Journal of Experimental Child Psychology 247 (2024) 106034

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

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

Associations between parents' autonomy supportive management language and children's science, technology, engineering, and mathematics talk during and after tinkering at home

Bianca M. Aldrich *, Catherine A. Haden

Department of Psychology, Loyola University Chicago, Chicago, IL 60626, USA

ARTICLE INFO

Article history:
Received 22 January 2024
Revised 3 July 2024
Available online 10 August 2024

Keywords:
Autonomy support
Informal learning
Parent–child conversation
STEM learning
Memory
Tinkering

ABSTRACT

We conducted a time series analysis of parents' autonomy supportive and directive language and parents' and children's STEM (science, technology, engineering, and mathematics) talk during and after a problem-solving activity (i.e., tinkering). Parent and child dyads (N = 61 children; M_{age} = 8.10 years; 31 boys; 54% White) were observed at home via Zoom. After tinkering, a researcher elicited children's reflections, and approximately 2 weeks later dyads reminisced together about the experience. During tinkering, the more autonomy supportive STEM talk parents used in 1 min, the more children talked about STEM in the next minute. During reminiscing, parents' autonomy support was also associated with children's STEM talk. Results suggest the importance of considering how both the content and style of parents' talk can support children's STEM engagement.

© 2024 Elsevier Inc. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

* Corresponding author.
E-mail address: baldrich@luc.edu (B.M. Aldrich).

https://doi.org/10.1016/j.jecp.2024.106034
0022-0965/© 2024 Elsevier Inc. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

Introduction

Advancing early STEM (science, technology, engineering, and mathematics) education is a priority in the United States because there is an increasing demand for STEM professionals to enhance innovation and competitiveness of the nation. Many efforts to encourage future STEM educational and career pursuits target early childhood curricula and teaching methods in schools. Nevertheless, researchers, educators, and policymakers also recognize the importance of STEM learning opportunities in everyday out-of-school contexts (National Research Council, 2009). Such informal educational settings include specially designed museum exhibits and programs for children. With the temporary closure of many museums due to the COVID-19 pandemic came a proliferation of online programming created by museum educators, including programming designed for children and caregivers to engage in STEM learning at home (Ennes et al., 2021). Our work focused on one of these online programs—an open-ended problem-solving (i.e., tinkering) activity designed by educators at a children's museum for families to do at home. We addressed how families engage in such informal learning opportunities at home and, more specifically, how the content and style of parents' talk during tinkering might link to children's STEM talk during the hands-on activity and afterward.

Tinkering is a form of playful problem solving that has surged in popularity in early childhood STEM education (Resnick & Rosenbaum, 2013). Part of the enthusiasm for tinkering is that it does not require prior knowledge or experience, and it can involve everyday practices of problem solving using commonplace materials (e.g., cardboard and glue). These characteristics can make STEM learning through tinkering accessible to the young and old and to individuals from diverse backgrounds (Vossoughi & Bevan, 2014). Consistent with constructivist theories (Harel & Papert, 1991; Piaget, 1970), the opportunities for rich engagement with objects and materials afforded by tinkering can support early learning. Furthermore, tinkering is often social, and communicative interactions between children and adults can, according to sociocultural theories, play an additional crucial role in children's learning (Gauvain, 2001; Rogoff, 1990; Vygotsky, 1978). Regarding STEM learning, tinkering provides opportunities for engagement in authentic practices of engineering, such as making, testing, and redesigning, that are emphasized in the *Next Generation Science Standards* (NGSS Lead States, 2013).

Content and style of parent–child conversational interactions

A growing literature characterizes the ways that parents scaffold hands-on informal learning activities through both the content (i.e., *what* they talk about) and the style (i.e., *how* they talk) of conversation with their children. This work shows that the frequency of specific content, such as STEM-related language, can predict children's subsequent skills in STEM domains (Casasola et al., 2020; Gunderson & Levine, 2011; Pruden et al., 2011). Likewise, research on family conversations in museums, in libraries, and at home suggests that the content of parent–child interactions can support children's STEM learning (Booth et al., 2020; Callanan et al., 2017; Crowley et al., 2001; Geerdts et al., 2015). For example, in Willard et al. (2019), the more that parents engaged in explanatory talk in a STEM-related museum exhibit, the more children talked about causality and engaged in STEM-related practices in the exhibit. Also, in several studies, the more parent–child dyads talked about STEM during science and engineering activities in museums, the more children recalled STEM-related information even weeks after the visit (Acosta et al., 2021; Benjamin et al., 2010, Haden et al., 2014; Marcus et al., 2021; Pagano et al., 2020; Sobel et al., 2021).

In addition to quantity, the style and sequencing of talk as interactions unfold can be important. For example, Callanan and colleagues (2020) considered sequential patterns of causal explanatory talk and exploratory behaviors when parents and children were observed in gears exhibits. They found that parents' causal explanatory talk was linked to children's systematic exploration (i.e., spinning gears), but only when parents' causal talk occurred *before* testing, not during or after testing, indicating the importance of timing of talk in the sequence of hands-on activities. Other work that has considered patterns of joint talk sequences, defined by when parents' open-ended questions are immediately followed by children's response, further suggests the importance of the sequencing of talk for children's learning. For example, in Jant and colleagues (2014), parent–child joint talk observed in an exhibit was positively associated with children's learning and subsequent remembering of the exhibit experiences.

In the current study, in addition to examining the STEM content of parents' and children's talk during tinkering, we also considered the style of interaction based on the concept of autonomy support (Ryan & Deci, 2017, 2020). According to self-determination theory, parental autonomy support involves encouraging and supporting children's initiative, taking children's perspectives, solving problems collaboratively, and offering choices. Autonomy support contrasts with a controlling parental style that involves pressuring children toward certain behaviors and solving problems for them. Also, parental autonomy support is linked to a wide range of positive outcomes, including persistence during play (Grolnick et al., 1984), executive function (Bernier et al., 2010; Bindman et al., 2015), math and spatial skills (Cimon-Paquet et al., 2020; Sorariutta et al., 2017), academic performance (Grolnick et al., 2014), and engagement in activities (Ng et al., 2004), including STEM activities (Sobel, 2023).

Museum studies have characterized the style of parent–child interactions based on who was setting the goals and leading the activity (Callanan et al., 2020; Medina & Sobel, 2020; Sobel et al., 2021). For example, parent–child dyads are considered child-led when children are working more independently from their parents, are considered joint-led when parents work in a collaborative and autonomy supportive manner with their children (e.g., jointly setting goals and making suggestions), and are considered parent-led when children receive little independence or autonomy from parents. Medina and Sobel (2020) found that children in parent-led dyads showed better performance in a posttest, but showed lower engagement, compared with children in the more autonomy supportive dyads. Callanan and colleagues (2020) found that child-led and joint-led dyads had children who engaged in more systematic exploration in gears exhibits compared with parent-led dyads. Particularly germane to our work, Grolnick and colleagues (2002) found evidence that autonomy support can have a stronger association with children's learning in more open-ended activities (i.e., activities with many possible solutions), analogous to tinkering, compared to closed-ended ones.

