker et al., 2022). Data collection occurred in fall 2019 in three public school districts and schools primarily serving students from lower-income backgrounds in a southern U.S. state within a large urban area. Data were collected at pretest only due to disruptions caused by the COVID-19 pandemic at the planned posttest period in May 2020. All data were collected with established protection of human participants through local institutional review board review and a written consent process completed by parents or guardians.

Child and family participants

Of the 182 children who participated in the study, 9 were excluded because they were missing all video observations (n = 2), the primary language used in the observation was not English or Spanish (n = 2), or the video sound quality was too poor to code reliably (n = 5). For the 173 children in the final analytic sample, the mean age was 4 years 5 months (SD = 0.35 months, range = 3 years 5 months to 5 years 0 months), and 52.60% of the participants were female. Demographic information was obtained from a parent questionnaire, with the majority of questionnaires being completed by mothers (n = 149, 86.13%), followed by fathers (n = 11, 6.36%), and finally by grandparents or other family members (n = 8, 4.63%) (n = 5 missing). For race, 50.87% of children were Black/African American (n = 88), 23.70% were White (n = 41), 5.78% were Asian (n = 10), 12.14% reported "other race" (n = 21), and 7.51% (n = 13) chose not to report race or were missing. For ethnicity, 35.84% of children were Hispanic or Latino/a (n = 62; n = missing). About 49.13% of parents reported speaking a language other than English at home (n = 85; n = 3 missing data), with Spanish being the most common language (n = 57, 67.06%), followed by other language (n = 13, 15.29%), an African language

(*n* = 9, 10.59%), Arabic (*n* = 3, 3.53%), and Vietnamese (3, 3.53%). When asked about the language that their children spoke most at home, 89.02% (*n* = 154) reported English.

To participate in the larger study, schools needed to serve a majority of students (≥50%) who qualified for free or reduced-price federal lunch or subsidies. Based on data reported by the Texas Education Agency for the 2019–2020 school year for our 20 participating schools, the percentage of students eligible for free or reduced-price meals was 92% across the 20 schools (min = 52.2%, max = 100%). About 38% of students were classified as English learners (min = 0%, max = 78.3%), and 7.18% of students had a special education program within their school (min = 2.4%, max = 13%). Median yearly household income from parents was $20,001 to $30,000 (missing for 26 families); this is consistent with the 2019 federal poverty threshold of $25,750 for a family of four. Median mother education was some college (missing *n* = 4), whereas median father education was high school diploma or GED (missing *n* = 10).

Recruitment procedures

Following approval from the school district and the classroom teacher to participate in the larger study, families within participating classrooms were recruited via meet-the-teacher and back-to-school family events at each school, flyers teachers sent home with children, and individual parent conversations at drop-off and pick-up times. This resulted in 20 participating schools and 46 prekindergarten classrooms. Parents in this sample provided written consent through study flyers and consents provided in English and Spanish. Focal parent–child dyads were eligible for the study if (a) the child was 3.5 to 5.0 years old as of September 1 of the school year, (b) the family spoke a primary language of English or Spanish (because the program was available in only these two languages), (c) the child had written parental consent, and (d) the consenting adult was a primary caregiver, most often the mother, although some fathers and grandparents were consented if they were determined to interact with the child routinely. The average number of consented dyads across our 46 participating classrooms was 3.89 (*SD* = 2.32; min = 1, max = 9); across our 20 participating schools, we had an average of 9 families per school participating in the study (*SD* = 4.91; min = 1, max = 17). All families received stipends for participation, including a $50 gift card after completing pretest activities.

Data collection

Families completed data collection activities at their children's school or home between September and early November 2019. Most data collection activities occurred in school facilities and after school at a time selected by families.

Child knowledge assessments

Child *math* knowledge and *science* knowledge were assessed using the Applied Problems and Science subsets of the Woodcock–Johnson IV (WJ) Tests of Cognitive Abilities (Schrank et al., 2014), a standardized assessment of children's knowledge of academic content with good reliability and validity (see Villarreal, 2015, for a test review). The Applied Problems subtest covers basic arithmetic such as counting, addition, and subtraction, whereas the Science subtest surveys children's basic disciplinary knowledge of biology, chemistry, and physics. Children's expressive *vocabulary* knowledge was assessed with the Expressive One-Word Picture Vocabulary Test-4 (EOWPVT; Martin & Brownell, 2011), a standardized assessment that requires children to name the one word that best describes a series of pictures. All assessments were administered by trained assessors according to the developer's standard procedures in English only during pretest because it was not feasible within the scope of this study to measure child knowledge in the many non-English languages used at home in addition to English.

Parent–child STEM activities

All three activities had a time limit (grocery store: 7 min; bridge: 8 min; book read: 7 min). Dyads were told when they had 1 min remaining and were told to continue interacting if they finished the activity before the time limit.

Activity 1: Grocery store. For the grocery store activity, each dyad was given a price list menu, a zip-lock with 12 $1 bills for shopping, a notepad and writing tool, five labeled baskets that held food items, a cash register, a shopping basket, and play food items comprising meats, fruits, grains, and dairy items (see Fig. 1A). The examiner gave the following instructions: "In this activity, you have 7 minutes to pretend to go grocery shopping. You and_____[your child] have $12 to buy food from our pretend store. Here is a price list for all the items and writing tools in case you want to make a grocery list. As you choose foods, make sure you include at least *one* fruit and *one* vegetable so you're making some healthy choices. When you're finished shopping, you can pay for the items by putting the money in the cash register".

Activity 2: Bridge challenge. During the bridge challenge, each dyad received a 20-piece wooden block set, 30 popsicle sticks, 30 paper straws, 1 ruler, 1 small sheet of cardboard, blue painter's tape, 1 toy car, 1 0.5-pound weight, and 1 laminated sheet of photos of sample bridges (see Fig. 1B). The examiner's instructions were as follows: "In this activity, you have 8 minutes to build a bridge. Here are some examples of different kinds of bridges [point to photos]. Here's your challenge: The bridge has to be at least 3 inches high [show ruler marked at 3 inches]. It has to be strong enough to hold a half-pound weight [show the weight]. It also needs to not break when you move this toy car across it [move car on table]. You and_____[your child] can use any of the materials here".

