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Parental Autonomy Support and Children's Stem Engagement During an At-Home Tinkering Activity

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PARENTAL AUTONOMY SUPPORT AND CHILDREN'S STEM ENGAGEMENT DURING AN AT-HOME TINKERING ACTIVITY

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ABSTRACT

Parents play an important role guiding children's learning of science, technology, engineering, and mathematics (STEM) in informal educational contexts. In this project, we considered the ways in which parents use autonomy supportive or controlling language to encourage or discourage children's independence in problem solving, as well as their feedback to children's ideas and behaviors. We looked at the association between autonomy support and children's behavioral, STEM, story, and emotional engagement during an at-home tinkering and storytelling activity. Parents and their 4- to 10- year old children were observed at home via Zoom. We coded parents' and children's behaviors using a time-sampling approach. Through a time-series analysis using Hierarchical Linear Models, we examined if parents' behaviors in one (1-minute) interval was associated to children's engagement in the activity in the next interval. We found that the more autonomy support parents offered in one minute of the activity, the more children talked about STEM concepts in the next minute. In addition, we found that these associations were bi-directional, such that children's STEM engagement was a predictor of parents' subsequent autonomy support. Controlling language had no associations to children's engagement and parental feedback had a bi-directional association to children's affective reactions. Finally, we found that prompting families to plan prior to the tinkering led parents to be more autonomy supportive over time compared to parents who were not prompted to plan.

Keywords: autonomy support, informal learning, STEM learning, tinkering, microanalytic approach

INTRODUCTION

Advancing early STEM (science, technology, engineering, mathematics) education is a national concern. STEM professionals are increasingly in demand to enhance the US innovation and competitiveness internationally. In addition, principles and practices of STEM are integral to most aspects of life, rendering knowledge of STEM vital to navigate day-to-day activities and dialogues (NRC, 2012). Still, many students do not recognize the importance of math and science to their lives (Aschbacher, 2010). Until relatively recently, attempts to encourage STEM education and career pursuits have targeted school curricula and teaching methods. Nevertheless, researchers, educators, and policy makers also recognize the importance of STEM learning opportunities in everyday out-of-school contexts (NRC, 2009).

Many informal STEM learning opportunities for young children are available in specially designed settings such as museum exhibits and programs created by informal STEM educators. A growing body of research indicates that designed settings and programs can offer families valuable opportunities for hands-on STEM engagement that can enhance children's understanding and interest in STEM (NRC, 2009). With the temporary closure of many informal learning institutions due to the COVID-19 pandemic, informal STEM educational opportunities proliferated online, with many museums and like informal learning institutions designing programming for children and families to engage in STEM activities at home. This project focuses on one such effort by the Chicago Children's Museum to provide opportunities for families to engage in tinkering at home.

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 (e.g., planning), and commonplace materials (e.g., cardboard and glue). These characteristics can make tinkering accessible to young and old, and individuals from diverse backgrounds. Tinkering encourages creativity and innovation to develop new solutions to problems in an open-ended manner. Tinkering can, to a considerable extent, draw on prior experiences and funds of knowledge, as families take part in many forms of tinkering in their everyday lives, such as playing with blocks or coming up with a new recipe (Pattinson & Montañez, 2020). Tinkering provides opportunities for STEM learning, and particularly, opportunities for families to engage in authentic practices of engineering, such as making, testing and redesigning.

In this project, we observed families tinkering at home while participating in a program designed at the outset of the pandemic by educators at Chicago Children's Museum. Our primary aim for this study is to advance understanding of the types of verbal behaviors parents use that can support children's STEM learning during tinkering. Our work is grounded in sociocultural theories that emphasize the crucial role of parent-child interactions in supporting children's learning (Gauvain, 2001; Rogoff, 1990, Vygotsky, 1978). In particular, parental scaffolding is characterized in terms of the extent to which parents' verbal behaviors encourage or discourage children's independence in problem-solving and decision-making (i.e., management language). This characterization of parental management language (e.g., Bindman et al., 2013; Clements et al., 2021; Kochanska et al., 1989; 1991) draws on Self Determination Theory (Ryan & Deci,

2017) as well as on research suggesting that management language can promote children's executive functioning (Bindman et al., 2013) and mathematics (Clements et al., 2021). We were also interested in the interplay between parental management language and feedback in children's engagement. Feedback may support children's sense of competence, which can promote greater engagement (Ryan & Deci, 2020). Using a microanalytic approach to examine parent-child interactions, we studied the extent to which these scaffolding strategies are associated to children's subsequent engagement during the activity.

In addition, we investigated potential associations among parents' behaviors, children's age, gender, and children's engagement. Children's age and gender can affect their engagement in learning, and parents may use different scaffolding strategies according to children's age and gender (Crowley et al., 2001; Marcus, 2016; Siegel et al., 2007). Yet, even within age groups and gender groups, there is still likely to be variability in parents' behaviors and in children's behaviors. We examined whether associations between parental guidance and children's engagement differed among boys and girls, and among children of different ages.

Finally, we examined whether prompting families to plan their creation prior to tinkering may affect parents' management language throughout the activity. Although tinkering is often characterized by a bottom-up approach to solving problems, making plans and predicting problems and solutions is also an effective strategy and skill for engineering learning (Brophy et al., 2008; Resnick & Rosenbaum, 2013). It is possible that planning may affect parents' feelings of confidence over the final project, which may affect management language during the activity.

The following sections offer an overview of the current literature regarding parents' conversational strategies that support children's learning during hands-on STEM activities and discuss autonomy support as a promising conversational strategy. We consider parental guidance in relation to children's age and gender, as well as planning in the context of a tinkering activity.

Conversational Strategies that Support Children's STEM Learning

According to sociocultural theories, children's cognitive development and learning occurs through social interactions with others, especially adults (Gauvain, 2001; Rogoff, 1990; Rogoff et al., 2018; Vygotsky, 1978). As children participate in the cultural practices of their communities, they gradually develop the skills needed to thrive in those environments with the guidance of experienced adults. Sociocultural theories emphasize the crucial role adults (and other more experienced interactional partners) play in children's learning. Bruner and colleagues (Wood et al., 1976) described how adults can *scaffold* children's learning by offering supports as children work toward achieving new skills and competencies

The emphasis on the social context of learning in everyday activities is grounded in sociocultural theories and has guided a growing literature concerning the ways that parents support children's STEM learning during hands-on activities in museums. The idea that learning is an active process that occurs through interaction with the environment has been around since the writings of Piaget (1952), and much research since his time has endorsed hands-on learning through manipulation and exploration. Following Piaget, museums and other informal learning institutions have focused on offering rich hands-on activities for young children's STEM learning. Moreover, constructivist notions about the importance of hands-on learning have been coupled with research focusing on the ways that parents scaffold children's hands-on learning through conversational interactions.

Parents' conversational scaffolding can be characterized in terms of content, that is, *what* parents talk about, and style, relating to *how* they talk with their children. The studies exemplified below demonstrate that both content and style of conversations are important to support children's learning.

Content of Parents' Talk with Children

STEM Talk

Consistent with sociocultural theories, parents' conversations about STEM during learning experiences, such as talking about numbers, spatial concepts, or engineering, are important sources of scaffolding that can enrich children's understanding of STEM. For instance, Levine and Gunderson (2011) found positive associations between parents' counting of observable objects when children were between 14-30 months old with children's knowledge of cardinal numbers at 46 months. In another longitudinal study, Pruden et al., (2011) found positive associations between parents' use of spatial language (i.e., language describing spatial properties of objects such as shape) when children were 14 to 46 months of age with children's spatial skills at 54 months of age.

Research in museums also indicates that hands-on activities can also result in better learning outcomes when paired with conversations about the experience (Acosta et al., 2021; Haden, 2010; Haden et al., 2014; Jant et al., 2014; Marcus et al., 2017). Acosta et al. (2021) examined parents' STEM talk, such as setting goals, planning, testing, redesigning, and math, with their children (5 to 10 years old) in a tinkering exhibit, as well as children's reflections on the experience immediately after. The researchers found that the more parents talked about STEM during tinkering, the more children talked about STEM in their reflections afterwards.

Similarly, Pagano et al. (2020) examined the effects of exhibit design in parent-child conversations and children's reflections on the experience two weeks later. The researchers found that programs with a clear goal and means for testing promoted more parent-child joint conversations about the engineering design process while building (e.g., setting goals, planning, testing, redesigning), and that these conversations were associated with children's independent talk about engineering when reflecting on their experiences two weeks later.

Explanations

Parents' explanations, such as causal explanations, abstract scientific principles, or associations to children's prior experiences, can advance children's learning during informal learning activities (Callanan & Jipson, 2001). Crowley et al. (2001) examined parent-child conversations in a museum exhibit and found that parents facilitated children's understanding of science by making associations with children's prior knowledge, using causal explanations, and explaining general principles. Children who explored a museum exhibit with their parents spent more time evaluating and focusing on the most important pieces of evidence compared to children who explored the exhibit alone or with peers, and they also remembered more information about the experience 2 weeks later.

To examine the role of causal explanations, Fender and Crowley (2007) observed parents' spontaneous causal explanations during an interactive science exhibit and children's conceptual learning in a posttest. Compared to children with parents who did not offered explanations, children with parents who spontaneously offered causal explanations showed better conceptual understanding (e.g., making connections between the exhibit device to related concepts and devices), as opposed to procedural understanding (e.g., how to make the device go faster). To explore the causal role of explanations, in a subsequent study, the researchers randomly assigned children to explanation or control conditions and found that children who received explanations in the exhibit were more likely to switch from procedural to conceptual understanding compared to children in the control group (Fender & Crowley, 2007).

Making associations with children's prior knowledge and prior experiences is also an effective strategy to support children's learning. Several studies have linked parents' conversational strategies that include associations to prior experiences with children's outcomes in learning and memory (Benjamin et al., 2010; Boland et al., 2003; Jant et al., 2014). These associations can help children contextualize their current experiences, which facilitates their understanding and make these experiences more meaningful.

Style of Parents' Talk with Children

Elaborative Style

In addition to scaffolding strategies that focus on the content of parents' conversations, some studies have examined the style of parents' conversations. Conversational style is characterized by a constellation of techniques that vary in terms of whether and how children's verbal participation is encouraged. One well-documented finding is that an elaborative style, a conversational approach characterized by many open-ended questions (e.g., "what", "why", "how") as well as building on children's answers, is conducive to children's learning. In the context of informal learning activities, a high elaborative style during the activity can contribute to children's STEM learning by inviting and encouraging their active participation in problem solving and advancing their understanding by elaborating on their answers. For example, in a study involving 4- to 7-year-olds, Jant et al. (2014) found that parents' who received conversation cards with open ended questions about the exhibit objects were more elaborative with their children during an exhibit experience than parents who did not. Moreover, the parents who received the conversation cards had children who engaged in the most spontaneous talk, the most non-verbal behaviors, and who remembered the most about their exhibit experiences 2 weeks later (Jant et al., 2014).