One way that autonomy support (vs. control) has been operationalized in the literature is in terms of parents' use of management language. Management language is defined as statements, questions, and directions used to promote (or limit) children's choices in decision making (Bindman et al., 2013; Grolnick et al., 2002). In Bindman and colleagues (2013), parents' use of suggestion (high autonomy/choice) language when children were 3 years old was positively related to concurrent executive functioning. By contrast, directive language (low autonomy/choice) at age 3 was negatively associated with children's executive functioning skills. Although little is known about how parents' autonomy supportive language might advance STEM learning, in Clements and colleagues (2021), parents who used more autonomy supportive management language also talked more about numbers with their preschoolers during structured play time.

The current study

This study was designed to explore how the content of parents' talk, as characterized using STEM-related language, and the style of parents' talk, as characterized by autonomy supportive and directive language, relates to children's STEM talk during and after an at-home tinkering activity. As part of a research–practice partnership between university researchers and informal STEM learning practitioners at Chicago Children's Museum, educators created a video introduction to a tinkering activity for families to engage in at home. In the video, an educator invites families to tinker and make a playground ride for a toy friend using materials around their home and encourages engagement in simplified steps of the engineering design process: making, testing, and fixing. In addition to the video's dissemination on social media platforms by the museum, the research team recruited a sample of participants who were observed via Zoom engaging in the tinkering activity.

At the outset of the activity, some of the families were encouraged to first plan what they would make before commencing tinkering. Some tinkerers take a bottom-up approach, solving problems as they appear while trying out different tools and materials, whereas others may choose to plan their creation and strategies before engaging with the materials (Resnick & Rosenbaum, 2013). Our question was whether prompting planning prior to tinkering might lead to different patterns of parental scaffolding (content and style). One possibility is that during planning, dyads would jointly develop goals and steps to accomplish the goals. In turn, parents might use more directive language during the building stage. On the other hand, a lack of planning may increase parents' worries or concerns over the final product, reducing their use of autonomy supportive language that would provide children with opportunities to make their own decisions in problem solving.

During tinkering, we measured the STEM content and autonomy supportive or directive style of parents' verbalizations. We also measured children's STEM talk. In doing so, we conducted a time series analysis to examine associations between parents' verbalizations in each 1 min of the interaction with children's STEM talk in each subsequent minute. This allowed us to establish temporal precedence of our predictors in relation to our outcome variable and to account for confounding variables at the individual level. Parents' autonomy supportive style and directive style were crossed with STEM content in these analyses, resulting in the following categories of parental talk: autonomy supportive STEM talk, directive STEM talk, and STEM-only talk as well as autonomy supportive-only talk and directive-only talk.

Taking this approach, we tested several hypotheses. First, we hypothesized that parents' STEM talk would be positively associated with children's STEM talk during and after the activity only when parents spoke in an autonomy supportive manner. Second, we hypothesized that parents' directives, whether containing STEM content or not, would be negatively associated with children's STEM talk during and after the activity. Third, we hypothesized a bidirectional association between parents and children's talk during the activity. Specifically, we anticipated that when children showed high STEM engagement in one moment of the activity, parents would respond with more autonomy supportive talk than when children showed low STEM engagement. Finally, regarding the planning manipulation, we explored whether parents in the planning condition would use more autonomy supportive STEM talk over time compared with parents in the no-planning condition.

Method

Participants

Families were recruited from October 2020 to November 2021 with the help of Chicago Children's Museum outreach efforts recontacting families who had participated in different studies at the museum and through word of mouth. We also used the Children Helping Science website (https://childrenhelpingscience.org; this took place before the website merged with the Lookit platform) and a listserv from other developmental researchers, obtaining a sample from different geographic locations across the United States. A total of 61 children (31 male and 30 female) aged 4 to 10 years (M = 8.10 years, SD = 1.72) participated with their parents (49 mothers and 12 fathers). In analyses using hierarchical linear models (HLM), sample sizes greater than 50 led to unbiased estimation of errors (Maas & Hox, 2005). Still, a post hoc power analysis, using Optimal Design Plus software, indicated that our sample size had low power to detect medium size effects of Level 2 variables such as children's age and planning condition (power = .50).

Detailed demographic information is presented in Table 1. The age range (4–10 years) is one that research shows is an important period for advancing STEM interest and learning (National Research Council, 2012). This is also the age group that our partners see in Chicago Children's Museum, and we wanted to design this study—conducted during the pandemic when the museum was closed—in ways that could inform programming in the exhibit when the museum reopened. An additional three families participated but were subsequently dropped from the analyses because of poor video/audio quality (n = 2) or the parent not being present during the tinkering session (n = 1). All families recruited included a target child and one parent, although three observations also included a sibling. All participants received a $25 gift card for their participation in the study.

Table 1
Participants' demographic information.

Demographics	*n* (%)
Children's race/ethnicity	
White	33 (54)
Black	9 (15)
Asian	5 (8)
Hispanic/Latino	3 (5)
Mixed	10 (16)
Not reported	1 (2)
Parents' race/ethnicity	
White	40 (65)
Black	8 (13)
Asian	7 (11)
Hispanic/Latino	1 (2)
Mixed	4 (7)
Not reported	1 (2)
Parents' education	
High school graduate	4 (7)
Associate degree	2 (3)
Bachelor's degree	17 (28)
Completed some postgraduate	3 (5)
Master's degree	25 (41)
PhD, law, or medical degree	10 (16)
Family income	
Less than $50,000	1 (2)
$50,000–$74,999	6 (10)
$75,000–$99,999	14 (23)
$100,000–$149,999	17 (28)
$150,000–$199,999	9 (15)
$200,000 or more	10 (16)
Not reported	4 (6)

Procedures

The study procedure was approved by Loyola University Chicago's institutional review board. Once consent was obtained, each family participated in two sessions that were audio- and video-recorded via Zoom. The first session involved observations of parents and children tinkering at home, followed by a researcher eliciting children's reflections about their tinkering immediately after experience. The second session occurred approximately 2 weeks later to record parent–child reminiscing conversations about their tinkering-at-home experience. This amount of delay parallels that of prior studies on children's memory of STEM activities (Acosta & Haden, 2023; Benjamin et al., 2010).

Observations of tinkering at home

Prior to the tinkering at home session, families were asked to gather materials such as cardboard, recyclables, string, glue, and tape. At the beginning of this first session, the researcher spent a few moments ensuring that the camera angle was such that video-recording would capture the parents and children in the workspace they had selected to engage in the tinkering activity. Then the researcher showed each family a 5-min video created by our collaborators at Chicago Children's Museum introducing the tinkering challenge of making a playground ride for a small toy friend (https://youtu.be/PRTwI9vDFoM). In the video, a museum educator describes several steps to complete the challenge, including choosing a small toy, planning, gathering materials, making the ride, and sharing a story about the toy and the ride. The educator also described the engineering process of making, testing, and fixing the creation and provided an example of a swing that had been made for a character named "Crunch" (a cork with eyes drawn on it) using cardboard, rubber bands, sticks, string, and tape.

Families were randomly assigned to either the planning condition (n = 32) or the no-planning condition (n = 29). Immediately after the video invitation to tinker, families in the no-planning condition were asked to start tinkering, working together as they normally would. Those in the planning condition were asked to take some time to plan the playground ride and the story they would tell about their toy friend and the ride. They were asked to choose a toy friend and decide what ride they would make and how they would make the ride fun and safe. Each of these elements had been mentioned in the video; therefore, the planning condition was aimed at emphasizing planning the connection between tinkering and storytelling. Once families indicated that they were done planning, they were also encouraged to work together as they normally would and began the tinkering activity. All participants were told at the outset of tinkering that they would have 30 min to complete the activity.