Activity 3: Book read. For the book read, each dyad was given a researcher-developed book (to ensure it was unfamiliar to all dyads) titled *The Amazing Seed* (Author, 2012) and 1 bean plant sequencing manipulative set, which included four plastic manipulatives that illustrated the seed, sprout, and plant at increasing sizes (see Fig. 1C). The book contained prototypical nonfiction text features such as table of contents, headings, figures, glossary, and index. The examiner's instructions to the dyad were as follows: "We are interested in the way parents and children share science books together. You may explore these materials mentioned in the book [point to seed manipulatives]".

Coding scheme: Parent–child STEM activities

Parent question types and parent talkativeness

Coders recorded the total frequency of focal utterances by pausing the video after each codeable utterance and replaying the utterance one time if needed. Coders counted the occurrence of specific question types that were then combined to form the closed and open question categories in this article. The *open question* category contained four separate question types: (a) general wh-questions (e.g., who, what, when, where questions), (b) why questions, (c) how procedural questions, and (d) how much/how many questions. The *closed question* category included yes/no questions, forced-choice questions (e.g., either/or), and fill-in-the-blank prompts that used rising intonation to signal that children should complete the sentence by filling in the missing (usually final) word (e.g., "This is a red app. . ." [apple]). We did not code closed questions by subcategory. Example questions from each category and further explanation of their characteristics can be found in Table 1. All question codes were mutually exclusive and exhaustive. This approach was adapted from previous video coding

Fig. 1. Activity setup for grocery store (A), bridge challenge (B), and book read (C) activities.

Table 1
Example question types by category

	Closed question examples	Open question examples
Grocery store	Yes/no: Did we pick any fruit? Forced-choice: Do you want the cake for dessert or the ice cream? Fill-in-the-blank: Bread costs_____. ($1.00)	General wh-: Where is the tomato? Why: Why do you think we should eat fruits and vegetables? How much/how many: How much money do we have left? How procedural: How can we make a sandwich?
Bridge	Yes/no: Can the little car go across now? Forced-choice: Should we use the straws or the popsicle sticks for this part of the bridge? Fill-in-the-blank: That shape is a_____. (triangle)	General wh-: What are you going to do? Why: Why does this part keep falling? How much/how many: How much tape do we need? How procedural: How can we make it stronger?
Book read	Yes/no: You see the vegetables? Forced-choice: Do you want to plant your seed in a pot or in the soil? Fill-in-the-blank: Just by looking at this page, we can see different kinds of_____. (seeds)	General wh-: What do you want to plant? Why: Why does a seed need a seed coat or shell? How much/how many: How many acorns do you see here? How procedural: How do seeds travel?

approaches that show good reliability for utterance counts without transcription (Pentimonti et al., 2012). Exact repetitions by the same speaker were omitted, but repetitions by the other speaker were included in the frequency count. Inaudible speech was excluded after two attempts to decipher the utterance. Speech directed at the examiner or any other person who entered the room was omitted from analysis.

In addition to parent questions, parent utterances were coded for use of concrete and abstract vocabulary as well as language containing numeracy and mathematical operations (grocery store), scientific processes and reasoning (bridge), and analogies and personal connections (book read). Overall *parent talkativeness* was approximated by summing all coded parent utterances within each context and then taking the average of these substantive parent utterances across all three activity contexts.

We used a multi-step training process to prepare the coders that included group practice and individual reliability monitoring on sets of at least two initial videos of each context that were coded independently and compared with master codes (i.e., consensus codes reached by the senior staff). After initial reliability was met ($\geq$.85 agreement), drift was checked using one or two additional videos midway through coding, and coders were held to the same criterion of $\geq$.85 agreement for drift checks. Inter-rater reliability during these drift checks was calculated using correlations between coders and master coders (i.e., senior investigators), using the square root of the frequency counts for each code (following Author et al., 2021).

Results

Descriptive statistics for question counts across activity contexts

Analyses were conducted using R Version 4.3.1 (R Core Team, 2023) using the "lme4()" (Bates et al., 2015) and "emmeans()" (Lenth, 2023) packages. Table 2 shows descriptive statistics for parent questions in each activity context. The open question category was created from the sum of four subcategories: why questions, how procedural questions, how much/how many questions, and general wh-questions. As seen in Table 2, general wh-questions were more common in the grocery store (M = 10.40) and book read (M = 9.37) activities compared with the bridge challenge (M = 3.33). Why and how procedural questions were relatively rare across all three activities but had the highest occurrence in the book read (M = 0.22) and bridge challenge (M = 0.99), respectively. How much/how many questions were rare in the bridge (M = 0.24) and book read (M = 0.01) activities but had a higher prevalence in the grocery store activity (M = 2.65). Although closed questions were not coded according to subcategories, their overall counts are provided as a reference point.

Table 2
Total parent questions by question type and activity

	Grocery store *n* = 172 Total *M* (*SD*)	Bridge *n* = 170 Total *M* (*SD*)	Book read *n* = 172 Total *M* (*SD*)
Open questions			
General wh-	1790 10.41 (6.51) range: 0–35	566 3.33 (3.28) range: 0–18	1611 9.37 (6.13) range: 0–25
Why	10 0.06 (0.26) range: 0–2	20 0.12 (0.42) range: 0–3	38 0.22 (0.65) range: 0–6
How (procedural)	32 0.19 (0.45) range: 0–2	168 0.99 (1.64) range: 0–9	73 0.42 (0.79) range: 0–5
How much/how many	456 2.65 (3.24) range: 0–19	40 0.24 (0.79) range: 0–7	2 0.01 (0.11) range: 0–1
Closed questions			
Yes/no, forced-choice, and fill-in-the-blank	1350 7.85 (5.33) range: 0–28	1160 6.82 (6.32) range: 0–41	1158 6.73 (4.87) range: 0–23

Differences in question types across activity contexts

To answer our first research question about how the frequency of parent open and closed questions varied across our three activity contexts, we fit a generalized linear mixed model (GLMM) with overall question frequency as the response variable using maximum likelihood (Laplace) approximation. This model assumed a Poisson distribution for the response variable and employed a logarithmic link function to account for the expected count nature of the data. This statistical approach has been implemented in previous research examining parent language to suitably accommodate non-normal, count-based utterance data (Gaudreau et al., 2022; Roby & Scott, 2022). Question type (open or closed), activity context (grocery store, bridge challenge, or book read), and their interactions were incorporated as fixed within-participant effects. This structure allowed us to examine both how the overall number of questions and the relative frequency of open and closed questions differed across activities. Parent talkativeness (represented by the average number of coded parent utterances across the three activities), child sex, parent's preferred language for study communications (scored as English or a language other than English), and maternal education were included in the model as fixed between-participant effects. Random intercepts were used to account for variability resulting from clustering of these pretest data at the child, classroom, and school levels.