Similarly, in a building exhibit, Benjamin et al. (2010) found that, compared to families who only received building instruction or were presented with models, families who received elaborative conversational prompts engaged in more joint talk during building and had children who remembered more two weeks after the experience. Families who received both building instruction and conversational prompts prior to tinkering were more likely to build frame structure and engage in more STEM talk (see also Haden et al., 2014).

Pedagogical Questions

Pedagogical questions are another element of style that involves parents asking a question to which they already know the answer, in an effort to further their children's exploration and learning (Bonawitz et al., 2011**;** Daubert et al., 2020; Yu et al., 2017). Pedagogical questions can advance STEM learning more so than direct instruction because it encourages children to explore and find answers, whereas instruction may undermine exploration causing children to focus only on what is being taught (Bonawitz et al., 2011). Yu et al. (2017) assigned children between four to six years of age to different conditions of instruction, including direct instruction to press a button on a novel toy given to them, or receiving a pedagogical question by a knowledgeable adult (i.e., "what does this button do?"). Pedagogical questions were as effective as direct instruction in encouraging understanding of the function of the button, with the added advantage of furthering exploration and discovery of other functions.

In summary, evidence from numerous studies of parent-child interactions in informal environments illustrates the importance of parental guidance and inform best practices to support children's STEM learning. In the present study, we extent this work to consider other ways that parents provide guidance and support for children's learning. In specific, we draw on Self Determination Theory to consider how parents may support STEM learning through an autonomy supportive conversational style and feedback content. In the next section we offer a brief overview of Self Determination Theory with special attention to the concepts of autonomy support and structure in educational and informal contexts, and we consider how children's engagement might vary by age, gender, competence to execute the activity, and the task at hand – in this case, tinkering.

Self Determination Theory

Self Determination Theory (Ryan & Deci, 2017) provides a useful framework for understanding the different ways in which parents and educators may engage children in STEM learning. In this view, humans are inherently active, curious, and social, when their basic psychological needs for autonomy, competence, and relatedness are satisfied in their social context (Ryan & Deci, 2017, 2020). With their basic needs satisfied, individuals develop a more autonomous type of motivation, seeing their actions as motivated by their own values and desires, not by external factors. The more autonomous the motivation, the better the long-term outcomes in well-being, learning, and performance. In the educational context, when children are autonomously motivated to learn, they become more engaged in the activity; that is, autonomous motivation leads to more energy and effort put into the task (Deci & Ryan, 2008). Effort and energy can be observed in the form of behavioral hands-on participation, cognitive engagement (i.e., in the use of learning strategies), and emotional reactions towards the activity (Hospel & Galand, 2016; Jang et al., 2010).

Autonomy Support

Autonomy supportive behaviors promote children's initiatives and sense of autonomy. This contrasts with *controlling behaviors* that pressure children towards certain behaviors and outcomes by issuing directives, giving children answers or executing tasks for the child (Ryan & Deci, 2020). Some examples of autonomy supportive behaviors include encouraging children's initiative and active participation, offering meaningful choices, giving rationales for rules, and adopting children's perspectives (Hospel & Galand, 2016; Ryan & Deci, 2020).

Whereas coercion, pressure, and rewards, can result in controlled motivation and low engagement overall (Anderson et al., 1976; Gagné & Deci, 2005; Leonard et al., 2021; Ryan & Deci, 2020), autonomy support, along with structure and relatedness, facilitate the internalization of values leading to autonomous motivation and high levels of behavioral, cognitive, and emotional engagement (Hospel & Galand, 2016; Jang et al., 2010; Ryan & Deci, 2017). Furthermore, autonomy support is associated with a wide range of positive outcomes in parenting and education for children of all ages. For example, parental autonomy support is linked to infants' persistence during play (Grolnick et al., 1984), higher executive function in toddlers (Bernier et al., 2010; Bindman et al., 2015), math and spatial skills in toddlers and elementary school children (Cimon-Paquet et al., 2020; Sorariutta et al., 2017), and performance in school among 6th graders (Grolnick et al., 2014).

Autonomy support in the context of *parents' management language* can be characterized by statements, questions, and directions used to guide children's behavior (Bindman et al., 2013; Clements et al., 2021). Bindman et al. (2013) identified six types of management language that varied in the degree of choice offered to the child. Overall, management language could be categorized as either directions (high control) or suggestion (low control). Bindman and colleagues (2013) examined parents' management language in conversations with their preschoolers during an at-home structured task of planning a pretend birthday party, and its associations with children's executive function growth over the following three years. Parents' use of directives tended to decrease as children got older, and directives were negatively associated with children's executive function at age three. That is, children who heard more controlling language demonstrated lower executive function compared to the children who heard more autonomy supportive language. Nonetheless, the children with lower executive function showed faster growth in their executive functioning skill compared to children who heard more autonomy supportive management language. The authors suggest that parents may adapt their management language according to children's ability to self-regulate. In this way, parents of children with higher executive function do not need to use many directives, whereas parents of children with lower executive function may use more directives as a scaffolding strategy. It is possible that, in some cases, more directive language could support children's development.

Clements et al. (2021) examined associations between parents' management language and parents' number talk (i.e., counting, cardinal values, magnitude comparisons, and other quantitative statements) which is considered critical for children's development of mathematical thinking. Families with children between 2 to 4 years of age played with a kitchen set and a set of blocks in a semi-private area of a large public event. Parents who talked more about number with their children also used more autonomy supportive management language. This suggests that effective scaffolding strategies may typically cluster together.

Autonomy Support and Structure

Structure refers to ways in which parents and educators foster children's sense of competence in activities by providing what is needed to succeed and achieve the established goals (Ryan & Deci, 2020). Structure involves setting clear goals and expectations, having consistent rules, and providing rich feedback to support children's performance. However, structure can also be provided in a controlling manner. For example, when parents impose clear and consistent rules without offering a rationale and without taking children's perspectives into account, children may still develop competence in the task. But in this case, children may follow the rules out of external controlled motivation rather than autonomous motivation.

In the school context, *feedback* has been considered "one of the most powerful and readily available practices teachers can implement to improve student achievement" (Harbour et al., 2015, p. 9). While negative feedback can support learning providing accuracy to academic thinking, evidence suggests that focusing and prioritizing positive feedback leads to the best results (Harbour et al., 2015). Positive feedback is associated with several positive outcomes, including student achievement, behavior, and engagement in the classroom. Although praise and rewards can sometimes lead to external controlled motivation, a meta-analysis indicates that when reward is contingent on performance, it is less likely to diminish individuals' intrinsic motivation on task since it informs individuals about their competence in the task (Deci et al., 1999).

Jang et al., (2010) examined 9th to 11th grade classrooms during English, math, science, or social studies classes. Teachers' autonomy support and structure were positively correlated. In addition, both autonomy support and structure are related with students' motivation and engagement in learning (Hospel & Galand, 2016; Jang et al., 2010; León et al., 2015; Thomas & Mueller, 2017), but they may be associated with different aspects of engagement. For example, Hospel and Galand (2016) found associations between both autonomy support and structure in 9th graders emotional engagement during a French class, but only structure was associated with students' behavioral engagement.

Autonomy Support in Informal Educational Contexts

Despite this growing body of research in the school context, little is known about the associations between autonomy support and structure with children's engagement in informal learning environments, where children spend a significant amount of their time. Spaces such as libraries, museums, zoos, and homes, provide learning opportunities for children of all ages and backgrounds (NRC, 2009; Brophy et al., 2008). The appeal of informal learning comes at least in part from level of autonomy they offer. Whereas learning in the classroom is often required, tested, and instilled by direct instruction, informal learning is typically driven by natural exploration and discovery as individuals chose where to go, what to read, listen or watch, and how to participate. Furthermore, children can receive more personalized guidance through one-on-one interactions with their parents in informal learning spaces compared to their interactions with a teacher in the classroom setting. Investigating how parents naturally interact with and engage their children in informal learning can provide insights into the role of autonomy support and structure in this particular context.

There is evidence suggesting that parents' non-verbal controlling behaviors may weaken children's engagement in informal learning environments (Sobel et al., 2020; Willard et al., 2019). For instance, Willard et al. (2019) examined parent interactions with their children (ages 4 to 6) in a museum exhibit where families could build and test gears, and researchers also examined children's performance and engagement in a follow-up task. The study revealed that the more time children spent fixing gears in the exhibit, the more time they tended to spend in the follow up task, whereas the more time parents spent fixing and solving problems for their children, the less persistent children were in the follow-up tasks. Similarly, Sobel et al (2020) found that, in an exhibit about electric circuits, the more actions parents initiated prior to achieving a goal during free play, the less likely children (4 – 7 years old) were to succeed in follow-up tasks related to building electric circuits. However, to our knowledge no study has examined the associations between parents' autonomy supportive or controlling verbalizations in informal learning environments.

Children's Age, Competence, and Gender

Children's age, gender, and competence in the task can influence parental conversations during learning activities. For example, in a museum tinkering exhibit, Marcus (2016) found that parents of younger children talked more about STEM than parents of older children, suggesting that parents may adapt their scaffolding according to their child's needs. Crowley et al. (2001) found gender differences in parents' explanations during a science exhibit, with parents providing more explanations to boys compared to girls. In fact, other studies suggest that interaction style and its associations to children's engagement may differ across activity context, child's age, gender, and competence in the task (Ng et al., 2004; Siegel et al., 2007; Sobel et al., 2020).

One study suggests that older children may require more autonomy support compared to younger children. Sobel et al. (2020) observed 4- to 7-year-old children and their parents interact at an electric circuit exhibit, and categorized the dyad interactions as being parent directed, child directed, and joint directed. Whereas older children in the child-directed and joint-directed groups tended to show higher competence and engagement in the exhibit, older children in the parent directed group showed a different pattern: although their success increased, they engaged in fewer challenges. Older children may be more sensitive to the negative effects of parental control. Conceivably this may be because as children grow they develop expectations of receiving more autonomy, and interpret parents' controlling behaviors as an indication that they are not competent in performing the task on their own (Leonard et al., 2021; Sobel et al., 2020). More research is needed to confirm whether older children may be more sensitive to the effects of autonomy support.

Antithetical to this notion, however, is evidence suggesting that parents' autonomy supportive and controlling behaviors appear to have a greater association with engagement for children with low competence compared to children with average or high competence in the task. Ng et al. (2004) examined the interactions of mothers and their 7 to 10 years old children while working on a task of findings strings of digits in a grid of digits. Mothers' controlling and autonomy supportive behaviors predicted engagement in the activity only for children who demonstrated low or average performance during the first four minutes of the task, but not for children who demonstrated high competence. One possible interpretation is that children with higher skills have a heightened sense of competence which increases their intrinsic motivation in the task, whereas children with lower skill may require more autonomy support to engage.