During tinkering, the researcher turned off the camera and microphone to avoid drawing attention to the video-recording. After the 30 min had elapsed, families were offered the option to take up to an additional 5 min to finish.

Children's reflections about their tinkering experience

Once they were done tinkering, the researcher turned the camera and microphone back on and asked the children to reflect on their tinkering experience. The researcher prompted the reflection by asking the following questions:

1. Tell me all about the story of your toy friend and their playground ride.
2. What did you make for your toy friend?
3. How did you make it?
4. Did you test it? How did it work?
5. Did you fix or change anything?
6. What did you learn?

Throughout the reflection, the researcher encouraged children to elaborate on their responses during the interview using general prompts such as "Tell me more" and "Anything else you would like to share?". The duration of these conversational reflections ranged from 4 to 13 min (M = 6.74 min, SD = 2.13) and were later transcribed verbatim. Children's number of words during the interview ranged from 131 to 950 (M = 415 words, SD = 208.92). After children's reflections, researchers collected demographic information from the parents.

Parent–child reminiscing about their tinkering experience

A total of 51 (84%) parent–child dyads participated in a follow-up interview session via Zoom after their tinkering session. This session was planned to take place two weeks after the first session, but the days between the first and second sessions ranged from 10 to 30, with an average of 16 days. During the follow-up session, families were told that the objective of the session was to understand how much children remember from their tinkering experiences. The researcher asked parents to talk to their children about their tinkering experience the way they would normally talk about past experiences together, asking as many questions as they liked. The duration of these parent–child reminiscing conversations ranged from 3 to 11 min (M = 5.24 min, SD = 2.19) and were later transcribed verbatim. Children's number of words during the reminiscing ranged from 213 to 1802 (M = 642 words, SD = 319.28).

Coding

We coded three types of data: video observations of the tinkering activity, transcripts of children's post-tinkering reflections, and transcripts of parent–child reminiscing.

Video observations of tinkering

For the video-recordings of tinkering, we used a time sampling coding method. In each 5-s interval, we coded for whether parents' and children's STEM talk was present and whether parents' talk was autonomy supportive or directive. Then, for parents, we counted the number of intervals where the content and style codes co-occurred. We chose small intervals of 5 s to avoid having multiple codable utterances within the same interval.

Parents' and children's STEM talk. In each interval, we coded separately for whether parents' STEM talk and children's STEM talk were present. Our coding system focused on STEM-related practices outlined in the Next Generation Science Standards (NGSS Lead States, 2013) and *A Framework for K–12 Science Education* (National Research Council, 2012). STEM talk was coded if the parent or child talked about comparing different materials (e.g., "Cardboard is stronger," "The strings are not even"), engaging in problem solving (e.g., "We need to tape it so it won't fall"), planning or setting goals (e.g., "I want to build a seesaw," "We could use these pieces as the walls"), engineering, math, and science concepts and practices (e.g., "We need to test it," "I think we just need to add more weight to balance," "I just need five more pieces," "We should count them up"), and asking for and providing explanations or evaluations (e.g., "It is safer now that we've taped it").

Parents' management language. In each interval, we further coded parents' autonomy support and directive language using a management language coding scheme adapted from Bindman and colleagues (2013). Parents' utterances containing a direction or question that had implications for the children's subsequent behaviors or for the outcome of the project were coded as autonomy supportive or directive. *Parents' directives* consisted of explicit directions (e.g., "Go get your toy friend"), qualified directions (i.e., explicit directions with a qualifying question at the end; e.g., "We will do the one on this side now, right?"), and ambiguous suggestions (i.e., statements in which it is not clear whether the child had a choice; e.g., the parent says "Can you test it now?" while already arranging for the toy to be tested). *Parents' autonomy supportive* language included transfer statements that transferred full autonomy to make decisions to the child (e.g., "What do you want to make?", "It is up to you"), single suggestions with clear choice to accept it or not (e.g., "You could use the strings to make stairs"), and utterances offering options to the child (e.g., "We can cut holes or add things on top").

Parents' STEM-directives and autonomy supportive STEM talk. After the coding of STEM content and management language style of parents' talk, we counted the co-occurrence of parents' STEM talk with parents' management language. When STEM talk was coded in the same interval as autonomy support or directive management language, the parent received a code for autonomy supportive STEM talk or directive STEM talk. In this way, parents could receive a code for autonomy supportive or directive talk that either was or was not STEM related, with the latter being when STEM talk and management language did not occur in the same interval. Fig. 1 illustrates the resulting coding categories for each time interval.

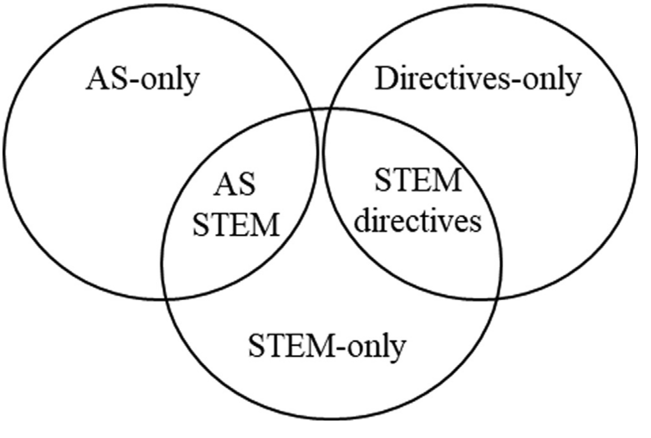

Fig. 1. Classification of parents' talk as autonomy supportive (AS) or directive, with or without co-occurring STEM (science, technology, engineering, and mathematics) talk.

Children's post-tinkering reflection and parent–child reminiscing

Children's STEM talk. We coded the transcripts for frequency of children's STEM talk in children's post-tinkering reflections (immediately after tinkering) as well as in the parent–child reminiscing conversations (weeks later). Because these interactions were much shorter in duration compared with the tinkering session, we did not use a time sampling coding method. Instead, the coding unit was instance of occurrence of STEM talk, involving the same STEM categories described for the tinkering session.

Parents' management language. To account for parents' language during the parent–child reminiscing session, we coded the frequency of parents' autonomy supportive talk (i.e., questions, suggestions, options) based on the transcripts of that interaction. The coding unit was instance of occurrence of autonomy supportive talk and statements. Because this activity was purely verbal, parents hardly ever used directives with their children. Thus, instead of coding parents' directives and qualified directives, we coded the number of statements and qualified statements about the tinkering experience parents used (e.g., "We made a swing," "After that we tested, right?"). Like directives in the context of a hands-on activity, parents' statements in the context of reminiscing limit children's choices and options when reporting their experience compared with parents' questions. We did not code parents' STEM talk during reminiscing because, due to the nature of the task, most questions and statements parents made were STEM related, (e.g., "What did we build?", "Do you remember what happened when we tested it?") and we could expect little variability in parents' STEM talk.

Inter-rater reliability

To establish inter-rater reliability, two researchers coded 20% of the observations independently. Cohen's kappa for overall identification of parents' autonomy support and directives was κ = .80, and the differentiation between autonomy supportive and directive codes was κ = .81. The agreement for parents' STEM talk during tinkering was κ = .75, and the agreement for children's STEM talk was also κ = .75. Agreement for children's STEM talk at reflection was κ = .78 and at the reminiscing session was κ = .81. Agreement for parents' autonomy supportive language and statements at the reminiscing session was κ = .85.