The model indicated significant fixed effects of maternal education, parent talkativeness, question type, activity context, and the interaction between question type and activity context on overall question frequency (see Table 3). Post hoc tests were conducted using estimated marginal means to determine differences in the number of open and closed questions across activities after accounting for these overall main effects. Pairwise comparisons of the estimated marginal means showed that closed questions were more frequent in the grocery store activity compared with both the book read ($\beta = 0.143$, $SE = 0.0403$, $z = 3.55$, $p < .01$) and bridge ($\beta = 0.127$, $SE = 0.0404$, $z = 3.151$, $p < .01$) activities, but there was no significant difference between the number of closed questions in the book read and bridge activities ($\beta = -0.016$, $SE = 0.042$, $z = -0.379$, $p = .92$). Open questions were significantly more frequent in the book read activity compared with the bridge activity ($\beta = 0.75$, $SE = 0.0432$, $z = 17.35$, $p < .0001$), and the grocery store activity had more open questions than both the book read ($\beta = 0.28$, $SE = 0.032$, $z = 8.67$, $p < .0001$) and bridge ($\beta = 1.03$, $SE = 0.042$, $z = 24.81$, $p < .0001$) activities (see Fig. 2). To address potential confusion, it is important to note that although the estimates for

Table 3
Fixed effect estimates of the general linear mixed model analysis of question frequency

Effect	*β*	*SE*	*z*	*p*
Intercept	1.83	0.095	19.33	<.0001
Question type (open)	0.53	0.035	15.22	<.0001
Activity context (book read)	−0.14	0.0403	−3.55	<.001
Activity context (bridge)	−0.13	0.0404	−3.15	<.01
Child sex (female)	−0.079	0.052	−1.51	.13
Preferred home language (non-English)	0.021	0.055	0.385	.70
Maternal education	0.032	0.016	2.04	<.05
Overall adult talkativeness	0.35	0.028	12.41	<.0001
Question Type (open) * Activity Type (book read)	−0.14	0.052	−2.65	<.01
Question Type (open) * Activity Type (bridge)	−0.90	0.058	−15.59	<.0001

Note. Reference levels for the categorical variables in this model are closed (question type), grocery store (activity context), and male (child sex). Parentheses next to an effect indicate a change from this reference level to the level stated in the parentheses.

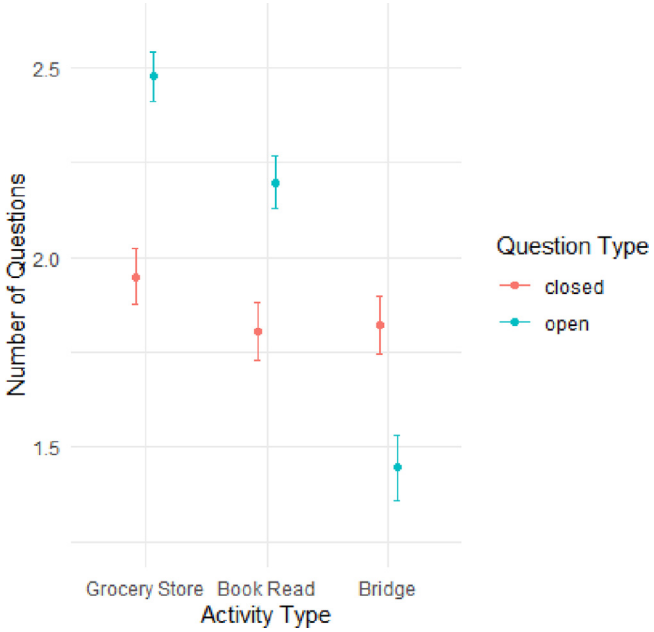

Fig. 2. Estimated marginal means of closed and open question frequency in the grocery store, book read, and bridge activities. Error bars indicate the 95% confidence intervals.

the pairwise comparisons match those presented in Table 3, the differences in direction of the effect and *z*-values stem from the calculation based on estimated marginal means rather than the raw model output.

Connecting parent question types, activity contexts, and child knowledge

To address our second research question about potential relations among parent questions, child knowledge, and activity context, we fit a series of three linear mixed-effect models using the restricted maximum likelihood estimation method with the standardized score for each knowledge assessment of interest (expressive vocabulary, science, and math) as response variables. To determine how the use of open and closed questions in each activity context related to children's content knowledge, we

included a set of six within-participant fixed effects corresponding to the frequency of each type of question (closed or open) in each activity context (grocery store, book read, or bridge). As in our model of overall question frequency, overall parent talkativeness, child sex, parent's preferred language for study communications, and maternal education were treated as between-participant fixed effects. Random intercepts were again used to account for classroom and school-level clustering.

In our dataset, children's standardized scores on the math (WJ Applied Problems) and science (WJ Science) measures were significantly correlated ($r = .55$, $p < .001$) with each other and with the standardized score of the verbal (EOWPVT) measure (WJ Applied Problems and EOWPVT: $r = .41$, $p < .0001$; WJ Science and EOWPVT: $r = .59$, $p < .0001$). This correlation was expected given that all three of these measures tap into children's verbal ability. Thus, children's performance on the expressive vocabulary assessment (EOWPVT) was included as a predictor in the models examining science and math knowledge to control for this general verbal ability.