Children's gender could also be an important factor to consider when examining associations between parental scaffolding and engagement. According to Self Determination Theory, basic needs for autonomy and competence are universal; hence, associations between autonomy support and structure with children's engagement should exist regardless of gender. However, one study identified gender differences in the school context. Lietaert et al. (2015) examined differences between 7th grade boys and girls from 59 Dutch schools and found that boys were overall less engaged in classes than girls, and that teacher's autonomy support was associated to engagement for boys but not for girls, whereas structure was equally associated to engagement for both groups. Lietaert and colleagues suggest that boys may have been less motivated and required more autonomy support to engage than girls because the school practices, with intense use of verbalizations and language, may be more suitable to girls. Another possible explanation is that girls may be more likely to put effort into boring tasks compared to boys. Arguably, these gender differences in informal learning contexts may be less pronounced, as these environments offer more opportunities for playful hands-on activities that are likely attractive for both boys and girls.

Tinkering and Planning

Tinkering can be an ideal context to investigate the associations between parental autonomy support and structure and children's STEM engagement. First, as a context full of opportunities for hands-on participation, we can examine the different aspects of children's engagement (i.e., behavioral, cognitive, and emotional) during the experience. In addition, tinkering involves rich problem solving and decision making, facilitating the observation of parental behaviors that scaffold, and encourage or discourage children's autonomy in the process. The open-ended nature of the activity may also suggest that autonomy support is all the more important to foster children's STEM engagement in this context (Grolnick et al., 2002).

In fact, a study conducted by Grolnick et al. (2002) indicates the autonomy support can have a stronger association to children's learning performance in more open-ended activities compared to more structured ones. In this study, mothers and their third-grade children worked together on two tasks, namely, writing a poem and solving a spatial map problem, and afterwards children were asked to perform similar tasks on their own. The negative effect of mothers' controlling behavior on children's later performance was stronger for the poem task compared to the map task. This suggests that children may be more sensitive to autonomy supportive and controlling behaviors during open-ended activities (i.e., activities in which there are many options and possible right answers) compared to more structured close-ended activities (i.e., activities with only one of few right answers). Possibly, because in close-ended activities there are one of very few ways to succeeded (i.e., few correct answers), performing well and sustaining a sense of competence may be more relevant to children than having a sense of autonomy and choice.

We were also interested in how planning before tinkering may affect the parent-child interaction during the 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. The question is whether prompting planning prior to tinkering may lead to a different pattern of parental scaffolding. One possibility is that during planning dyads would jointly develop goals and steps to accomplish the goals. In turn, parents might use more directive and controlling language during the building stage. On the other hand, a lack of planning may increase parents' worries or concerns over the final product affecting how they manage their children's behaviors. In the study conducted by Grolnick and colleagues (2002), mothers in the poem task who were told that their children would be evaluated were more controlling than mothers who did not receive this high-pressure treatment before the activity (see also Grolnick et al., 2007). Therefore, another possibility is that by planning first, parents may feel less pressured or worried about the end result and may grant children more autonomy and independence to make decisions and solve problems while building.

Current Study

The current study was designed to explore parents' conversational style, as characterized by management language, and conversational content, as characterized by feedback, in association to children's engagement during a STEM learning activity. The data is part of a larger research project in partnership Chicago Children's Museum that focuses on tinkering and storytelling. Parent-child dyads watched a video introduction to an activity and then were observed via Zoom as they tinkered using materials available to them at home. The video instructed families to build a playground ride for a toy friend and to create a story about the toy and the ride. We were interested in how parents' verbalizations might be associated with children's hands-on engagement, STEM engagement, story engagement, and affective engagement during the activity.

To this end, we used Hierarchical Linear Models (HLM) to conduct a time-series analysis examining effects within and between dyads. These analyses were conducted using the software HLM6. The analysis within dyads consists of a series of 1-minute intervals in which parents' management language and feedback were used as predictors of children's engagement in the subsequent interval. Our data set is designed with lagged variables, such that the scores for parents' behaviors each interval match children's engagement in the following interval. Regression lines are created for each dyad, with unique intercepts and slopes, to test whether the associations of parents' behaviors in one interval and children's engagement in the next are significant. For between dyads effects (i.e., level-2 variables), we used children's age, gender, and planning condition as predictors of the intercepts and slopes of the within dyads regression lines, testing whether the association between parents' behaviors and children's engagement vary as a function of these between-subject variables.

Using HLM analysis yields several advantages to nested data such as this compared to more traditional approaches such as ANOVAs and multiple regression (Raudenbush & Bryk, 2002). First, it does not assume independence of observations, of error terms, or homogeneity in variance for all observations. It also does not require that each participant have the exact same number of time points measured. Above all, it allows for the examination of cross-level effects, so that we can examine the effects of parents' behaviors in children's engagement (level-1) while also accounting for the effects of level-2 predictors such as treatment condition, children's age, or gender on the outcome variable.

We advanced the following research questions and hypotheses:

1. What is the association between autonomy parental support, control, and feedback during a tinkering activity?
    a. We hypothesized linear positive association between autonomy support and feedback.
    b. We hypothesized linear negative association between autonomy support and control.
2. What is the interplay between autonomy support and feedback on children's engagement? Are both concepts equally associated with engagement or are they associated with different aspects of engagement?
    a. We hypothesized that autonomy support would be a stronger predictor of children's STEM, emotional, and story engagement, whereas parental feedback would be a stronger predictor of children's behavioral engagement.
3. Are children's age and gender predictors of engagement? Are there interaction effects between parents' verbal behaviors and children's age and gender?
    a. We hypothesized that parental autonomy support and control would be stronger predictors of engagement for older children compared to younger children, whereas feedback would be a stronger predictor of engagement for younger children compared to older children.
    b. We hypothesized that autonomy support and structure would be equally associated with engagement for both boys and girls.
4. Does prompting families to plan prior to tinkering leads to different patterns of parental management language over time in the interaction?

   a. We hypothesized that parents in the no-planning condition would use less autonomy support and more control over time compared to parents in planning condition.

5. Can children's level of engagement also predict parental use of autonomy supportive or controlling management language?
   a. We hypothesized a bi-directional relationship between parental behaviors and children's engagement. We expected that low engagement would predict more subsequent controlling language, whereas high engagement would predict more autonomy supportive management language.

METHOD

Participants

Children in the study were between the ages of 5 and 10 years old (*M* = 8.10, SD = 1.72). A total of 64 children and their parents consented to participate (12 fathers, 52 mothers), although only data from 61 (31 male, 30 female children) were analyzed in this study 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 some observations also included a sibling. Detailed demographic information is presented at Table 1. All participants received a $25 gift card for their participation in the study.

Procedures

General procedures

Participant families were observed individually via Zoom. Families were asked to gather materials prior to the Zoom meeting, such as cardboard, recyclables, string, glue, tape, etc. At the beginning of the session, the researcher showed the family a video created by our collaborators at Chicago Children's Museum, introducing the tinkering challenge of creating a playground ride for a small toy friend (https://youtu.be/PRTwI9vDFoM). In the video, a museum educator introduced 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 instruction also described the engineering process of making, testing, and fixing the creation, and provided an example of a swing made out of recyclables.

Table 1. Participants' Demographic Information

Teeny Tiny Playground Program (N= 61)	
Child *M* age (SD)	8.10 (1.72)
Range	5 - 10
Sex	
Male	30
Female	31
Child Race/Ethnicity	
Caucasian	33 (54%)
African American/Black	9 (15%)
Asian	5 (8%)
Hispanic/Latino	3 (5%)
Mixed	10 (16%)
Not reported	1 (2%)
Parent Race/Ethnicity	
Caucasian	40 (65%)
African American/Black	8 (13%)
Asian	7 (11%)
Hispanic/Latino	1 (2%)
Mixed	4 (7%)
Not reported	1 (2%)
Parent 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%)
Ph.D., Law, 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%)

After participants saw the video, the researcher explained to all families that they would have thirty minutes to complete the tinkering activity and asked them to work together as they normally would. At this point, researchers would turn off their camera and microphone, and turn on the thirty-minute timer. After 30 minutes, all families were given the option to take up to another 5 minutes to finish up. At the conclusion of the tinkering activity, the researcher turned the camera and microphone on and asked the children questions about their story and about the activity (this interview was not analyzed for this study). After the interview, researchers collected demographic information from the parents.

Planning conditions

The manipulation of planning condition came immediately after showing the video introducing the tinkering challenge. Families were randomly assigned to one of two conditions. In the planning condition, right after showing the video and before turning on the 30-minute timer, the researcher asked the family to take some time to plan the playground ride and the story they would tell about the toy and the ride; specifically, families were asked to choose a toy friend and decide what ride they would make and how they would make the ride fun and safe. In the no-planning condition, the researcher told families they could start the tinkering activity immediately after the video.

Coding

We used a time sampling coding method to code parents' behaviors and children's engagement in 5 seconds intervals. Each 5-second interval was then summed and aggregated into 1-minute intervals. This way, parents' scores for management language scales (0-3) and feedback scale (0-3) each minute can range from 0 to 36 (12 intervals x max 3 points/interval).

Scores of child's engagement level (0-1) can range between 0 to 12 each one-minute interval (12 intervals x max 1 point/interval).

To establish inter-rater reliability, two researchers coded 20% of the observations independently. For parents' behaviors, the kappa for overall identification of parents' behaviors was k = .80, the discrimination between management language and feedback was k = .81, the agreement across the six categories of management language was k = .78, and agreement on the feedback scale was k =.79. For children's engagement, the kappa for overall identification of engagement was k = .75, and the discrimination between different types of engagement was k = .87.

Parents' management language

We coded parents' autonomy support and controlling behaviors using a management language coding scheme adapted from Bindman et al. (2013). Parents' utterances containing a direction or question that had implications for the child's subsequent behaviors or for the outcome of the project was rated according to an autonomy support or controlling scale. We divided the management language types from Bindman et al. (2013) into 2 scales (1- 3) for autonomy support and controlling language, allowing us to better examine the effects of each scale on children's subsequent engagement.

Controlling language. Each interval, controlling utterances were rated on a scale from 1 (least controlling) to 3 (most controlling). Explicit directions (e.g., "go get your toy friend") were coded as 3. Qualified directions, which are explicit directions with a qualifying question at the end (e.g., "we will do the one on this side now, right?"), were rated as 2. Finally, ambiguous suggestions, or statements in which it is not clear whether the child had a choice (e.g., parent says “can you test it now?” while already arranging for the toy to be tested), were coded as 1.

Autonomy supportive language. Autonomy supportive management language was coded each interval on scale from 1 (least autonomy supportive) to 3 (most autonomy supportive). Parents’ transfer statements, which transferred to the child full autonomy to make decision (e.g., “What do you want to make?”, “it is up to you”) were rated as 3. Utterances that offered a suggestion with clear choice to accept it or not were rated as 2 (e.g., “you could use the strings to make stairs”). Utterances that offered a limited number of options to the child (e.g., “we can cut holes or add things on top”) were rated as 1.