Data preparation

When examining associations between parent–child talk during tinkering, we adopted a microanalytic approach. The use of time series analyses offers several advantages over traditional regression analyses. First, by not aggregating behaviors to the individual level, we are able to examine individual variability across time. Second, individuals serve as their own control when examining time-varying changes in the outcome variable, ruling out confounding influences at the individual level such as individual traits (Duckworth et al., 2010). Finally, by using a time-lagged design, we could establish temporal precedence of our predictors in relation to our outcome variable.

In advance of the main analyses, we aggregated scores from the 5-s interval coding of parents' and children's talk during tinkering into 1-min scores for each coded variable. Therefore, in every 1-min interval, each coded category of parents' and children's talk could range from 0 to 12 (12 intervals/min $\times$ max 1 point/interval). We took this step because when time intervals are too fine, as in the case of 5-s intervals, patterns of change may be clouded by statistical noise (Lerner et al., 2009). Thus, we used 1-min intervals as our unit of analysis of talk during tinkering. For example, if in 1 min a child talked about STEM in 3 of the 12 intervals, the child score for that 1 min would be 3.

Results

Preliminary analyses

We conducted descriptive analyses of the parent and child talk variables to identify the distribution of data and possible outliers. Time spent tinkering ranged from 12 to 41 min, and the average was 31 min (*SD* = 6.22). Because families varied in the amount of time spent tinkering, and because in our time series analysis we used 1-min intervals as the unit of analysis, in preliminary analyses we examined the proportion of codes per minute for all the parent and child talk variables during the tinkering activity. Therefore, if a parent received a total score of 25 for autonomy supportive STEM talk while tinkering for 30 min with the child, the proportion of autonomy supportive STEM talk per minute would be 25/30, equaling 0.83 per minute. The scores for post-tinkering reflection and parent–child reminiscing represent the frequencies across the interactions (with number of words controlled for in main analysis).

We identified one outlier (z-score > |3|) in parents' STEM-directives and children's STEM talk and two outliers in parents' autonomy supportive STEM talk. There was also one outlier in parents' statements and children's STEM talk during the reminiscing session. To maintain the relative order of the data, these outliers were recoded to the next highest score. Table 2 displays the descriptive statistics for the continuous parent and child talk during tinkering with outliers removed, and Table 3 displays the descriptives for the variables during post-tinkering reflection and parent–child reminiscing. Correlations between the parent and child talk variables are shown in Table 4. We examined whether parents' and children's talk varied as a function of demographic variables. Children's age was positively correlated with their STEM talk during the post-tinkering reflection, $r(59) = .32$, $p = .01$, and negatively associated with parents' autonomy support during the reminiscing session, $r(59) = -.47$, $p < .001$. No other correlations between age and the parents' and children's talk were found. We also found effects of children's gender. Specifically, girls showed more STEM talk during tinkering compared with boys, $t(59) = 2.82$, $p = .01$ (see Table S1 in online supplementary material).

Our analyses showed a significant difference in children's STEM talk during tinkering based on parents' STEM occupation, $t(58) = 2.63$, $p = .01$. Specifically, children with parents holding STEM-related jobs (as described in the U.S. Department of Labor database of jobs; National Center for O*NET Development, 2023) showed higher STEM talk during tinkering ($M = 1.11$, $SD = 0.30$), compared with children with parents in non-STEM occupations ($M = 0.85$, $SD = 0.39$). In addition, parents' years education was positively correlated with time spent tinkering, $r(58) = .33$, $p = .01$, and with autonomy supportive STEM talk during tinkering, $r(58) = .26$, $p = .04$. No differences were found across parents' gender (but note that our sample consisted primarily of mothers) or other demographic information. We included significant covariates in our main analyses.

Main analyses

We used HLM to conduct time series analyses with HLM6 software. With this approach, we can examine how changes in parents' behaviors are associated with changes in children's STEM talk from 1 min to the next during the activity while also accounting for the effects of Level 2 (i.e., inter-individual) factors on the outcome variable, such as treatment condition, children's age, and gender. In essence, our HLM analyses create regression lines for each participant, for example, examining the associations between the scores of parents' autonomy supportive STEM talk in 1 min and children's STEM talk in the next minute. These minute-to-minute regression lines are then averaged across participants. In this way, associations found in our HLM analyses are controlled for other individual factors, thereby no longer reflecting zero-order correlations but instead partial correlations.

Table 2
Proportion of codes per minute for parent and child talk during tinkering.

Talk during tinkering	Mean (*SD*)	Range
Parent autonomy support STEM	0.71 (0.38)	0.00–1.68
Parent autonomy support-only	0.88 (0.34)	0.06–1.74
Parent STEM-directives	0.17 (0.14)	0.00–0.55
Parent directives-only	0.77 (0.50)	0.13–2.00
Parent STEM-only	0.43 (0.22)	0.03–1.10
Children's STEM talk	0.99 (0.42)	0.16–2.20

Note. STEM, science, technology, engineering, and mathematics.

Table 3
Frequency of parent and child talk at post-tinkering reflection and parent–child reminiscing.

Children's and parents' talk	Mean (*SD*)	Range
Children's post-tinkering reflection		
Children's STEM	16.16 (8.18)	3.00–39.00
Parent–child reminiscing		
Children's STEM	10.00 (6.77)	0.00–24.00
Parents' autonomy support	17.16 (11.14)	2.00–41.00
Parents' statements	21.84 (13.74)	1.00–49.00

Note. STEM, science, technology, engineering, and mathematics.

Table 4
Correlations among parent and child talk variables.

	1	2	3	4	5	6	7	8	9	10
1. Parent autonomy support STEM during tinkering	–									
2. Parent autonomy support-only during tinkering	.18	–								
3. Parent STEM-directives during tinkering	.15	.29**	–							
4. Parent directives-only during tinkering	−.05	−.15	.36***	–						
5. Parent STEM-only during tinkering	.18	.07	.39***	.08	–					
6. Child STEM during tinkering	.25*	.22	.04	−.18	.08	–				
7. Child STEM at reflection	.02	.19	.07	−.16	.10	.35***	–			
8. Child STEM at reminiscing	.16	.07	.01	−.05	−.10	.18	.44***	–		
9. Parent autonomy support at reminiscing	.30**	.20	.02	.04	.06	−.12	−.11	.08	–	
10. Parent statements at reminiscing	.13	.18	.08	−.05	.24	−.12	.07	.18	.41***	–

* p = .056.
** Correlation is significant at the $p < .05$ level (two-tailed).
*** Correlation is significant at the $p < .01$ level (two-tailed).

To ensure that the models used provided a good fit for the data, we used delta deviance (ΔD) tests. These tests were conducted by subtracting the deviance score of the current model from the deviance score of a simpler model of the same outcome variable with no predictors. The difference in deviance statistics is distributed asymptotically as a chi-square distribution, with degrees of freedom equal to the number of added predictors. Large delta deviance scores suggest a good fit (Singer & Willett, 2003).