Across the three models, question type only predicted child knowledge on the science assessment. Specifically, higher frequencies of parent open questions during the book read activity predicted higher child scores on the WJ Science subtest ($\beta = 0.395$, $SE = 0.122$, $t = 3.23$, $p < .01$). As expected, higher performance on the EOWPVT predicted higher performance on both the WJ Applied Problems ($\beta = 0.50$, $SE = 0.084$, $t = 5.99$, $p < .0001$) and WJ Science ($\beta = 0.51$, $SE = 0.056$, $t = 8.99$, $p < .0001$) subtests. In line with previous research (e.g., Pace et al., 2017), children's performance on the EOWPVT, which was conducted solely in English, was negatively predicted by parent's preferred language for study communication being a language other than English ($\beta = -4.51$, $SE = 2.08$, $t = -2.17$, $p < .05$) and positively predicted by higher levels of maternal education ($\beta = 2.13$, $SE = 0.64$, $t = 3.34$, $p < .01$).

We chose to focus on question frequency in our analysis to easily capture the prevalence of both open and closed parent questions across the three activity contexts. However, in acknowledgment of a wide body of work that examines language use in terms of relative distributions (e.g., Callanan et al., 2020; Choi et al., 2020; McHugh et al., 2024; Rowe & Snow, 2020), we also conducted supplementary analyses using the proportion of open questions (see Appendix A1 in online supplementary material). Complementary to the main findings, we found that both the grocery store and book read activities had higher proportions of parent open questions compared with the bridge activity ($\beta_1 = 2.19$, $SE = 0.26$, $z = 8.58$, $p < .0001$; $\beta_2 = 1.77$, $SE = 0.25$, $z = 7.21$, $p < .0001$). However, we did not find a significant difference in the proportion of parent open questions in the grocery store activity and the book read activity in this supplementary model ($\beta_1 = 0.42$, $SE = 0.24$, $z = 1.73$, $p = .19$). This discrepancy reflects differences in the sensitivity of our main (frequency) and supplementary (proportion) analyses arising from the way in which the total number of questions was accounted for in each model. Although the absolute counts of parent open questions differed between the grocery store and book read activities, differences in the relative distribution of these questions were not statistically significant. However, overall the supplementary analyses largely replicate our main findings, demonstrating the robustness of our results.

Overall, our data reveal a nuanced relation between parent questioning styles and children's skill development, notably that high frequencies of questions alone are not predictive of children's content knowledge. Although the grocery store activity contained the most open and closed questions of the three activity contexts, these questions did not relate to children's skills, whereas the number of open questions in the book read activity did. This distinction suggests that activity context plays an important role in shaping the verbal input that parents provide and how this input relates to child ability.

Discussion

The current study examined how parent questions differed across informal STEM activities and how they were associated with child knowledge in three domains (science, math, and expressive vocabulary). We looked specifically at differences in parents' use of *open* and *closed* questions during STEM interactions with their children. Our open question category included *why* questions, *how procedural* questions, general *wh*-questions, and *how much/how many* questions that have been shown to elicit elaborative responses from children or to encourage learning (see Purpura et al., 2017; Rowe

et al., 2017). In contrast, our closed question category included *yes/no, forced-choice,* and *fill-in-the-blank* questions that invoke a constrained set of responses, can sometimes be answered automatically, and often embed the expected child response in the question itself.

Frequency of open and closed questions across activities

Our results indicate clear differences in parent question use across the grocery store, bridge, and book read activities. The grocery store activity contained the highest relative frequency of both *open* and *closed* questions. As predicted, questions about money and counting the number of food items (*how much/how many* questions) were common, suggesting that parents used frequent questions about quantities in line with the goals of the activity. Parents also asked many closed questions, some of which were about their children's preferences (e.g., "Do you want the cake for dessert or the ice cream?"). Asking a combination of open and closed questions may have helped to focus children's attention on different aspects of the activity.

Parents produced more open questions during the book read compared with the bridge activity, but not as many as in the grocery store activity. In addition, although the book read had fewer closed questions compared with the grocery store activity, their frequency was not significantly different than the bridge activity, suggesting that parents used a mixture of both open and closed questions. This observation aligns with our predictions and complements previous research showing that parents produce many different question types during book reads and that many kinds of language prompts elicit responses from children (e.g., Justice, Weber, Ezell, & Bakeman, 2002; Lonigan, Bloomfield, Dyer, & Samwel, 1999). Variation in parents' question types during the book read may have resulted from experience with community interventions encouraging parents to use varied language strategies during reading (see Huebner & Payne, 2010; LaCour et al., 2013).

The bridge activity had the lowest frequency of open questions, which may be explained by prior work suggesting that child talk during tinkering and constructive play is closely tied to the goal of creating the finished structure (e.g., Cohen & Emmons, 2017). It could be that parents used closed questions such as yes/no questions instead of open questions to delegate responsibility for bridge construction (e.g., Can you hold the blocks while I tape this part?). Parents may have also asked their children yes/no questions about whether they wanted to build with specific materials. Further research is needed to explore these possibilities.

Considering socioeconomic status

Some research has suggested that parents from lower socioeconomic backgrounds differ in the frequency and type of questions they pose compared with parents from higher socioeconomic backgrounds (e.g., Duong et al., 2021; Yu et al., 2019). The current study recruited a sample of families that reported household incomes at or near the poverty line and that were enrolled in preschools where the majority of students received free or reduced-price lunch. Although the relation between parents' socioeconomic status and parent question use was not the focus of this study, it is important to note that even though parents with more years of formal education (used here as an indicator of socioeconomic status) did ask more questions during our activities, all parents produced patterns of open and closed questions that varied by activity. Thus, despite representing a more diverse range of economic, linguistic, racial, and educational backgrounds than much of the prior literature, parents in this study exposed their children to a mixture of open *and* closed questions and the cognitive contexts surrounding both. In terms of child knowledge, as shown in previous bodies of research (e.g., Bornstein et al., 2003), we found that children had higher levels of expressive vocabulary knowledge when their parents had more years of formal education. However, parent education did *not* predict children's math or science knowledge, demonstrating nuance in its relationship with child knowledge.

Relating question type, activity type, and child skills

Our analysis uncovered significant relations between higher frequencies of parent *open questions* in the book read activity and higher child science knowledge that held after parent talkativeness and

demographic variables such as maternal education and family's preferred language for study communication were included. Due to the correlational nature of the data, the direction of this relation cannot be determined. Open questions during science book activities may lead to higher science knowledge in children, parents may ask their children more open questions when they have higher science knowledge, or both processes may be at play at once. Reading science books may also create opportunities for both open questions and other language related to science. Furthermore, the narrative structure of our book may have provided parents with natural stopping points to ask their children more in-depth questions and reflect more intently on the science. Regardless of causality, this association reveals that children's science knowledge and parents' questioning approach are linked and complements previous findings that open questions elicit longer, more cognitively sophisticated responses in children (Brubacher, Timms, Powell, & Bearman, 2019; Deshmukh et al., 2019; Worley, 2015).