Parents’ Structure

We developed a coding scheme to capture parental structure characterized by feedback. To differentiate from codes in management language, feedback codes captured only evaluations of the project or of child’s idea that did not imply suggestions or directions to the child. Parents’ feedback was rated on a scale from 1 to 3, varying on the degree to which the feedback may support children’s *sense* of competence. Negative feedback with information about problems (e.g., “I think this is a bit too short”) was coded as 1. Praise and encouragement (e.g., “great idea”, “good job!”) were rated as 2. Feedback that involved evaluations with explanations (e.g., “It is kind of safe because it isn't 100% slippery”) were rated as 3.

Children’s Engagement

We developed a coding scheme to capture children’s engagement across the four categories described below. We coded each 5-second interval in which the child expressed engagement (present/absent) in the form of:

Behavioral engagement. we coded each interval in which the child engaged in non-verbal engineering practices of building, improving, or testing their project. Building and improving actions include cutting/tearing, adding/attaching, drawing, and removing parts of the project. Testing behaviors involved placing the toy in the ride and letting it go, or clearly testing parts of the project during building.

STEM Talk. We coded each interval in which the child's utterance demonstrated high level of cognitive engagement in STEM talk. This included comparing different materials (e.g., "cardboard is stronger", "the strings are not even"), problem solving (e.g., "we need cardboard to make it sturdier"), planning and setting goals ("We could build a seesaw", "we could use these pieces as walls"), talking about science or math (e.g., "I think we just need to add more weight to balance", "I just need five more pieces"), asking or offering explanations ("why is it getting stuck?"), reflecting and evaluating (e.g., "it is safer now that we've taped it").

Emotional Engagement. We coded each interval in which the child expressed emotional engagement such as excitement or frustration (e.g., claps, yells, laughs, jumps). It also included utterances about their wants, feelings, likes and dislikes, and utterances asking to continue building after the zoom session or asking to build more than one playground ride.

Story Engagement. As this activity involves storytelling, we coded story engagement each interval in which the child named the toy character, talked about character's tastes, thoughts, actions and conflicts. It also included pretend play with character and talking about the setting of the story.

RESULTS

Preliminary Analyses

Descriptive analyses of families' time spent tinkering and overall scores for the main coded variables were conducted to identify the distribution of data and possible outliers. Time spent tinkering ranged from 12 to 41 minutes, and the average was 31 minutes (*SD* = 6.22). Since families varied in the amount of time spent tinkering, we examined the proportion of the scores per minute in most of the variables of interest except for story and emotional engagement. We used the total score during the activity for story and emotional engagement because they were low occurring and uncorrelated with time spent in the activity.

We identified one outlier (Z-score > |3|) for each of the following codes: autonomy support, feedback, STEM engagement, and emotional engagement. (For feedback and STEM engagement, the outlier scores were from the same family). To maintain the relative order of the data, these four outlier scores were recoded to the next highest score (Osborne & Overbay, 2004). Table 2 displays descriptive statistics for the continuous variables coded. Correlations between the coded variables are shown in Table 3**.**

We conducted independent-sample *t*-tests to examine whether participants' assigned condition (planning, no planning) had an effect in any of the coded variables and found no significant differences across groups. We also examined associations between coded variables and participants demographic variables as reported below.

Table 2. Participants' Demographic Information

Variable	Mean (SD)	Range	Skewness	Kurtosis
		Proportion of scores per minutes		
Autonomy support	3.73 (1.39)	0.18 – 7.45	0.63	0.99
Control	2.34 (1.52)	0.28 – 5.96	2.10	-0.99
Feedback	1.07 (0.56)	0.25 – 2.49	2.76	-0.03
Behavioral	1.02 (0.52)	0.13 – 2.09	1.50	-1.22
STEM	0.97 (0.40)	0.16 – 2.05	1.94	0.57
		Total score		
Emotional	11.80 (9.55)	0 – 37	2.67	0.20
Story	8.20 (6.80)	0 – 26	2.63	-0.10

Table 3. Correlations Among Coded Variables

	1.	2.	3.	4.	5.	6.
1. Autonomy	-					
2. Control	-.14	-				
3. Feedback	.17	.03	-			
4. Behavior	-.10	-.14	.38**	-		
5. STEM	.33*	-.15	.18	.27*	-	
6. Emotion	.13	-.04	.11	.20	.34**	-
7. Story	.16	.01	.00	-.06	-.07	.34**

Note. * Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed)

Gender

Children's gender was associated to their engagement as shown in Table 4. Specifically, girls showed higher STEM engagement, $t(58) = 2.62$, $p = .011$, and emotional engagement, $t(58) = 2.83$, $p = .006$, compared to boys. There were no significant differences in time spent in the activity by gender, $t = 0.02$, $p = .49$. Since emotional engagement was skewed and had a bimodal distribution, we ran a Chi-Square test using a dichotomous variable for emotional engagement based on a median split. The results confirmed a greater proportion of girls in the high emotional engagement group compared to boys, X^2 (1) = 7.28, p = .007. Therefore, we controlled for child gender in main analyses of STEM and emotional engagement.

Table 4. Main Variables by Child Gender

Variable	Males Mean (*SD*)	Females Mean (*SD*)	*t*	*p*
	Proportion of scores per minute			
Autonomy support	3.42 (1.38)	3.91 (1.22)	1.45	.15
Control	2.61 (1.77)	2.08 (1.20)	1.37	.17
Feedback	0.97 (0.48)	1.13 (0.58)	1.11	.27
Behavioral	0.91 (0.49)	1.12 (0.53)	1.57	.12
STEM	0.82 (0.40)	1.07 (0.31)	2.62	.01
	Total score			
Emotional	8.50 (7.8)	15.10 (10.11)	2.83	.006
Story	7.41 (6.42)	8.94 (7.17)	0.86	.39

Child's Age

We examined associations between children's age and the main variables of interest using independent-samples t-tests. Since children's age was negatively skewed, we transformed it into a dichotomous variable based on a median split. The younger age group was on average 6.74 years old (range = 5 – 8), and the older age groups was 9.5 years old (range = 9 – 10). There was a difference on parents' autonomy support based on child age, t(58) = 2.59, p = .012. Specifically, parents were displaying more autonomy support with younger children (M = 4.08, SD = 1.29) compared to older children (M = 3.25, SD = 1.21). Therefore, we included child's age in the main analyses of autonomy support.

Parents' STEM job

Parents' report of their occupation was coded as being STEM-related or non-STEM-related based on the US Department of Labor database of jobs (National Center for O*NET

Development, 2020). Some examples of STEM occupations coded in our sample were software engineer, research assistant, nurse, statistician. We ran independent-samples t-tests to examine if there was a mean difference in the variables coded between the two groups of occupations. We found a significant difference in children's STEM engagement based on parents' STEM occupation, $t(58) = 2.63$, $p = .01$. Specifically, children with parents in STEM related jobs showed higher STEM engagement ($M = 1.11$, $SD = 0.30$), compared to children with parents in non-STEM occupations ($M = 0.85$, $SD = 0.39$). Therefore, we added parents' STEM occupation as a covariate in our main analyses of children's STEM engagement.

Family Income and Parental Education

Descriptive statistics of family income and parents' education is provided in Table 1. To examined correlations between income and education as well as income and the coded variables we conducted a Spearman's rho test. Family income and education were not correlated, $r_s(55) = .09$, $p = .51$. We found a significant correlation between income and children's behavioral engagement, $r_s(55) = .40$, $p = .002$. We also examined associations between parents' years of education ($M = 17.90$, $SD = 2.59$) and the coded variables using Pearson correlation test. Results indicate a significant correlation between parents' education and time spent tinkering, $r(58) = .33$, $p = .01$, children's story engagement, $r(57) = .26$, $p = .042$, and children's emotional engagement, $r(57) = .27$, $p = 0.04$. We controlled for family income in main analyses of behavioral engagement and controlled for parental education in main analyses story and emotional engagement.

Ethnicity

Frequencies of parents' and children's ethnicity is provided in Table 1. To examine potential differences in the coded variables based on ethnicity, we conducted analyses of variance (ANOVAs) using parents' and children's ethnicity as a factor and children's engagement or parental behaviors as dependent variables. The analyses revealed no significant differences among children or parents' ethnicity group in the coded variables.

Main Analysis

Hypothesis 1

The first hypothesis was that parental autonomy support and parental feedback would be positively associated. The data did not support this hypothesis. As shown in Table 3, the two variables were not correlated. A scatterplot of the two variables showed no linear or curvilinear trends. Still, we examined the possibility of a curvilinear association by running a multiple regression analysis with autonomy support as the dependent variable and both feedback and a quadratic feedback term as predictors. The predictors did not explain significant amount of variance in autonomy support, $R^2 = .07$, $p = .13$, suggesting that in this sample, autonomy support and feedback were not associated.

Hypothesis 1b was that parental autonomy support would be negatively associated with parental control. The two variables were not linearly correlated as we predicted. However, we tested for curvilinear effects by conducting a multiple regression analysis with a quadratic effect of control and the quadratic effect was significant as shown in Table 5. That is, at low levels of control, there was a positive association between autonomy support and control, but at high levels of control the association was negative as expected.

Table 5. Regression Analysis Summary for Control Predicting Autonomy Support

Variable	Unstandardized Coefficients		Standardized Coefficients		
	B	*SE*	*β*	*t*	*p*
Constant	5.21	.88		5.95	<.001
Age	-.27	.09	-.35	-2.96	.004
Control	.96	.40	1.11	2.41	.02
Control^2	-.21	.07	-1.40	-3.02	.004

Note. $F(3, 57) = 6.11$, $p < .001$, $R^2 = .25$

Hypothesis 2

Hypothesis 2 predicted that high levels of parental autonomy support and feedback in one interval would be associated with higher levels of children's engagement in the following interval, whereas high levels of parental control would have the opposite effect. Specifically, we hypothesized that parental autonomy support would be a better predictor of children's STEM, emotional, and story engagement, whereas parental feedback would be a stronger predictor of children's behavioral engagement. To test this hypothesis, we ran several HLM analyses each using a different measure of engagement as the outcome variable. We first created a null model (i.e., model with no predictors) for later comparison, and then we added parental behaviors as predictors one at a time using deviance statistics to compare goodness-of-fit for each model. For a summary of all HLM analyses, see Supplementary Materials. We only found significant results when modeling children's STEM and emotional engagement, as described in the following two sections.