Effects of time on parents' and children's talk

Before examining associations between the different types of parents' and children's talk, we examined how different types of talk changed over time during tinkering. The HLM analyses showed that time had a significant negative effect on children's STEM talk (β_{10} = −0.01, $p < .001$), parents' autonomy supportive STEM talk (β_{10} = −0.01, $p < .001$), and parents' autonomy supportive-only talk (β_{10} = −0.02, $p < .001$), suggesting that over time children talked less about STEM and parents used less autonomy supportive talk. On the other hand, time had a positive association with parents' STEM-directives talk (β_{10} = 0.003, p = .002), suggesting that this type of talk tended to increase over time during tinkering. Time had no significant association with parents' directives-only talk (β_{10} = 0.004, p = .24) or parents' STEM-only talk (β_{10} = 0.004, p = .07). We controlled for time in our subsequent HLM analyses.

Parents' autonomy support and children's STEM talk during tinkering

We hypothesized that only parents' autonomy supportive STEM talk in 1 min of tinkering would be positively associated with children's STEM talk in the next minute. The data corroborated our hypothesis given that only parents' autonomy supportive STEM talk (β_{20} = 0.09, *SE* = 0.02, $p < .001$), but no other type of parental language, was a significant predictor of children's subsequent STEM talk. The final model of predictors of children's STEM talk includes children's age, gender, and parents' STEM occupation as Level 2 predictors, and is presented in Table 5. The full results of these analyses, with each type of parental talk as a predictor of children's subsequent STEM talk, is presented in Table S2 of the supplementary material. In sum, we found that the more parents' provided autonomy supportive STEM talk in 1 min of tinkering, the more children talked about STEM in the next minute.

We hypothesized that children's STEM talk in 1 min would also be positively associated with parents' subsequent autonomy supportive STEM talk in a bidirectional manner. To examine this, we ran separate HLM models testing whether children's STEM talk could predict the different types of parents' subsequent talk. Contrary to our hypothesis, we did not find a significant association between children's STEM talk in 1 min and parents' autonomy supportive or directive talk in the next minute. Table S3 of the supplementary material shows the full results of these analyses, with children's STEM talk each minute as a predictor of each type of parental talk in the subsequent minute of tinkering.

Effects of planning condition

We conducted independent-sample *t* tests to examine whether participants' assigned condition (planning or no planning) had an effect on any of the parents' and children's talk variables and found no significant differences across groups. As a manipulation check, we coded how long it took each family to begin manipulating materials for building once the family began the activity as a measure of planning time. We found no significant difference in planning time across the planning (M = 5.66, SD = 3.03) and no-planning (M = 4.59, SD = 3.63) conditions, $t(59) = 1.23$, $p = .22$. This suggests that some families in the no-planning condition chose to spend time planning, and some families in the planning condition may have spent little time planning. Time spent planning was not associated with any of our main variables. We further examined parent–child talk during the planning time across the two conditions. We found that parents in the planning condition used more autonomy supportive STEM talk while planning (M = 5.14, SD = 3.68) than parents in the no-planning condition (M = 3.71, SD = 2.75), $t(59) = 1.72$, $p = .046$.

We explored whether parents in the planning condition would have a smaller decrease in autonomy support across time compared with parents in the no-planning condition. Table 6 shows the association of time, condition, and interaction effects on parents' autonomy supportive STEM talk. As shown in Table 6, parents tended to use less autonomy supportive STEM talk across time ($\beta_{10} = -0.02$, $p < .001$). However, parents in the planning condition had a slower decrease in autonomy supportive STEM talk than parents in the no-planning condition ($\beta_{11} = 0.01$, $p = .026$), as shown in Fig. 2. We found no significant interaction effects between time and condition in predicting other types of parents' language (see Table S4 in supplementary material).

Table 5
Final hierarchical linear model predicting children's STEM talk.

	Parameter	Child STEM talk
		B (SE)
Initial status (π_{0i})		
Intercept	β_{00}	0.87 (0.08)***
Child age	β_{01}	0.08 (0.03)**
Child gender	β_{02}	0.21 (0.08)*
Parent STEM occupation	β_{03}	0.31 (0.09)**
Rate of change (π_{1i})		
Time (min)	β_{10}	−0.01 (0.002)***
Parent autonomy support STEM talk	β_{20}	0.09 (0.02)***
Variance components		
Within-person	e_i	1.00 (1.00)
Initial status	r_0	0.26 (0.07)***
Goodness of fit		
Delta deviance(df)		$\Delta D(5) = 19.45$***

Note. STEM, science, technology, engineering, and mathematics.
* Significant at the $p < .05$ level.
** Significant at the $p < .01$ level.
*** Significant at the $p < .001$ level.

Associations with children's STEM talk during post-tinkering reflection and parent–child reminiscing

We hypothesized that parents' autonomy supportive STEM talk during tinkering would be positively associated with children's STEM talk in their post-tinkering reflections and parent–child reminiscing. However, as shown in Table 3, the variables were not correlated. We did find a positive correlation between children's STEM talk during reflection and age, $r(59) = .32$, $p = .01$, indicating that older children were talking more about STEM in their reflections compared with younger children. There were no other significant differences in STEM talk during post-tinkering reflection based on demographic variables. Even after accounting for the number of words children used in the post-tinkering reflections and the effects of age, parents' autonomy supportive STEM talk during tinkering showed no associations with children's STEM talk in these reflections ($B = 0.49$, $SE = 2.56$, $p = .85$).

In the parent–child reminiscing session, parents' autonomy support was negatively correlated with children's age, $r(48) = -.47$, $p < .001$, and children's STEM talk was positively related with years of parents' education, $r(48) = .33$, $p = .02$. Parents' autonomy support during the reminiscing was associated with children's STEM talk ($B = 0.18$, $SE = 0.08$, $p = .03$) after controlling for number of words ($B = 0.09$, $SE = 0.03$, $p < .001$), parents' years of education ($B = 0.92$, $SE = 0.32$, $p = .01$), and children's age ($B = 0.99$, $SE = 0.52$, $p = .06$). However, contrary to our hypothesis, neither parents' autonomy support ($B = 3.20$, $SE = 2.33$, $p = .18$), nor parents' statements ($B = -0.02$, $SE = 0.07$, $p = .82$) during tinkering were associated with children's STEM talk during reminiscing.

Discussion

We considered both the content and style of parents' talk with their children during an at-home tinkering activity designed for STEM learning. As such, this work unites lines of prior research that address impacts of what parents say and how they say it for supporting children's STEM engagement and learning. Using time series analyses, we examined the STEM content of parents and children as well as the autonomy supportive or directive language style used by parents minute by minute during tinkering. We found that whereas children's STEM talk and parents' autonomy supportive STEM talk tended to decrease over time, parents' STEM-directives increased. Overall, during tinkering, parents' communication of STEM-related content in an autonomy supportive manner in one interval predicted an increase in children's STEM talk in the next. Children's STEM talk during tinkering was not predicted by parents' autonomy supportive language unrelated to STEM or by parents' STEM talk conveyed in other than an autonomy supportive manner. In the parent–child reminiscing, children's STEM talk was only linked to parents' autonomy supportive talk occurring during the reminiscing

Table 6
Hierarchical linear model testing interaction effects of time and planning condition on parents' autonomy supportive STEM talk.