Surprisingly, we did not find any other significant relations between children's content knowledge and parents' use of open and closed questions. For example, there was no relation between parent questioning during the grocery store activity and child content knowledge even though it specifically targeted math skills and elicited high frequencies of parent open and closed questions. One possible explanation is that because each food item cost $1, the required mathematical operations were straightforward for children and did not require parents to tailor their questioning strategies based on child math skill. That is, parents may have been comfortable using the same questioning approach (e.g., higher frequencies of open questions) regardless of child math ability. It should also be noted that there were high frequencies of how much/how many open questions in the grocery store activity, which may have elicited different cognitive approaches in children than the why, how procedural, and general wh-questions that are typically discussed as facilitators of child learning in book reads (Deshmukh et al., 2019; Lee & Kinzie, 2012; Rowe, Leech, & Cabrera, 2017). Alternatively, parents could have explored math concepts with their children without using questions at all.

It was also unexpected that parent questions during the book read did not relate to the expressive vocabulary measure given that this is a consistent relation in meta-analytic research on parent–child book reads (Heidlage et al., 2020). Some possibilities to explore include considering whether the science focus of the book led parents to prioritize their children's science knowledge over their vocabulary knowledge when deciding what kinds of questions to ask and whether the science-focused content in the book perhaps caused parents' questions to be more effective at fostering children's science knowledge than vocabulary knowledge. Likewise, there were no relations with parent open or closed questions during the bridge activity and child knowledge.

Evaluating the role of questions in informal STEM learning

Although we found a significant relation in only one activity context between the type of questions parents used and child knowledge, these findings do not necessarily indicate that parents' use of questions in other contexts does not shape child learning. Our results showing that parent open questions during the book read related to child science knowledge at this single time point are correlational in nature and have several potential explanations. If parent questioning influences child learning, it could be that asking open questions during a science book read is an effective means of promoting child learning and that asking neither open nor closed questions is effective in other contexts. If child knowledge influences parent questioning, it could also be that factors other than children's content knowledge drive the types of questions parents ask during different activity contexts and that children benefit from this question input regardless of how closely it is tied to their initial understanding. For example, activity structure may have influenced parent questions more so than children's current knowledge. Both the grocery store and bridge activities had clear objectives that needed to be completed by a time limit, whereas the book read was presented as a more flexible, less constrained task. Thus, whereas parents may have used questions in the grocery store and bridge activities to advance toward the activity's goal rather than expanding their children's current understanding, the book read may have provided them with more freedom to focus directly on their children's knowledge of the science concepts in the book. Regardless, our findings clearly illustrate that the questions parents asked their children during an activity about building a usable structure differed from the questions they asked during an activity about calculating food prices and during a science book read. Thus, as

they completed these activities, children received distinctive question input from their parents that may have contributed to downstream learning and knowledge.

Of course, the underlying relation between parent questions and child knowledge may flow in the opposite direction. That is, rather than parent questions promoting child learning, children's level of knowledge may elicit different kinds of questions from parents. In our case, parents may have asked more open questions during the science book read when their children had higher levels of science knowledge because they believed their children had enough understanding to elaborate in a more cognitively demanding way. Once again, our results do not suggest that open questions during the book read are the only means parents can use to respond to their children's knowledge within this directionality. Parents may use other types of language to respond to their children's understanding, or children's developing knowledge may have elicited more particular types of questions over time. Longitudinal work that examines a greater breadth of language input would help to clarify these possibilities and give more insight into the direction of this relationship.

Research examining how causal language, causal reasoning, and exploration interface during parent–child interactions in museum settings provides additional perspective on the relationship between parent questions and child skill in different activity contexts and highlights the importance of more closely examining the time sequence of parent questions within activities in future work. Studies from this body of work have found that overall frequency of parent language is not always directly related to child reasoning (e.g., Callanan et al., 2020; McHugh et al., 2024). Rather, these studies have shown that the relationship between parent language input and child cognitive outcomes is mediated by systematic child exploration (Callanan et al., 2020; McHugh et al., 2024). Informative parent language input predicted children's performance of key actions during exploration, such as turning a knob to direct airflow in an airway exhibit and activating the leading gear in a gear mechanism (Callanan et al., 2020; McHugh et al., 2024). This exploratory behavior in turn predicted cognitive outcomes in children, such as their success in answering challenge questions about concepts from the exhibit (Callanan et al., 2020; McHugh et al., 2024). These findings suggest that determining when and how parents ask specific questions is an important complement to analyzing their raw frequencies. A fruitful future direction would be to evaluate the temporal context in which parent questions occur during different activity types and their relationship to children's physical exploration and actions.

Work in the museum space has also suggested that the role of parental input in children's exploration and learning varies by activity (Callanan et al., 2020; McHugh et al., 2024; Sobel et al., 2021; Willard et al., 2019), which raises questions about how the goal-directedness of our activities may have affected parent–child interactions. For example, Sobel et al. (2021) found that preschool- and young elementary school-aged children with parents who set structured goals for their interactions in an electric circuit exhibit attempted fewer electric circuit challenge activities of their own, and Callanan et al. (2020) found that children engaged in more systematic exploration in a gear exhibit when they interacted collaboratively with their parents as opposed to following goals set by their parents. However, McHugh et al. (2024) found that parent-led interactions and goal-setting facilitated more systematic exploration in an airflow exhibit, which had a less clear mechanism than the Callanan et al. (2020) gear exhibit. These findings suggest that goal-setting from parent-directed interactions may best support children's learning during activities with abstract concepts that require extra explanation, whereas having more collaborative and open-ended interactions during concrete tasks gives children a greater sense of agency and more opportunities to engage with materials in novel ways that allow them to be exposed to challenge.