STEM Engagement. The data partially supported our hypothesis, as the most parsimonious model for STEM engagement included parental autonomy support, $\beta_{10} = 0.03$, $p < .001$, and time, -0.01, $p < .001$, as level-1 predictors. Although feedback showed a positive association with STEM engagement, β_{20} 0.04, $p = .003$, it did not significantly improve the model with only autonomy support, $X^2(1) = 0.37$, $p > .05$. As shown in Figure 1, when all parental behaviors were entered as level-1 predictors, only autonomy support and feedback showed a positive significant association to STEM engagement, whereas control showed a negative but non-significant effect. To account for children's gender, age, and parents' STEM occupation, we included those variables as level-2 predictors in the final model. In addition, as shown in Figure 2, we tested random slopes for autonomy support and time, and only a random effect of time was found, $\sigma^2_1 = 0.01$, $p = .005$, suggesting that the slopes based on time varied significantly across participants. The final model is illustrated in Equation 1.

$$STEM = 0.83 + 0.07*AGE + 0.19*GENDER + 0.33*STEM\ JOB \quad (1)$$

$$+ 0.03*AUTONOMY - 0.01*MINUTES + 0.44_i + 0.01*MINUTES_i + 0.1_i$$

Figure 1. Associations Between Parental Behaviors and Children's Subsequent STEM Talk

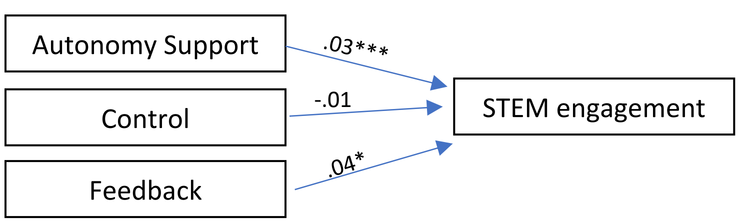
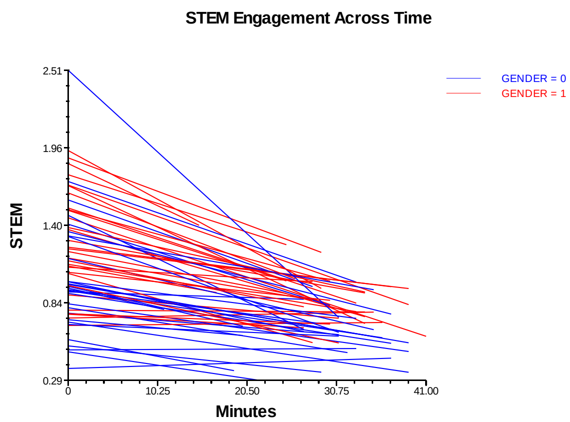


Figure 2. Random Slopes of STEM Engagement Across Time



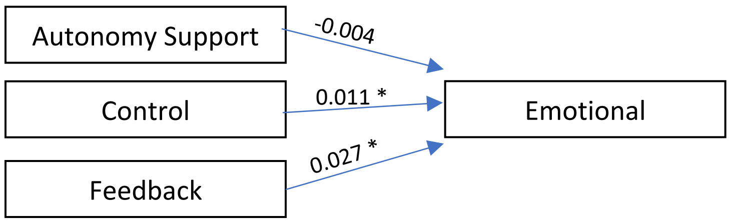
Note. Boys = gender 0, girls = gender 1.

Emotional engagement. Contrary to our hypothesis, feedback but not autonomy support, showed a significant association to children's emotional engagement. In the final model, only parental feedback, $\beta_{10} = 0.03$, $p = .03$, and time, $\beta_{20} = 0.01$, $p < .005$, were included as level-1 predictors of children's emotional engagement, after controlling for child's gender and parental years of education. Although control had a positive association with emotional engagement, as shown in Figure 3, the model was worse than the null model, X^2 (1) = -2.01. The intercept for children's emotional engagement was not significantly different from zero. We also tested for random slopes in feedback and time and found a significant random effect of slope based on time, $\sigma^2{}_1 = 0.01$ $p = .023$, suggesting that the effects of time in emotional engagement varied across participants. The final model is described in Equation 2. Interestingly, in a multiple regression analysis of the overall interaction, none of the parental behaviors were significant predictors of children's emotional engagement after controlling for children's gender and parental education.

$$EMOTIONAL = 0.07 + 0.23*GENDER - 0.004*EDUCATION \quad (2)$$

$$+ 0.03*FEEDBACK + 0.01*MINUTES + 0.03_i + 0.01*MINUTES_i + 0.67_i$$

Figure 3. Associations Between Parental Behaviors and Children's Subsequent Emotional Engagement



Hypothesis 3a

We hypothesized that parental autonomy support and control would be stronger predictors of engagement for older children compared to younger children. On the other hand, we predicted that feedback would be a stronger predictor of engagement for younger children. To test this hypothesis, we ran models for children's engagement using age as an interaction term with autonomy support, control, and feedback separately in each model. We found no models better than the null model with a significant interaction between children's age and parents' behaviors. When examining STEM engagement, we found a marginally significant negative interaction between age and parental control, $\beta_{11} = -0.005$, $p = .069$, suggesting that controlling language may have greater negative effect for older children compared to younger children. We also found a positive interaction between age and parental feedback, $\beta_{11} = 0.01$, $p = .042$; however, these models were not better than the null model. We also divided participants in 2 different age groups based on a median split, since our age variable was positively skewed. Still, we found no significant interactions. Therefore, contrary to our hypothesis, we cannot reject the null hypothesis that children's age does not interact with parental behaviors when predicting their engagement.

Hypothesis 3b

It was hypothesized that autonomy support and feedback would predict children's engagement for boys and girls similarly. To test this hypothesis, we ran models using the measures of children's engagement as outcome variables and using gender as an interaction term with parental behaviors. In line with our hypothesis, we found no interaction effects between gender and parental behaviors as predictors of any type of engagement, suggesting that the effects of parental behaviors on children's engagement did not differ based on children's gender.

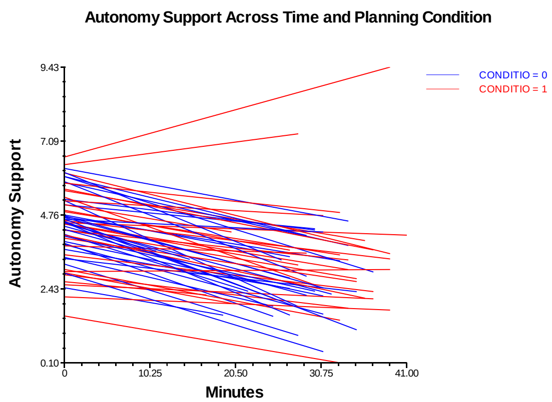
Hypothesis 4

Hypothesis 4 stated that the pattern of parental management language over time would differ based on the assigned condition, and that parents in the planning condition would have a smaller decrease in autonomy support across time compared to parents in the no-planning condition. The findings supported this hypothesis, showing that parents tended to use less autonomy support across time, $\beta_{10} = -0.07$, $p < .001$; however, parents in the planning condition had a slower decrease over time than to parents in the no-planning condition, $\beta_{11} = 0.04$, $p = .048$, after controlling for children's age and gender. In other words, the negative slopes were steeper for parents in the no-planning condition as shown in Figure 4. In addition, we found a significant effect of random slopes, indicating that the slopes varied across participants, $\sigma^2_1 = 0.05$, $p = .003$. The final model is illustrated in Equation 3.

$$AUTONOMY = 4.23 - 0.24*AGE + 0.67*GENDER - 0.32*CONDITION \quad (3)$$

$$- 0.07*MINUTES + 0.04*CONDITION*MINUTES + 1.27_i + 0.05*MINUTES_i + 3.23_i$$

Figure 4. Random Slopes of Autonomy Support Over Time Across Conditions



Note. Planning condition = 1, No-planning condition = 0.

When examining parental control, we found only a main effect of time, $\beta_{10} = 0.03$, $p = .002$, suggesting that parents tended to use more controlling language overtime, but no main effect of condition, $\beta_{01} = -0.60$, $p > .05$, or interaction between time and condition, $\beta_{11} = 0.004$, $p > .05$. In the final model, we again found a significant random slope effect suggesting that the slopes varied across participants, $\sigma^2_1 = 0.06$, $p < .001$. The final model is expressed in Equation 4.

$$CONTROL = 1.76 + 0.03*MINUTES + 1.10_i + 0.06*MINUTES_i + 2.89_i \quad (4)$$

Hypothesis 5

We hypothesized that children's engagement in one interval could also predict parents' management language in the subsequent interval. To examine this, we ran separate HLM models having parental autonomy support and parental control as outcome variables, children's engagement as level-1 predictors, and we controlled for time by adding that variable as a level-2 predictor.

Autonomy support. Only children's STEM engagement was a significant predictor of parents' autonomy support in the next interval, $\beta_{10} = 0.315$, $p < .001$, after controlling for time. As we hypothesized, higher STEM engagement in one interval, was associated with higher parental autonomy support in the next minute The final model is described in Equation 5.

$$AUTONOMY\ SUPPORT = 3.72 - 0.26*AGE_i + 0.57*GENDER_i \quad (5)$$

$$- 0.04*MINUTES_{ij} + 0.31*STEM_i + 1.22_i + 0.05*MINUTES_i + 3.22_i$$

Control. We found no significant associations between the categories of children's engagement with parental control. Although children's emotional engagement appeared to have a positive effect on parents' controlling language, that association was no longer significant once we added random slopes for the association between time and control. The more parsimonious model was the one with only time as a predictor with random slopes, as described previously in Equation 4.

Feedback. We found that children's emotional engagement, $\beta_{10} = 0.15$, $p = .02$, and time, $\beta_{20} = .102$, $p > .05$, were positively associated with parental feedback. Although children's STEM engagement also showed a positive association, the variable did not improve the model. We tested for random slopes and found a random effect of emotional engagement; however, the reliability estimates for emotional coefficient were 0.28, which is considered low. Therefore, we kept the slopes fixed in the final model. Equation 6 illustrates the final model.

$$FEEDBACK = 0.78 + 0.1*\ MINUTES_{ij} + 0.15*EMOTION_i + 0.53_i \quad (6)$$

$$+ 1.54_i$$

DISCUSSION

We investigated moment-to-moment associations between parental autonomy support, control, and feedback, with children's engagement during a tinkering activity. We used HLM analyses with a lagged design to examine associations between parental behaviors in one 1-minute intervals with children's engagement in the subsequent interval. Based on Self Determination Theory (Ryan & Deci, 2020), a sense of autonomy and competence promote greater effort in the task; hence, we expected that higher autonomy support and feedback would be associated with greater engagement, whereas controlling language would predict lower subsequent engagement. Overall, autonomy support and feedback showed some positive associations with children's engagement. However, contrary to what we expected, we found no associations between parental control and children's engagement.

One of the strengths of this study is our innovative statistical analyses. Rather than establishing associations between parents' overall behavioral scores with children's overall engagement scores through the whole interaction, we implemented a micro analytic approach using HLM looking at these associations in moment-to-moment interactions. This approach offers several advantages to the regression analyses traditionally used. First, by not aggregating behaviors to the individual level, we are able to examine individual variability across time. By doing so, we are able to use individuals as their own control when examining time-varying changes in the outcome variable based on a time varying predictor, ruling out confounding influences at the individual level such as individual traits (Duckworth et al., 2010).