	Parameter	Autonomy supportive STEM talk
		B (SE)
Initial status		
Intercept	β_{00}	0.93 (0.08)**
Condition	β_{01}	−0.09 (0.12)
Rate of change		
Time (min)	β_{10}	−0.02 (0.003)***
Time*Condition	β_{11}	0.01 (0.005)*
Variance components		
Within-person	e_i	0.92 (0.84)
Initial status	r_0	0.40 (0.16)***
Goodness of fit		
Delta deviance(df)		$\Delta D(3) = 8.64$*

Note. STEM, science, technology, engineering, and mathematics.
* Significant at the $p < .05$ level.
** Significant at the $p < .01$ level.
*** Significant at the $p < .001$ level.

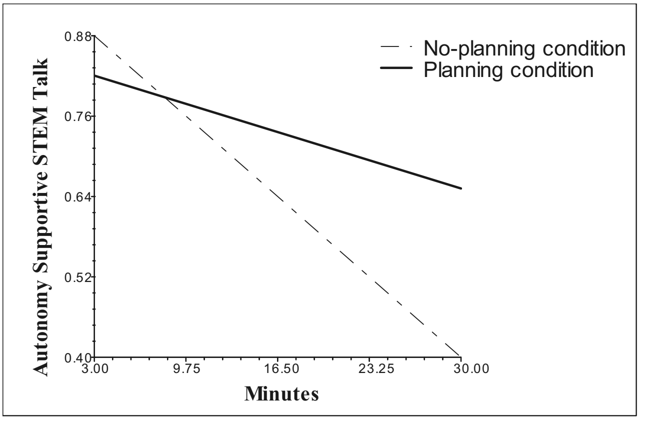

Fig. 2. Changes in proportion of parents' autonomy supportive STEM (science, technology, engineering, and mathematics) talk per minute across time and condition.

session. Parents' directives-only and STEM-directives were not associated with children's STEM talk during, immediately after, or weeks after the informal learning activity.

Parents' autonomy support and children's STEM talk

We looked at both the content and style of parents' talk during the tinkering-at-home activity in relation to children's talk during tinkering. Our findings of minute-to-minute associations between parents' autonomy supportive STEM language and children's STEM talk add to the informal STEM learning literature that has mostly focused on the frequency or percentage (of the total) of content of parents' talk in relation to children's talk. Numerous studies involving observations in museums, in libraries, and at home illustrate that the frequency of parents' STEM talk is associated with the frequency of children's STEM talk as activities unfold (Acosta et al., 2021, Callanan et al., 2017; Haden et al., 2014; Pagano et al., 2020). Other work not specific to STEM education further demonstrates associations between the frequency of adults' autonomy supportive language and children's cognitive skills and learning (Cimon-Paquet et al., 2020; Grolnick et al., 2014; León et al., 2015; Sorariutta et al., 2017). Our results add evidence to this prior work that during an informal STEM-related activity, consideration of both the content and style of parents' talk may be especially critical in understanding ways to advance STEM learning opportunities for children. Indeed, STEM content alone, or use of autonomy supportive style alone, did not predict children's STEM talk in the time series analyses. Rather, links to children's STEM talk during the activity were observed when content and style were considered in combination, specifically when parents provided STEM information in an autonomy supportive manner. These results suggest a potential mechanism by which parents' talk can advance children's STEM learning. We illustrate this idea in Excerpt 1 with a parent–child conversation during tinkering about how to create a drop tower ride that could slide down on its own. The mother is using a high degree of autonomy supportive STEM talk by asking open-ended planning questions (e.g., "How do I make it bigger?"), which elicits insights from the child about using weight to solve the problem:

Excerpt 1

Mother:	Okay, so it's not sliding down on its own.
Child:	We need to make it closer.
Mother:	Right, so ...
Child:	We have to make it slide down on its own, or otherwise when we remove it, it's not gonna slide down.
Mother:	Do you want me to make it more of a hole? Or what does make it bigger mean?
Child:	Well. Oh, it would be like so it could go down faster.
Mother:	How do I make it bigger?
Child:	Well, how do you make it go down?
Mother:	How do you think?
Child:	Uh, I know! Weight!

Children's STEM talk during tinkering was positively associated with their STEM talk during post-tinkering reflection, and children's STEM talk during reflection was positively associated with their STEM talk during parent–child reminiscing. Contrary to what we expected, parents' autonomy supportive STEM talk during tinkering was not associated with children's STEM talk in the post-tinkering reflection or parent–child reminiscing. In fact, none of the categories of parents' verbalizations during tinkering was related to children's STEM talk after tinkering. However, autonomy supportive talk during parent–child reminiscing was linked to children's STEM talk when reminiscing. We did not differentiate between STEM-related and non-STEM-related talk by parents during reminiscing because virtually all of the questions and statements parents posed were engineering-related—about building, testing, and problem solving. Our finding is in line with prior studies (Cleveland & Morris, 2014; Cleveland and Reese, 2005), showing that preschoolers with mothers who used a more autonomy supportive style tended to provide more details of prior experiences when reminiscing with their mothers than those with mothers who used less autonomy support. Taken together, the results of our study could indicate that parents' autonomy support may have stronger short-term/immediate effects on children's STEM engagement compared with long-term effects. This explanation is also consistent with self-determination theory's claim that the benefits of autonomy support occur via increased motivation and effort placed in the task at hand (Ryan & Deci, 2020).

Girls in our sample talked more about STEM during tinkering than boys, but no other gender differences were found in the associations between parents' language and children's STEM talk during and after tinkering. The gender difference in STEM talk is noteworthy considering current efforts to increase girls' engagement in STEM. Recent studies have shown that engineering activities designed to help someone can increase STEM engagement among girls (Letourneau & Bennett, 2020). Therefore, higher STEM engagement among girls in our sample could be due to the prompt given to create a playground ride to help a toy friend.

Parents' directives and children's STEM talk

We expected to find negative associations between parents' directives and children's STEM talk given that directives could reflect a form of parental control. According to self-determination theory, control produces extrinsic types of motivation that are linked with lower levels of effort and engagement (Ryan & Deci, 2020). However, we found no associations between parents' directives or STEM-directives and children's STEM talk during or after tinkering. It is possible that these types of verbalizations in the informal learning context do not reflect control as described by self-determination theory. That is, in the context of a tinkering at home activity, parents may be using commands and directions to help children achieve their own goals for the activity, not to coerce or pressure them to behave in a certain way. Even highly autonomy supportive parents may use some well-placed directives to help advance children's problem solving. Moreover, prior work in the context of parent–child semi-structured play suggests that the frequent use of directives may be parents' response to children's needs to scaffold their abilities (Bindman et al., 2013). This may be the case especially for very young children, as suggested by one study showing that preschoolers in parent-directed dyads learned more in the context of a museum exhibit than those in child-directed or jointly directed groups (Medina & Sobel, 2020).

In some cases, directive talk may inhibit children's own problem-solving behaviors and limit their autonomy, whereas in other cases, this simplification of task may be necessary for children to achieve their goals. Excerpt 2 illustrates a mother's use of directives (e.g., "Look what I am doing," "Put your two fingers in between one [elastic band]") after the child tried to tie an elastic band around part of the creation but was unsuccessful. In this case, the mother's directives occur in response to the child's struggle and reflect an effort to help the child complete the task, not an attempt to pressure or control the child's behaviors.

Excerpt 2

Mother:	Now open it up.
Child:	I can't open it.
Mother:	Now look at what I'm doing. You see how both ends are open?
Child:	Mhm.
Mother:	Put your two fingers in between one [elastic band]. Look at what I'm doing. And then take the other end and pull it.
Mother:	There you go! Pull it through the middle. Now pull this loop up.
Mother:	There you go! And now look, we have something to hold.