In our case, both the grocery store and bridge activities had clearly defined objectives set by the experimenter. Dyads needed to stay within a budget and select at least one fruit and one vegetable during the grocery store activity and build a bridge with certain specifications during the bridge activity. By contrast, during the book activity they were simply told to explore the book and accompanying materials. The only relationship we observed between child content knowledge and parent questions was between parent open questions in this more open-ended book read activity and child science knowledge. Additional work could probe how goals set by parents and the experimenter may have affected parent questions and their relationship to child outcomes. One potential avenue to explore is varying the instructions given to parents at the beginning of the activity. Research such as

Willard et al. (2019) has shown that parents and children behave differently during playful STEM activities depending on whether the parents were instructed to explain a STEM concept, allow their children to explore the STEM activity, or engage with their children as usual.

Limitations

There are several key limitations to the current study that warrant discussion. First, to support reliability in the coding, the classification of questions as open or closed was done based on the presence of key words rather than their context. For example, any question containing the word "what" was considered an open question, although *what* questions could range from simple labeling questions (e.g., "What is this?") to the more elaborative questions typically associated with the wh- category (e.g., "What do you think we should do next?"). Although the goal of the current study was to provide a general overview of the use of different question types across activities, further work could consider the variation in which specific question words are used and the intentions behind the questions.

Second, we are limited in our ability to speculate about the impact of these different question types on children's learning opportunities. Whereas the current study considered only one time point, future work could look more in depth at how different question types differentially affect later cognitive and academic processes. Tracking changes over time would offer a clearer understanding of the cause-and-effect relationship between parent questioning style and children's knowledge. In addition, analyzing the physical interactions between parents and children during different activities is a ripe area for further work given that it would be useful to know what the dyads were doing during the activity when different types of language occurred.

Third, children's expressive vocabulary, math, and science knowledge were measured only in English, which limits our ability to characterize the skills of children who are also learning a non-English language at home. For children who speak primarily a non-English language with their parents, we might expect that the relation between parent questions and child skills in English would be weaker than for children who use primarily English with their parents. Future studies with linguistically diverse families should strive to measure child skills in ways that capture what they know across all of their developing languages.

Finally, further work could more deeply explore additional types of parent verbal input. We focused on parent questions in the current study because we wanted to illustrate variation in parent talk across activity contexts, and questions was the only consistent language category that was coded across all three activities. Future research could look at variation in other types of language that may co-occur across different activities, such as analogies, or could more carefully examine the specific types of language input in certain activities that are related to child knowledge. For example, parent numeracy-related talk during the grocery store activity might better predict child math knowledge than parent questions.

Conclusions

The findings from the current study reveal that parent questions vary widely across informal STEM activity contexts and illuminate the need for further research about the implications for children's developing STEM knowledge and parent–child informal STEM interactions. If parents modulate their questioning in response to child knowledge to match their children's knowledge level, this behavior could be leveraged to design playful learning activities that elicit rich language input from parents of children with a wide range of abilities. Alternatively, children may learn more effectively when their parents ask certain types of questions during different activities, a pattern that could be used to enhance the guidance given to parents in engagement programs.

More observational research is needed to determine the directionality and nuances of parents' use of questions under different STEM activity conditions. Additional experimental research is also needed to understand the effects of training parents to provide verbal support, so that useful recommendations can be given to parents about the kinds of guidance that would best promote learning for their children. Reviews of parent interventions confirm that little attention has been paid to the role of

supporting children's language and thinking (Haring Biel et al., 2020). Nonetheless, these observational data suggest that parents should be supported to consider how both the activity context and their children's knowledge guide responsive conversations that support their children's learning during informal STEM activities.

Acknowledgments

Funding for this study was provided by the National Science Foundation, Advancing Informal STEM Learning (AISL) Division (1811356), and by the Institute of Education Sciences, Training Program in Early Interventions Within Research–Practice Partnerships (R324B200018). Special thanks go to the families who took part in this project and allowed us to observe their play as well as the museum educators and staff who worked with the participants: Cheryl McCallum, Gisela Trevino, Belkis Hernandez, Tiffany Espinosa, and Armando Orduña. We are grateful to the research team that supported this project: Donna Gehret, Allison Hill, Gabrielle Barnett, Cindy Elias, Ivet Hirlas, Mauricio Yanez, Wei Wu, Dana DeMaster, Mike Assel, and Gloria Yeomans-Maldonado.

Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.jecp.2024.106000.

References

Bates, D., Mächler, M., Bolker, B. M., & Walker, S. C. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*, 1–48.

Benjamin, N., Haden, C. A., & Wilkerson, E. (2010). Enhancing building, conversation, and learning through caregiver–child interactions in a children's museum. *Developmental Psychology, 46*, 502–515.

Bermudez, V. N., Salazar, J., Garcia, L., Ochoa, K. D., Pesch, A., Roldan, W., Soto-Lara, S., Gomez, W., Rodriguez, R., Hirsh-Pasek, K., Ahn, J., & Bustamante, A. S. (2023). Designing culturally situated playful environments for early STEM learning with a Latine community. *Early Childhood Research Quarterly, 65*, 205–216.

Bornstein, M. H., Hahn, C.-S., Suwalsky, J. T. D., & Haynes, O. M. (2003). Socioeconomic status, parenting, and child development: The Hollingshead Four-Factor Index of Social Status and the socioeconomic index of occupations. In M. H. Bornstein & R. H. Bradley (Eds.), *Socioeconomic status, parenting, and child development* (pp. 29–82). Lawrence Erlbaum.

Brubacher, S. P., Timms, L., Powell, M., & Bearman, M. (2019). "She wanted to know the full story": Children's perceptions of open versus closed questions. *Child Maltreatment, 24*, 222–231.

Callanan, M. A., Legare, C. H., Sobel, D. M., Jaeger, G. J., Letourneau, S., McHugh, S. R., Willard, A., Brinkman, A., Finiasz, Z., Rubio, E., Barnett, A., Gose, R., Martin, J. L., Meisner, R., & Watson, J. (2020). Exploration, explanation, and parent–child interaction in museums. *Monographs of the Society for Research in Child Development, 85*, 7–137.

Choi, B., Nelson, C. A., Rowe, M. L., & Tager-Flusberg, H. (2020). Reciprocal influences between parent input and child language skills in dyads involving high- and low-risk infants for autism spectrum disorder. *Autism Research, 13*, 1168–1183.