In addition, by using a time-lagged design, we can establish temporal precedence of our predictors in relation to our outcome variable, strengthening the argument of an influence over the dependent variable. Whereas traditional regression analyses may be explained as associations between parents' and children's traits, this method provides robust evidence that changes in autonomy support relate to changes in children's engagement. Finally, HLM allows us to model cross-level effects, examining how variables at the individual-level affects the moment-to-moment associations.We further examined different aspects of children's engagement, the roles of children's age and gender in these associations, the effects of planning condition on parental behaviors, and bidirectionality between parents' behaviors and children's engagement. In what follows, we provide a summary of the main findings in connection to prior work, as well as a discussion of the limitations and future directions.

Autonomy Support, Feedback, and Control

Our first research question in this study was about the associations between parental autonomy support and feedback during a tinkering activity. We hypothesized that these two constructs to be positively associated, since prior research suggests that effective scaffolding strategies tend to cluster together (Clements et al., 2021), and that that teacher autonomy support and structure tend to be positively associated (Aelterman et al., 2019; Hospel & Galand, 2016; Jang et al., 2010). We expected that parents who offered more autonomy support would elicit more verbal and non-verbal responses from children, which in turn would increase opportunities for parents to provide children with feedback. However, our results did not support our hypothesis, as we found no associations between parental autonomy support and feedback.

Our null finding seems to contrast previous studies in the school context, but there are several possible explanations. First, it is plausible that some parents who provide children with high autonomy support also provide frequent feedback, while others take a more trial and error approach, letting their children test different ideas and receive feedback from the physical environment. This latter approach is consistent with a more engineering-rich approach to tinkering (Bevan, 2017), and is also shown to be an effective pedagogical strategy as it is used in Montessori schools (Denervaud et al., 2020). Since feedback tends to be frequently used in more traditional formal education as means for guiding children's learning, it may be more highly correlated with autonomy support in that context compared to less structured contexts of parent-child interaction where other forms of scaffolding may be implemented instead.

Another reason for the contrast between our findings and those from school research may be related to differences in how structure was measured. In this study, we coded parental feedback on a scale based on the extent to which it may have supported children's *sense* of competence, differentiating between negative, positive, and feedback that had an explanation. It is possible that higher autonomy support may predict more frequent feedback, but not necessarily more positive compared to negative feedback. As next steps, we plan on examining positive and negative feedback as a single element re-examine possible associations with autonomy support.

Next, we examined associations between autonomy support and control. We expected to find a negative linear association between the two variables, but instead we found a curvilinear (concave) association. This suggests that some controlling language may reflect parents' involvement and guidance during the activity as it shows a positive association with autonomy support. However, the relationship is reversed at high frequencies of controlling language. Our findings diverge with those from prior studies suggesting linear negative associations between parental autonomy supportive and controlling language towards preschoolers during unstructured play (Bindman et al., 2013; Clements et al., 2021). One possible explanation for the divergence may be the way how the composite scores for autonomy support and control were arranged in those studies compared to the current study. Whereas in those studies autonomy supportive language also included the category of "ambiguous suggestions", in our study ambiguous suggestions were categorized as controlling language. This may explain the positive association between the two variables at low frequencies of control.

Predictors of Children's Engagement

STEM Engagement

As we hypothesized, autonomy support was the strongest predictor of children's engagement in STEM talk moment-to-moment. This finding is in line with prior research showing positive associations between autonomy support and children's cognitive skills, reflection and critical thinking, and academic performance (Cimon-Paquet et al., 2020; Grolnick et al., 2014; Leon et al., 2015; Sorariutta et al., 2017). According to Self Determination Theory, a sense of autonomy is essential to develop more autonomous or intrinsic types of motivations that are not only beneficial for a person's well-being but associated with positive competence outcomes and greater effort placed on the task (Deci & Ryan, 2008; Ryan & Deci, 2020). Interestingly, in the context of a problem-solving activity such as tinkering, we found that the effects of autonomy support were not general but specific to children's subsequent cognitive engagement (i.e., STEM talk). Parents' open-ended questions invite children to engage in planning and problem solving, and parents' suggestions and options can also elicit children's explanations for their choices. In other words, autonomy supportive language in this context tends to invite higher order thinking and complex responses from children, as children are put in charge to make decisions about their creations.

We had also expected to find negative associations between parental control and children's STEM engagement. According to Self Determination Theory, control stands in contrast with autonomy support and produces more extrinsic types of motivation that are linked with lower levels of effort and engagement (Deci & Ryan, 2008; Ryan & Deci, 2020). In our study, however, we found no associations between controlling management language and children's engagement, suggesting that parental commands and step-by-step instructions did not undermine or promote children's engagement.

One possible explanation for this null finding may be that these types of verbalizations in the informal learning context are not capturing control as the construct described by Self Determination Theory. That is, children in our sample were arguably interested and engaged in the activity. In this context, it is likely that parents were using commands and instructions as a way to help children achieve their own goals for the activity, not as a way to coerce or pressure them to behave in a certain way. This is consistent with the curvilinear association found between autonomy support and control mentioned previously, as it shows that autonomy support and controlling language work together to an extent. Highly autonomy supportive parents may use some well-placed controlling statements with the goal of problem solving. Moreover, prior work in the context of parent-child semi-structured play has also suggested that the frequent use of controlling language may be parents' response to children with low levels of competence in a way to scaffold their abilities (Bindman et al., 2013). This may be the case especially for very young children, as one study showed that preschoolers in parent-directed dyads showed better learning in the context of a museum exhibit compared to those in the child- or jointly-directed groups (Medina & Sobel, 2020).

On the other hand, some studies that looked at non-verbal control, such as taking over and performing actions for the child during learning activities both in laboratory (Leonard et al., 2019) and museum settings (Sobel et al., 2021; Willard et al., 2019), have found negative associations with children's learning outcomes and persistence in the activity. It is plausible that children are more likely to interpret non-verbal control, as opposed to controlling management language, as an indicator that they are not competent to complete a task on their own, therefore lowering their motivations to engage in the task. Future research should consider the effects of both verbal and non-verbal control in different aspects of children's engagement in informal learning.

In line with our hypothesis, we found that whereas feedback also had a positive association with children's STEM engagement, it did not explain significant variance in engagement after accounting for autonomy support. Because autonomy support tends to invite more cognitive engagement, we expected that its effects may be more evident in STEM engagement in the next moment compared to the effects of feedback as it tends to occur after children behave.

Emotional Engagement

Contrary to our hypothesis, autonomy support was not linked to children's emotional engagement, but feedback showed a positive effect. This was surprising, since we expected that autonomy support would promoting children's sense of ownership over their projects, therefore increasing both their expressions of negative emotions over failures as well as positive emotions over successes. In fact, a study by Hospel and Galand (2016) in a classroom setting indicated that teacher's autonomy support and structure were linked to emotional engagement among 9th grade students. One possible explanation for the contrasting results may be related to the activity context. The effects of autonomy support in promoting greater emotional engagement could be more evident in contexts where emotional engagement is typically low, such as unfamiliar contexts (Thomas & Mueller, 2017) or during less engaging activities such as homework completion (Valdés-Cuervo et al., 2022). A study conducted among 7th graders in the classroom context (Tsai et al., 2008) has also found that autonomy support and control were better predictors of students' interest and enjoyment of subject over time among students with low initial interest compared to those with high initial interest. Since the activity in this study was likely engaging and attractive to children, autonomy support may play a smaller role in increasing emotional engagement.

Another possible explanation is related to the supposed different effects of autonomy support over positive versus negative emotions. Hospel and Galand (2016) found that whereas autonomy support had a positive association to positive emotions, it was negatively associated with negative emotions. In our study, we did not discriminate between positive and negative emotions in our measure of emotional engagement, which could explain the contrasting results. That is, it is possible that the positive effects of autonomy support over positive emotions were compensated by its negative effects over negative emotions, resulting in a null association.

Regarding the effects of feedback on children's emotional engagement, we believe that feedback was supporting children's sense of competence in the activity, which in turn promoted greater subsequent affective reactions. Interestingly, both feedback and emotional engagement were increasing over time and seemed to be more frequently occurring in moments of testing, which tends to occur in the later stages of engineering. As children were testing and receiving feedback from the physical environment, parents may have offered further feedback as praise for their successes or negative feedback indicating what went wrong. In that way, parental negative feedback may have led to negative emotions such as frustration, whereas positive feedback may have elicited expressions of joy and celebration.

The effects of time over parents' and children's behaviors may be reflecting changes in the stages of the engineering design process (i.e., planning, building, testing, redesigning). In fact, prior research has indicated that parents change their interaction style at different phases of a science activity. Specifically, Siegel and colleagues (2007) found that parents tended to be more directive during a prediction phase and more collaborative during the testing phase in an at-home sink- or- float task. It could be that some parental scaffolding strategies are more strongly linked to children's engagement in certain stages of engineering compared to others. It could also be that some strategies used at earlier stages could have delayed effects at later stages, for example, autonomy support during planning could have effects on children's emotional engagement when testing. Investigating these associations at specific stages and across stages may be an interesting direction for future research.

Children's emotional engagement in the activity seems to be relevant for science learning. In fact, we found a positive correlation between children's emotional engagement and their STEM engagement during tinkering. This is in accordance with the Broaden- and- Build Theory (Frederickson, 2013), which states that positive emotions lead to new patterns of thinking and behavior that support learning. According to Frederickson (2013), positive emotions facilitate persistence as well as control strategies, such as thinking about learning goals and current state, observing one's own learning, compensating for learning deficits, and associating new knowledge to old knowledge. Although we did not discriminate between positive and negative emotions in this study, it is plausible that in this context children were expressing more positive emotions and these emotions may have supported their cognitive engagement in the activity.

Behavioral Engagement

We hypothesized that parental feedback would be a predictor of children's subsequent behavioral engagement. This hypothesis was in accord with prior research in the school setting (Hospel & Galand, 2016; Jang et al., 2010) and on the notion that feedback would promote children's sense of competence on the activity therefore increasing motivations to manipulate the materials to complete the task (Ryan & Deci, 2020). However, we found no associations between parents' behaviors and children's subsequent behavioral engagement in our time-series analyses. Interestingly, we found a positive association between parents' feedback and children's behavioral engagement in a multiple regression analyses of the whole interaction. This could suggest that feedback may in fact promote greater behavioral engagement, but the effects may be more delayed than the 1-minute lags we examined. One the other hand, it could also suggest that children who were more behaviorally engaged had parents who responded by offering more feedback.

Another factor that may play a role on children's behavioral engagement is the materials and tools available to them as well as the type of ride they chose to create. In our preliminary analyses, we found that family income was positively associated with children's behavioral engagement. Perhaps income is associated with the materials and tools available at home as well as with children's experiences with these objects. Future studies should investigate children's behavioral engagement in tinkering in relation to the tools and materials used, as well as the engineering goal.