Planning condition

We were interested in whether prompting families to plan prior to tinkering could lead to a more autonomy supportive interaction over time compared with families who were not prompted to plan. Autonomy support can be highly demanding of parents (Distefano & Meuwissen, 2022), so we expected that as parents' energy resources decreased over time, they would become less autonomy supportive. In fact, we have found that parents tend to use less autonomy supportive talk and less autonomy supportive STEM talk over time during tinkering. However, when comparing families in the planning versus no-planning conditions, we found that the negative effect of time on autonomy support was greater for families who were not prompted to plan prior to tinkering. That is, parents in the no-planning condition had a greater decrease in autonomy support over time compared with parents in the planning condition. We noted that planning time tended to be characterized by many open-ended questions to children. By asking families to plan before tinkering, we may have primed parents to ask children more questions which was then carried throughout the rest of the activity. Although interesting, these findings need to be interpreted cautiously considering that they are based on a relatively small sample.

Limitations

Our study is not without limitations. First, our sample size was underpowered to identify small to medium effects of Level 2 variables, including age and gender. Because of this, we cannot draw conclusions about the role of children's age in the minute-by-minute associations of parents' and children's talk. In future work with a larger sample size, we would expect to see that the association between parents' autonomy supportive STEM talk and children's STEM talk would be stronger for older children compared to younger children given that older children may be more sensitive to parents' autonomy supportive and controlling behaviors (Sobel et al., 2021).

Second, the sample was not as racially and ethnically diverse as samples we have recruited in the museum, and lack of diversity in the sample limits generalizability. Because this study was conducted during the COVID-19 pandemic, we recruited our participants from websites such as Children Helping Science (https://childrenhelpingscience.org), our database of previous participants, and listservs from other developmental researchers. This recruitment strategy resulted in a sample that was primarily White and highly educated. In addition, the lack of correlation between families' income and education with some of the language variables could be due to the restricted range of income and educational background. Other ways of reaching diverse audiences are needed, particularly to address the lack of research aimed at understanding ways to broaden participation in STEM (see Acosta & Haden, 2023, for a related example of such work).

Finally, our study lacks a standardized assessment of children's language capacity. Because the tinkering activity was coded based on video-recordings and not transcripts, we do not have a measure of language that could be extracted from these data. In children's post-tinkering reflections and reminiscing, which were coded with transcripts, we attempted to minimize this problem by controlling for the number of words children used.

Conclusions

Despite these limitations, the current study makes a meaningful contribution to the literature. Specifically, our findings suggest that parents' use of autonomy supportive STEM talk can promote children's STEM talk on a minute-to-minute basis as an activity unfolds. For museum program practices, our study suggests that creating opportunities for caregivers and children to talk about their ideas prior to beginning a hands-on activity may promote a more autonomy supportive interaction over time, which can facilitate STEM learning. Future work could consider ways that museum educators themselves might use autonomy supportive STEM language when interacting with families both to model the behavior for caregivers and to elicit more STEM engagement from children. Overall, our results recommend consideration of both the content and style of parents' talk when seeking to elucidate ways that parent–child conversational interactions support informal STEM learning opportunities for children at home.

CRediT authorship contribution statement

Bianca M. Aldrich: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Catherine A. Haden:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization.

Data availability

Data will be made available on request.

Acknowledgments

This research was supported by the National Science Foundation under a collaborative grant (DRL 1906940/1906839/1906808). We thank Kim Koin (Chicago Children's Museum) for her contributions to this project and Alexandra Salame, Maddie Brophy, Milla Metlicka, and Noor Arja for their research assistance. We also thank Lauren Pagano and Riley George for providing thoughtful comments on a draft of this article. Finally, we are grateful to the families who participated in this study. This study was not preregistered. The data, analytic method, and coding schemes from this study will be made available via an open-source repository at the conclusion of the larger project of which this study is a part.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2024.106034.

References

Acosta, D. I., & Haden, C. A. (2023). Supporting Latine children's informal engineering learning through tinkering and oral storytelling. *Developmental Psychology, 59*(12), 2342–2355. https://doi.org/10.1037/dev0001648.

Acosta, D. I., Polinsky, N. J., Haden, C. A., & Uttal, D. H. (2021). Whether and how knowledge moderates linkages between parent–child conversations and children's reflections about tinkering in a children's museum. *Journal of Cognition and Development, 22*(2), 226–245. https://doi.org/10.1080/15248372.2020.1871350.

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*(2), 502–515. https://doi.org/10.1037/a0017822.

Bernier, A., Carlson, S. M., & Whipple, N. (2010). From external regulation to self-regulation: Early parenting precursors of young children's executive functioning. *Child Development, 81*(1), 326–339. https://doi.org/10.1111/j.1467-8624.2009.01397.x.

Bindman, S. W., Hindman, A. H., Bowles, R. P., & Morrison, F. J. (2013). The contributions of parental management language to executive function in preschool children. *Early Childhood Research Quarterly, 28*(3), 529–539. https://doi.org/10.1016/j.ecresq.2013.03.003.

Bindman, S. W., Pomerantz, E. M., & Roisman, G. I. (2015). Do children's executive functions account for associations between early autonomy-supportive parenting and achievement through high school? *Journal of Educational Psychology, 107*(3), 756–770. https://doi.org/10.1037/edu0000017.

Booth, A. E., Shavlik, M., & Haden, C. A. (2020). Parents' causal talk: Links to children's causal stance and emerging scientific literacy. *Developmental Psychology, 56*(11), 2055–2064. https://doi.org/10.1037/dev0001108.

Callanan, M. A., Castañeda, C. L., Luce, M. R., & Martin, J. L. (2017). Family science talk in museums: Predicting children's engagement from variations in talk and activity. *Child Development, 88*(5), 1492–1504. https://doi.org/10.1111/cdev.12886.

Callanan, M. A., Legare, C. H., Sobel, D. M., Jaeger, G. J., Letourneau, S., McHugh, S. R., ... Watson, J. (2020). Exploration, explanation, and parent–child interaction in museums. *Monographs of the Society for Research in Child Development, 85*(1), 7–137. https://doi.org/10.1111/mono.12412.

Casasola, M., Wei, W. S., Suh, D. D., Donskoy, P., & Ransom, A. (2020). Children's exposure to spatial language promotes their spatial thinking. *Journal of Experimental Psychology: General, 149*(6), 1116–1136. https://doi.org/10.1037/xge0000699.

Cimon-Paquet, C., Bernier, A., Matte-Gagné, C., & Mageau, G. A. (2020). Early maternal autonomy support and mathematical achievement trajectories during elementary school. *Learning and Individual Differences, 79*, 101855. https://doi.org/10.1016/j.lindif.2020.101855.

Clements, L. J., LeMahieu, R. A., Nelson, A. E., Eason, S. H., & Dearing, E. (2021). Associations between parents' number talk and management language with young children. *Journal of Applied Developmental Psychology, 73*, 101261. https://doi.org/10.1016/j.appdev.2021.101261.

Cleveland, E. S., & Morris, A. (2014). Autonomy support and structure enhance children's memory and motivation to reminisce: A parental training study. *Journal of Cognition and Development, 15*(3), 414–436. https://doi.org/10.1080/15248372.2012.742901.