Cohen, L. E., & Emmons, J. (2017). Block play: Spatial language with preschool and school-aged children. *Early Child Development and Care, 187*, 967–977.

Cohrssen, C., & Niklas, F. (2019). Using mathematics games in preschool settings to support the development of children's numeracy skills. *International Journal of Early Years Education, 27*, 322–339.

Cristofaro, T. N., & Tamis-LeMonda, C. S. (2012). Mother–child conversations at 36 months and at pre-kindergarten: Relations to children's school readiness. *Journal of Early Childhood Literacy, 12*, 68–97.

Deshmukh, R. S., Pentimonti, J. M., Zucker, T. A., & Curry, B. (2022). Teachers' use of scaffolds within conversations during shared book reading. *Language, Speech, & Hearing Sciences in Schools, 53*(1), 150–166.

Deshmukh, R. S., Zucker, T. A., Tambyraja, S. R., Pentimonti, J. M., Bowles, R. P., & Justice, L. M. (2019). Teachers' use of questions during shared book reading: Relations to child responses. *Early Childhood Research Quarterly, 49*, 59–68.

Duong, S., Bachman, H. J., Votruba-Drzal, E., & Libertus, M. E. (2021). What's in a question? Parents' question use in dyadic interactions and the relation to preschool-aged children's math abilities. *Journal of Experimental Child Psychology, 211*, 105213.

Gaudreau, C., Hirsh-Pasek, K., & Golinkoff, R. M. (2022). What's in a distraction? The effect of parental cell phone use on parents' and children's question-asking. *Developmental Psychology, 58*, 55–68.

Haden, C. A. (2010). Talking about science in museums. *Child Development Perspectives, 4*, 62–67.

Haden, C. A., Jant, E. A., Hoffman, P. C., Marcus, M., Geddes, J. R., & Gaskins, S. (2014). Supporting family conversations and children's STEM learning in a children's museum. *Early Childhood Research Quarterly, 29*, 333–344.

Hanner, E., Braham, E. J., Elliott, L., & Libertus, M. E. (2019). Promoting math talk in adult–child interactions through grocery store signs. *Mind, Brain, and Education, 13*, 110–118.

Haring Biel, C. H., Buzhardt, J., Brown, J. A., Romano, M. K., Lorio, C. M., Windsor, K. S., Kaczmarek, L. A., Gwin, R., Sandall, S. S., & Goldstein, H. (2020). Language interventions taught to caregivers in homes and classrooms: A review of intervention and implementation fidelity. *Early Childhood Research Quarterly, 50*, 140–156.

Heidlage, J. K., Cunningham, J. E., Kaiser, A. P., Trivette, C. M., Barton, E. E., Frey, J. R., & Roberts, M. Y. (2020). The effects of parent-implemented language interventions on child linguistic outcomes: A meta-analysis. *Early Childhood Research Quarterly, 50*, 6–23.

Huebner, C. E., & Payne, K. (2010). Home support for emergent literacy: Follow-up of a community-based implementation of dialogic reading. *Journal of Applied Developmental Psychology, 31*, 195–201.

Jirout, J. J., Eisen, S., Sargent, Z., & Evans, T. M. (2022). Mother–child synchrony is high across child executive function levels for both physical and digital spatial play. *Trends in Neuroscience and Education, 29*, 100183.

Justice, L. M., Weber, S. E., Ezell, H. K., & Bakeman, R. (2002). A sequential analysis of children's responsiveness to parental print references during shared book-reading interactions. *American Journal of Speech-Language Pathology, 11*, 30–40.

Kim, Y. S. G., & Park, Y. H. (2015). Parent–child interactions in book reading and narrative skill for prekindergarteners: Exploring "during" vs. "after" book reading interactions. *International Journal of Early Childhood Education, 21*, 1–21.

LaCour, M., McDonald, C., Tissington, L., & Thomason, G. (2013). Improving pre-kindergarten children's attitude and interest in reading through a parent workshop on the use of dialogic reading techniques. *Reading Improvement, 50*, 1–11.

Landry, S. H., Smith, K. E., Swank, P. R., Zucker, T., Crawford, A. D., & Solari, E. F. (2012). The effects of a responsive parenting intervention on parent–child interactions during shared book reading. *Developmental Psychology, 48*(4), 969–986.

Lee, Y., & Kinzie, M. B. (2012). Teacher question and student response with regard to cognition and language use. *Instructional Science, 40*, 857–874.

LeFevre, J. A., Skwarchuk, S. L., Smith-Chant, B. L., Fast, L., Kamawar, D., & Bisanz, J. (2009). Home numeracy experiences and children's math performance in the early school years. *Canadian Journal of Behavioural Science, 41*, 55–66.

Lenth, R. (2023). *emmeans: Estimated marginal means, aka least squares means.* R package 1.8.8. https://cran.r-project.org/web/packages/emmeans/index.html.

Leyva, D., Reese, E., & Wiser, M. (2012). Early understanding of the functions of print: Parent-child interaction and preschoolers' notating skills. *First Language, 32*(3), 301–323.

Leyva, D., Tamis-LeMonda, C. S., Yoshikawa, H., Jimenez-Robbins, C., & Malachowski, L. (2017). Grocery games: How ethnically diverse low-income mothers support children's reading and mathematics. *Early Childhood Research Quarterly*, *40*, 63–76. https://doi.org/10.1016/j.ecresq.2017.01.001

Lillard, A., Pinkham, A. M., & Smith, E. (2010). Pretend play and cognitive development. In U. Goswami (Ed.), *Blackwell handbook of childhood cognitive development* (2nd ed., pp. 285–311). John Wiley & Sons, Incorporated.

Lin, X., Yang, W., Wu, L., Zhu, L., Wu, D., & Li, H. (2021). Using an inquiry-based science and engineering program to promote science knowledge, problem-solving skills and approaches to learning in preschool children. *Early Education and Development, 32*, 695–713.

Lonigan, C. J., Bloomfield Dyer, S. M., & Samwel, C. S. (1999). Effects of two shared-reading interventions on emergent literacy skills of at-risk preschoolers. *Journal of Early Intervention, 22*(4), 306–322.