Story Engagement

Concerning children's story engagement, we hypothesized that by providing children with more autonomy, children would engage in more storytelling while tinkering. Prior research in parent-child reminiscing has indicated that more autonomy supportive parents tend to have preschoolers with who told more elaborative stories (Cleveland & Morris, 2014; Cleveland & Reese, 2005; Kelly, 2018). Although this study investigates older children in the context of invented stories, we speculated that as parents granted children autonomy to make decisions during the activity, children would also make more decisions about what they wanted their story to be. However, we did not find any associations between parental behaviors and children's story engagement. Children's story engagement was somewhat low compared to the other types of engagement, probably because they were focusing more on the engineering aspect of the activity compared to the story aspect. In this context, it may be that children's storytelling is influenced by parents' story talk during the activity, and less so by parental management language or feedback.

One interesting finding from our study was the positive correlations between storytelling and children's emotional engagement during the activity. Previous research has shown that tinkering activities designed with the goal to help a character in need promoted high engagement among girls (Letourneau & Bennett, 2020). The current study seems to corroborate the idea that children's storytelling may promote high emotional engagement, and our study also suggests that emotional engagement is positively correlated with children's STEM engagement. Therefore, it may be valuable to encourage storytelling during tinkering. Although we found no significant differences in storytelling across planning conditions, families who were in the planning condition seemed to talk more about the story during the planning time. It could be that the lack of significant associations was due to an overall low frequency of storytelling in the activity, and more research may be needed to determine the effects of planning over storytelling.

Children's Age

We were mainly interested in the role of age in the associations between parental scaffolding and children's engagement. Previous studies suggested that children working with controlling parents were showing lower levels of engagement in a post-test, and the effects were stronger for older children in that group (Sobel et al., 2020). The authors suggested that older children may interpret parents controlling behaviors as indicators of a lack of competence, becoming less motivated to engage in the activity. Therefore, we expected that autonomy support and control would have stronger linkages with children's engagement for older children compared to younger children, and that feedback would be a stronger predictor of engagement for younger children compared to older children. However, we did not find interactions between management language and age in children's engagement. Although this may suggest that the effects of scaffolding are the same across children of different ages, there are also alternative explanations.

In the study from Sobel and colleagues (2020), parent-child dyads explored electric circuits in a museum exhibit, then children engaged in electric circuit challenges during a post-test. Parents who were more directive with children during free-play had children who engaged less in the post-test, and the effect was greater for older children with directive parents. A reason for the discrepancy between our null findings and the findings from Sobel et al. (2020) may relate to differences in the age of participants in the two samples. Whereas the age of children in our sample ranged from 5 to 10 years old (with few 5-year-old children), Sobel and colleagues (2020) recruited children between 4 to 7 years old. Therefore, it may be that age differences in the effects of parental scaffolding are more evident when comparing children younger and older than 5 years old than when comparing different ages older than 5 years old. In other words, it is possible that around age 5 children, when children typically begin kindergarten, they undergo important developmental changes in motor, social, or cognitive skills, that influence the effects of parental scaffolding on their engagement.

Another possible explanation for the non-significant interaction effect between autonomy support and age may be due to our measure of autonomy support. It may be that older children were benefiting more from autonomy support than younger children, but not necessarily benefiting more from autonomy supportive management language. That is, perhaps older children were taking more advantage of receiving autonomy even when the autonomy did not involve frequent questions and suggestions. In fact, we found that parents were using more autonomy supportive language with younger children compared to older children in this study, likely as a form of scaffolding. Our HLM analysis also indicated that age had a positive effect in the intercept of children’s behavioral and STEM engagement, suggesting that older children may have required less management language to engage in the task. It is also plausible that parents used different autonomy supportive language with younger and older children. For example, parents may have offered more suggestions and options to younger children, but more transfer statements with older children. Therefore, in future analyses we plan on exploring whether age was associated with specific types of autonomy supportive language.

Finally, we cannot rule out the possibility that our null finding may be due to our small sample size or to the skewed distribution of children's age in our sample. That is, we had more older children (9-10-years old) in our sample than younger children, and perhaps we would have found significant effects if the ages were more normally distributed. More studies with larger samples are needed to better understand the effects of age in these associations.

Children's Gender

We were interested in examining whether the effects of autonomy support were the same for boys and girls. A study by Lietaert and colleagues (2015) found that among 7th graders from several schools in Netherlands, autonomy support was associated with engagement only for boys, but not girls. However, as the authors pointed out, girls were more engaged in class than boys, and it may be that girls are more willing to engage in less interesting activities whereas boys may require more autonomy support to engage in that context. Therefore, we expected that in informal learning contexts there would be no gender differences as the activities tend to be interesting and engaging. In line with our predictions, we found no differences in the associations between parental behaviors and children's engagement across boys and girls.

In our sample, girls showed higher engagement than boys, specifically in STEM talk and emotional expression. This is noteworthy considering current national efforts to increase girls' engagement in STEM. As previously mentioned, recent studies have shown the potential of narratives to evoke empathy and increase STEM engagement among girls during engineering activities (Letourneau & Bennett, 2020). Therefore, higher STEM and emotional engagement among girls in our sample could be due to the story element present in the activity. In fact, in ongoing analyses of this data we are finding that high frequency of storytelling seems to be associated with STEM engagement differently across boys and girls (Aldrich et al., 2022).

Planning Condition

We were interested in examining if prompting families to plan prior to tinkering could lead to a more autonomy supportive interaction across time compared to families who were not prompted to plan. Autonomy support can be highly demanding of parents (Distefano & Meuwissen, 2022), so we expected that parents' energy resources would decrease overtime and they would become less autonomy supportive and more controlling. In fact, we have found that parents tended to become less autonomy supportive and more controlling overtime 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 overtime compared to parents in the planning condition.

This finding was in line with our predictions and with prior studies showing that mothers tend to be less autonomy supportive under conditions of high pressure (Grolnick et al., 2002; 2007). We believe that constructing a joint plan prior to tinkering may have helped parents be less concerned over the final product of their creations, and therefore be more autonomy supportive to their children. We also noted that planning time tended to be characterized by many open-ended questions to children. Hence, another possibility is that by asking families to plan before tinkering we primed parents to ask children more questions, and that style of conversation was carried out throughout the rest of the activity. In any case, the study suggests that prompting families to plan beforehand may promote a more autonomy supportive interaction overtime.

Bi-directionality

In this study we also wanted to examine whether there is evidence of a bi-directional relationship between parents' behaviors and children's engagement. According to sociocultural theories (Rogoff, 2018; Vygotsky, 1978), individuals change and are changed by their social environments in a reciprocal manner. Based on that idea, we expected that children's engagement would not only be influenced by parental behaviors but would also influence parents' behaviors. Specifically, we hypothesized that higher engagement from children may elicit higher subsequent autonomy support and feedback from parents compared to lower engagement.

We found that children's STEM engagement was positively associated with subsequent parental autonomy support. This suggests that in the same way that autonomy support may promote children's STEM talk, children's STEM engagement may elicit more autonomy support from parents in the next interval in a circular manner. It may be that as children engage in STEM talk such as planning and problem solving their designs, parents may respond by asking further open-ended questions to probe children's thinking or providing suggestions that align with children's ideas. On the other hand, when children are disengaged, parents may be more focused on keeping children on task or completing the activity rather than providing them with autonomy.

In the same manner, we found that just as parental feedback seemed to be associated with children's subsequent emotional engagement, children's emotional engagement seems to also elicit more parental feedback in a subsequent interval. It may be that when children express frustration during the interaction parents may offer more feedback on what went wrong, and when children succeed, and express positive emotions parents may provide more positive feedback and praise.

Limitations and Future Directions

There are several limitations to the current study. First, our sample size was somewhat small when considering HLM analysis of level-2 variables. A prior study has suggested that sample sizes at level-2 greater than 50 lead to unbiased estimation of errors (Hox & Maas, 2004). Still, when running a post-hoc power analysis using Optimal Design Plus, we found that our sample size had a power of 0.85 for large effects but low power to detect medium size effects (power = .50). Therefore, some of our null findings regarding our level-2 variables could have been due to our small sample size.

A second limitation is that our sample was not very diverse. Since this study was conducted during the COVID-19 pandemic, we recruited our participants from websites such as children helping science, our database of previous participants, and list-servs from other Developmental researchers. This recruitment strategy resulted in a sample that was primarily White, highly educated and high in SES. Prior research has indicated differences in parent-child interactions based on parental ethnicity (Distefano & Meuwissen, 2022) as well as education

(Solis & Callanan, 2021). For this reason, going forward, we hope to recruit more diverse samples from the museum setting to ensure the generalizability of our findings.

Another limitation is that this study cannot inform who is driving the effects between parents and children's behaviors. Although we have indicated bidirectional associations between these variables, whether it is children's initial engagement or parents' initial behaviors that propel the subsequent circular associations is still unknown, and it may vary across participants. Still, we found that the slopes of autonomy support predicting children's STEM engagement did not vary significantly across participants. This may suggest that autonomy support was effectively promoting subsequent STEM engagement even for children who may have had lower overall STEM engagement.

Finally, in this study we did not code equivalent behaviors between parents and children; for example, we did not code parents' STEM talk or parents' emotional display as we did for children. It could be that parents' STEM talk is correlated with their autonomy support, and that parental STEM talk, *not* autonomy support, was associated with children's engagement. To overcome that limitation, we are currently coding parental STEM talk in our observations and we intent to further examine associations between parental STEM talk and autonomy support, as well as between both variables in relation to children's STEM talk.

As a future direction, we are interested in further investigating these parent-child interactions at specific stages of tinkering. In our statistical analysis, we looked at very small-time lags between the associations between parental behaviors and children's engagement. As next steps, we want to better understand how parental behaviors may associate to children's engagement differently at distinct stages of the process (e.g., planning, building, testing, redesigning).

Implications

The current study makes significant contributions to theory and practice. For the field of developmental science, our study provides evidence of bidirectional relations between parental scaffolding practices and children's engagement in learning activities. In line with sociocultural theories, children's behaviors are influenced but are also influencing their parents' behaviors. For the autonomy support literature, our study also provides significant contributions. It suggests that in the informal learning context, autonomy supportive language may promote children's subsequent STEM engagement in specific, and this effect is observed in a small interval of time. Controlling management language, on the other hand, showed no effects, suggesting that parents' directives do not undermine children's engagement in the task.

The study also offers practical contributions to science learning and informal education. For museum program practices, both online and in person, 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. Museum educators themselves may also want to use autonomy supportive language when interacting with families, both to model the behavior to parents and to elicit more cognitive engagement from children. Finally, the study also suggests that including a story element to informal learning activities may increase children's emotional and STEM engagement, perhaps especially among girls.