Cleveland, E. S., & Reese, E. (2005). Maternal structure and autonomy support in conversations about the past: Contributions to children's autobiographical memory. *Developmental Psychology, 41*(2), 376–388. https://doi.org/10.1037/0012-1649.41.2.376.

Crowley, K., Callanan, M. A., Jipson, J. L., Galco, J., Topping, K., & Shrager, J. (2001). Shared scientific thinking in everyday parent–child activity. *Science Education, 85*(6), 712–732. https://doi.org/10.1002/sce.1035.

Distefano, R., & Meuwissen, A. S. (2022). Parenting in context: A systematic review of the correlates of autonomy support. *Journal of Family Theory & Review, 14*(4), 571–592. https://doi.org/10.1111/jftr.12465.

Duckworth, A. L., Tsukayama, E., & May, H. (2010). Establishing causality using longitudinal hierarchical linear modeling: An illustration predicting achievement from self-control. *Social Psychological and Personality Science, 1*(4), 311–317. https://doi.org/10.1177/1948550609359707.

Ennes, M., Wagner-Pelkey, A., & McVey, M. (2021). Museum-based online learning one year after COVID-19 museum closures. *Journal of Museum Education, 46*(4), 467–480. https://doi.org/10.1080/10598650.2021.1982221.

Gauvain, M. (2001). *The social context of cognitive development*. Guilford Press.

Geerdts, M. S., Van de Walle, G. A., & LoBue, V. (2015). Daily animal exposure and children's biological concepts. *Journal of Experimental Child Psychology, 130*, 132–146. https://doi.org/10.1016/j.jecp.2014.10.001.

Grolnick, W., Frodi, A., & Bridges, L. (1984). Maternal control style and the mastery motivation of one-year-olds. *Infant Mental Health Journal, 5*(2), 72–82. https://doi.org/10.1002/1097-0355(198422)5:2<72::AID-IMHJ2280050203>3.0.CO;2-O.

Grolnick, W. S., Gurland, S. T., DeCourcey, W., & Jacob, K. (2002). Antecedents and consequences of mothers' autonomy support: An experimental investigation. *Developmental Psychology, 38*(1), 143–155. https://doi.org/10.1037/0012-1649.38.1.143.

Grolnick, W. S., Raftery-Helmer, J. N., Marbell, K. N., Flamm, E. S., Cardemil, E. V., & Sanchez, M. (2014). Parental provision of structure: Implementation and correlates in three domains. *Merrill-Palmer Quarterly, 60*(3), 355–384. https://doi.org/10.13110/merrpalmquar1982.60.3.0355.

Gunderson, E. A., & Levine, S. C. (2011). Some types of parent number talk count more than others: Relations between parents' input and children's cardinal-number knowledge. *Developmental Science, 14*(5), 1021–1032. https://doi.org/10.1111/j.1467-7687.2011.01050.x.

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*(3), 333–344. https://doi.org/10.1016/j.ecresq.2014.04.004.

Harel, I., & Papert, S. (Eds.). (1991). *Constructionism*. Ablex Publishing.
Jant, E. A., Haden, C. A., Uttal, D. H., & Babcock, E. (2014). Conversation and object manipulation influence children's learning in a museum. *Child Development, 85*(5), 2029–2045. https://doi.org/10.1111/cdev.12252.
León, J., Núñez, J. L., & Liew, J. (2015). Self-determination and STEM education: Effects of autonomy, motivation, and self-regulated learning on high school math achievement. *Learning and Individual Differences, 43*, 156–163. https://doi.org/10.1016/j.lindif.2015.08.017.
Lerner, R. M., Schwartz, S. J., & Phelps, E. (2009). Problematics of time and timing in the longitudinal study of human development: Theoretical and methodological issues. *Human Development, 52*(1), 44–68. https://doi.org/10.1159/000189215.
Letourneau, S. M., & Bennett, D. (2020). Using narratives to evoke empathy and support girls' engagement in engineering Retrieved from. *Connected Science Learning, 3*(3). https://par.nsf.gov/biblio/10211271.
Maas, C. J., & Hox, J. J. (2005). Sufficient sample sizes for multilevel modeling. *Methodology: European Journal of Research Methods for the Behavioral and Social Sciences, 1*(3), 86–92. https://doi.org/10.1027/1614-2241.1.3.86.
Marcus, M., Tõugu, P., Haden, C. A., & Uttal, D. H. (2021). Advancing opportunities for children's informal STEM learning transfer through parent–child narrative reflection. *Child Development, 92*(5), e1075–e1084. https://doi.org/10.1111/cdev.13641.
Medina, C., & Sobel, D. M. (2020). Caregiver–child interaction influences causal learning and engagement during structured play. *Journal of Experimental Child Psychology, 189*, 104678. https://doi.org/10.1016/j.jecp.2019.104678.
National Center for O*NET Development. (2023, April 15). *O*NET OnLine.* https://www.onetonline.org/find/stem?t=0.
National Research Council (2009). *Learning science in informal environments: People, places, and pursuits*. National Academies Press.
National Research Council (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.
Ng, F.-F.-Y., Kenney-Benson, G. A., & Pomerantz, E. M. (2004). Children's achievement moderates the effects of mothers' use of control and autonomy support. *Child Development, 75*(3), 764–780. https://doi.org/10.1111/j.1467-8624.2004.00705.x.
NGSS Lead States (2013). *Next Generation Science Standards: For states, by states*. National Academies Press.
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. https://doi.org/10.1016/j.jecp.2020.104944.
Piaget, J. (1970). *Science of education and the psychology of the child*. D. Coltman, Trans.). Longman.
Pruden, S. M., Levine, S. C., & Huttenlocher, J. (2011). Children's spatial thinking: Does talk about the spatial world matter? *Developmental Science, 14*(6), 1417–1430. https://doi.org/10.1111/j.1467-7687.2011.01088.x.
Resnick, M., & Rosenbaum, E. (2013). Designing for tinkerability. In M. Honey & D. Kanter (Eds.), *Design. Make. Play: Growing the next generation of STEM innovators* (pp. 163–181). Routledge.
Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context*. Oxford University Press.
Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. Guilford Press.
Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology, 61*, 101860. https://doi.org/10.1016/j.cedpsych.2020.101860.
Singer, J. D., & Willett, J. B. (2003). Applied longitudinal data analysis: Modeling change and event occurrence. *Oxford University Press*. https://doi.org/10.1093/acprof:oso/9780195152968.001.0001.
Sobel, D. M. (2023). Science, technology, engineering, and mathematics (STEM) engagement from parent–child interaction in informal learning environments. *Current Directions in Psychological Science, 32*(6), 454–461. https://doi.org/10.1177/09637214231190632.
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*(3), e13057. https://doi.org/10.1111/desc.13057.
Sorariutta, A., Hannula-Sormunen, M. M., & Silvén, M. (2017). Maternal sensitivity in responding during play and children's pre-mathematical skills: A longitudinal study from infancy to preschool age. *European Journal of Developmental Psychology, 14*(1), 1–15. https://doi.org/10.1080/17405629.2016.1140641.
Vossoughi, S., & Bevan, B. (2014). *Making and tinkering: A review of the literature* (pp. 1–55). National Research Council Committee on Out of School Time STEM.
Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.
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*(5), e598–e617. https://doi.org/10.1111/cdev.13232.