Lu, L., Vasilyeva, M., & Laski, E. V. (2023). Minor changes, big differences? Effects of manipulating play materials on parental math talk. *Developmental Psychology, 59*, 1283–1299.

Marcus, M., Acosta, D. I., Tõugu, P., Uttal, D. H., & Haden, C. A. (2021). Tinkering with testing: Understanding how museum program design advances engineering learning opportunities for children. *Frontiers in Psychology, 12*, 2763.

Martin, N. A., & Brownell, R. (2011). *Expressive One-Word Picture Vocabulary Test-4 (EOWPVT-4).* Academic Therapy Publications.

Masek, L. R., McMillan, B. T., Paterson, S. J., Tamis-LeMonda, C. S., Golinkoff, R. M., & Hirsh-Pasek, K. (2021). Where language meets attention: How contingent interactions promote learning. *Developmental Review, 60*, 100961.

McHugh, S. R., Callanan, M., Jaeger, G., Legare, C. H., & Sobel, D. M. (2024). Explaining and exploring the dynamics of parent–child interactions and children's causal reasoning at a children's museum exhibit. *Child Development, 95*, 845–861.

Mermelshtine, R. (2017). Parent–child learning interactions: A review of the literature on scaffolding. *British Journal of Educational Psychology, 87*, 241–254.

Mol, S. E., Bus, A. G., De Jong, M. T., & Smeets, D. J. (2008). Added value of dialogic parent–child book readings: A meta-analysis. *Early Education and Development, 19*, 7–26.

Neale, D., & Whitebread, D. (2019). Maternal scaffolding during play with 12- to 24-month-old infants: Stability over time and relations with emerging effortful control. *Metacognition and Learning, 14*, 265–289.

Pace, A., Luo, R., Hirsh-Pasek, K., & Golinkoff, R. M. (2017). Identifying pathways between socioeconomic status and language development. *Annual Review of Linguistics, 3*, 285–308.

Pagano, L. C., Haden, C. A., & Uttal, D. H. (2020). Museum program design supports parent–child engineering talk during tinkering and reminiscing. *Journal of Experimental Child Psychology, 200*, 104944.

Pentimonti, J. M., Zucker, T. A., Justice, L. M., Petscher, Y., Piasta, S. B., & Kaderavek, J. N. (2012). A standardized tool for assessing the quality of classroom-based shared reading: Systematic Assessment of Book Reading (SABR). *Early Childhood Research Quarterly, 27*(3), 512–528.

Purpura, D. J., Napoli, A. R., Wehrspann, E. A., & Gold, Z. S. (2017). Causal connections between mathematical language and mathematical knowledge: A dialogic reading intervention. *Journal of Research on Educational Effectiveness, 10*, 116–137.

R Core Team (2023). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org.

Reynolds, E., Vernon-Feagans, L., Bratsch-Hines, M., Baker, C. E., & Family Life Project Key Investigators (2019). Mothers' and fathers' language input from 6 to 36 months in rural two-parent families: Relations to children's kindergarten achievement. *Early Childhood Research Quarterly, 47*, 385–395.

Roby, E., & Scott, R. M. (2022). Exploring the impact of parental education, ethnicity and context on parent and child mental-state language. *Cognitive Development, 62*, 101169.

Rowe, M. L., Leech, K. A., & Cabrera, N. (2017). Going beyond input quantity: Wh-questions matter for toddlers' language and cognitive development. *Cognitive Science, 41*, 162–179.

Rowe, M. L., & Snow, C. E. (2020). Analyzing input quality along three dimensions: Interactive, linguistic, and conceptual. *Journal of Child Language, 47*, 5–21.

Schatz, J. L., Suarez-Rivera, C., Kaplan, B. E., & Tamis-LeMonda, C. S. (2022). Infants' object interactions are long and complex during everyday joint engagement. *Developmental Science, 25*, e13239.

Schrank, F. A., Mather, N., & McGrew, K. S. (2014). *Woodcock-Johnson IV Tests of Achievement*. Riverside Publishing.
Shirefley, T. A., & Leaper, C. (2022). Mothers' and fathers' science-related talk with daughters and sons while reading life and physical science books. *Frontiers in Psychology, 12*, 813572.
Sobel, D. M., Letourneau, S. M., Legare, C. H., & Callanan, M. (2021). Relations between parent–child interaction and children's engagement and learning at a museum exhibit about electric circuits. *Developmental Science, 24*, e13057.
Suarez-Rivera, C., Schatz, J. L., Herzberg, O., & Tamis-LeMonda, C. S. (2022). Joint engagement in the home environment is frequent, multimodal, timely, and structured. *Infancy, 27*, 232–254.
Tamis-LeMonda, C. S., Kuchirko, Y., & Song, L. (2014). Why is infant language learning facilitated by parental responsiveness? *Current Directions in Psychological Science, 23*, 121–126.
Tompkins, V., Bengochea, A., Nicol, S., & Justice, L. M. (2017). Maternal inferential input and children's language skills. *Reading Research Quarterly, 52*, 397–416.
Towson, J. A., Fettig, A., Fleury, V. P., & Abarca, D. L. (2017). Dialogic reading in early childhood settings: A summary of the evidence base. *Topics in Early Childhood Special Education, 37*, 132–146.
Villarreal, V. (2015). Test review: Schrank, F. A., Mather, N., & McGrew, K. S. (2014). Woodcock-Johnson IV Tests of Achievement. *Journal of Psychoeducational Assessment, 33*, 391–398.
Willard, A. K., Busch, J. T., Cullum, K. A., Letourneau, S. M., Sobel, D. M., Callanan, M., & Legare, C. H. (2019). Explain this, explore that: A study of parent–child interaction in a children's museum. *Child Development, 90*, e598–e617.
Worley, P. (2015). Open thinking, closed questioning: Two kinds of open and closed question. *Journal of Philosophy in Schools, 2*, 17–29.
Yu, Y., Bonawitz, E., & Shafto, P. (2019). Pedagogical questions in parent–child conversations. *Child Development, 90*, 147–161.
Zucker, T. A., Yeomans Maldonado, G., Assel, M., McCallum, C., Elias, C., Swint, J. M., & Lal, L. (2022). Informal science, technology, engineering, and math learning conditions to increase parent involvement with young children experiencing poverty. *Frontiers in Psychology, 13*.