APPENDIX A

SUMMARY TABLES OF HLM ANALYSIS

Table 6. HLM Models to Predict STEM Engagement Hypothesis 2

	Model A	Model B	Model C	Model D	Model F	Model G	Model H
Predictors	Null Model	Autonomy	Autonomy + Control	Autonomy + Feedback	Autonomy + Time and Level-2	Model F + random Autonomy slope	Model F + random time slope
Intercept B_{00}	0.95 (0.50)*	0.81 (0.05)*	0.84 (0.05)*	0.77 (0.04) *	0.82 (0.10)*	0.82 (0.10)*	0.83 (0.09)*
B_{01} *Age*					0.08 (0.02)*	0.07 (0.02)*	0.07 (0.02)*
B_{02} *Gender*					0.20 (0.08)*	0.20 (0.07)*	0.19 (0.07)*
B_{03} *Job*					0.31 (0.08)*	0.31 (0.08)*	0.33 (0.07)*
B_{10} *Autonomy*		0.04 (0.01)*	0.03 (0.01)*	0.04 (0.01)*	0.03 (0.01)*	0.03 (0.01)*	0.03 (0.01)*
B_{20}			-0.01 (0.01)	0.04 (0.01)*	-0.01 (0.00)*	-0.01 (0.00)*	-0.01 (0.00)*
r_0	0.33 (0.11)*	0.31 (0.10)*	0.31 (0.10)*	0.31 (0.10)*	0.25 (0.06)*	0.22 (0.05) *	0.44 (0.19)*
r_1						0.01 (0.00)	0.01 (0.00) *
e_{ij}	1.02 (1.03)	1.01 (1.02)	1.01 (1.02)	1.01 (1.02)	1.00 (1.01)	1.00 (1.01)	1.00 (0.99)
Deviance	5594.14	5573.90	5581.84	5575.89	5548.69	5547.44	5532.99

Note. * Significance level at or below .05.

Table 7. HLM Models to Predict STEM Engagement Hypothesis 3

	Model A	Model B	Model C	Model D	Model E	Model F	Model G
Predictor	Null Model	Autonomy *age	Autonomy * gender	Control * age	Control *gender	Feedback *age	Feedback *gender
Intercept B_{00}	0.95 (0.50)*	0.70 (0.07 *	0.7 (0.07)*	0.86 (0.07)*	0.86 (0.07)*	0.80 (0.07)*	0.81 (0.07)*
B_{01} *Age*		0.03 (0.02)		0.05 (0.02)*		0.02 (0.02)	
B_{02} *Gender*		0.22 (0.09)*	0.23 (0.09)*	0.24 (0.09)*	0.25 (0.09)*	0.24 (0.09)*	0.19 (0.09)*
B_{10}		0.04 (0.01)*	0.04 (0.01)*	-0.01 (0.01)*	-0.01 (0.01)	0.03 (0.01)*	0.01 (0.02)
B_{11}		0.00 (0.00)	-0.00 (0.01)	-0.01 (0.00)	0.00 (0.01)	0.01 (0.01)*	0.05 (0.03)*
r_0	0.33 (0.11)*	0.29 (0.08) *	0.30 (0.09) *	0.31 (0.10)*	0.31 (0.09)*	0.30 (0.09)*	0.31 (0.09) *
r_1							
e_{ij}	1.02 (1.03)	1.01 (1.01)	1.01 (1.02)	1.01 (1.03)	1.02 (1.03)	1.01 (1.03)	1.01 (1.03)
Deviance	5594.14	5582.57	5577.03	5605.32	5598.39	5600.01	5591.06

Table 8. HLM Models to Predict Emotional Engagement Hypothesis 2

	Model A	Model B	Model C	Model D	Model E	Model F	Model G
Predictor	Null model	Autonomy	Control	Feedback	Feedback + time	Model E random time slope	Model F + gender + education
B_{00} (*SE*)	0.40 (0.04) *	0.41 (0.05)*	0.37 (0.04)*	0.36 (0.04)*	0.26 (0.04) *	0.27 (0.04)*	0.07 (0.23)
B_{01} *Gender*							0.23 (0.08)*
B_{02} *Education*							0.00 (0.01)
B_{10}		-0.01 (0.01)	0.01 (0.00)*	0.03 (0.01)*	0.03 (0.01)*	0.03 (0.01) *	0.03 (0.01)*
B_{20} *Time*					0.01 (0.00)*	0.01 (0.00)*	0.01 (0.00)*
r_0	0.32 (0.10)*	0.32 (0.10)*	0.32 (0.10)*	0.32 (0.10) *	0.32 (0.10)*	0.30 (0.09)*	0.30 (0.09)*
r_1						0.01 (0.00)*	0.01 (0.00)*
e_{ij}	0.68 (0.46)	0.68 (0.46)	0.68 (0.46)	0.68 (0.46)	0.67 (0.45)	0.67 (0.44)*	0.67 (0.44)
Deviance	4077.24	4083.66	4079.25	4070.62	4066.28	4054.47	4056.36

Note. Random slope for feedback was non-significant, $r_1 = 0.04$, $p = .18$

Table 9. HLM Models to Predict Emotional Engagement Hypothesis 3

Predictors	Model A Null Model	Model B Autonomy * age	Model C Autonomy * gender	Model D Control * age	Model E Control * gender	Model F Feedback * age	Model G Feedback * gender
B_{00} (SE)	0.4 (0.04)*	0.41 (0.05)*	0.27 (0.05)*	0.37 (0.04)*	0.26 (0.04)*	0.36 (0.04)*	0.24 (0.03)*
B_{01} *Age*		0.02 (0.03)		-0.00 (0.02)		-0.00 (0.02)	
B_{02} *Gender*			0.29 (0.09)*		0.21 (0.08)*		0.24 (0.07)*
B_{10}		-0.01 (0.01)	0.00 (0.01)	0.12 (0.00)	0.00 (0.00)	0.03 (0.01)*	0.03 (0.02)
B_{11}		-0.00 (0.00)	-0.01 (0.01)	0.00 (0.00)	0.02 (0.01)*	0.01 (0.01)	0.01 (0.02)
r_0	0.32 (0.10)*	0.33 (0.11)*	0.30 (0.09)*	0.32 (0.11)*	0.29 (0.09)*	0.32 (0.10)*	0.29 (0.09)*
e_{ij}	0.68 (0.46)	0.68 (0.46)	0.68 (0.46)	0.68 (0.46)	0.68 (0.46)	0.68 (0.46)	0.68 (0.46)
Deviance	4077.24	4096.66	4084.12	4093.01	4076.75	4081.97	4071.06

Table 10. HLM Models to Predict Behavioral Engagement Hypothesis 2

	Model A	Model B	Model C	Model D	Model E
Predictors	Null Model	Autonomy	Feedback	Control	Time
Intercept B_{00} (*SE*)	1.0 (0.06)*	1.06 (0.07)*	0.97 (0.07)*	0.96 (0.07)*	0.81 (0.08)*
B_{10}		-0.02 (0.01)*	0.03 (0.02)	0.02 (0.01)	0.01 (0.00)*
r_0	0.46 (0.21) *	0.46 (0.21)*	0.46 (0.21)*	0.47 (0.22)*	0.47 (0.22)*
e_{ij}	1.13 (1.29)	1.13 (1.28)	1.14 (1.29)	1.13 (1.29)	1.13 (1.28)
Deviance	6043.24	6044.45	6044.89	6044.36	6030.44

Table 11. HLM Models to Predict Behavioral Engagement Hypothesis 3

	Model A	Model B	Model C	Model D	Model E	Model F	Model G
Predictors	Null Model	Autonomy * age	Autonomy * gender	Control * age	Control * gender	Feedback * age	Feedback * gender
B_{00} (*SE*)	1.0 (0.06)*	1.06 (0.07)*	0.97 (0.1)*	0.96 (0.07)*	0.87 (0.09)*	0.97 (0.07)*	0.86 (0.09)*
B_{01} *Age*		0.06 (0.04)		0.04 (0.04)		0.06 (0.04)	
B_{02} *Gender*			0.19 (0.14)		0.16 (0.13)		0.22 (0.14)
B_{10}		-0.02 (0.01)*	-0.02 (0.01)	0.02 (0.01)*	0.01 (0.01)	0.03 (0.02)	0.04 (0.02)
B_{11}		-0.00 (0.00)	0.00 (0.01)	0.01 (0.00)	0.02 (0.02)	-0.01 (0.01)	-0.03 (0.03)
r_0	0.46 (0.21)*	0.46 (0.21)*	0.45 (0.21)*	0.46 (0.22)*	0.46 (0.21)*	0.45 (0.20)*	0.45 (0.20)*
e_{ij}	1.13 (1.29)	1.13 (1.29)	1.13 (1.29)	1.13 (1.29)	1.13 (1.29)	1.14 (1.29)	1.14 (1.29)
Deviance	6043.24	6056.25	6050.64	6054.64	6049.53	6054.71	6049.26

Table 12. HLM Models to Predict Story Engagement Hypothesis 2

	Model A	Model B	Model C	Model D
Predictors	Null Model	Autonomy	Feedback	Control
Intercept B_{00}	0.28 (0.03)*	0.29 (0.04)*	0.27 (0.03)*	0.27 (0.03)*
B_{10}		-0.00 (0.00)	0.01 (0.01)	0.01 (0.01)
r_0	0.24 (0.06)*	0.24 (0.06)*	0.23 (0.05)*	0.24 (0.06)*
e_i	0.69 (0.47)	0.69 (0.47)	0.69 (0.47)	0.69 (0.47)
Deviance	4096.75	4103.73	4101.13	4101.78

Table 13. HLM Models to Predict Story Engagement Hypothesis 3

	Model A	Model B	Model C	Model D	Model E	Model F	Model G
	Null Model	Autonomy * age	Autonomy * gender	Control * age	Control * gender	Feedback * age	Feedback * gender
B_{00} (*SE*)	0.28 (0.03)*	0.29 (0.04)*	0.27 (0.06)*	0.27 (0.03)*	0.26 (0.05)*	0.27 (0.03)*	0.26 (0.05)*
B_{01} *Age*		0.02 (0.02)		-0.01 (0.02)		-0.00 (0.02)	
B_{02} *Gender*			0.30 (0.08)		0.01 (0.07)		0.02 (0.07)
B_{10}		-0.00 (0.00)	0.003 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.02 (0.02)
B_{11}		-0.01 (0.00)	-0.01 (0.01)	0.01 (0.00)*	0.00 (0.01)	0.00 (0.01)	-0.01 (0.02)
r_0	0.24 (0.06)*	0.24 (0.06)*	0.24 (0.06)*	0.24 (0.06)*	0.24 (0.06)*	0.24 (0.06)*	0.24 (0.06)*
e_i	0.69 (0.47)	0.69 (0.47)	0.69 (0.47)	0.69 (0.47)	0.69 (0.47)	0.69 (0.47)	0.69 (0.47)
Deviance	4096.75	4116.07	4114.20	4114.27	4112.52	4115.39	4110.14

Table 14. HLM Models to Predict Autonomy Support Hypothesis 4

Predictors	Model A Null Model	Model B Minutes	Model C Minutes + condition	Model D Minutes * condition	Model E Model D + age, gender	Model F Model E + random slope
Intercept B_{00} (SE)	3.68 (0.18)*	4.35 (0.21)*	4.20 (0.25)*	4.52 (0.28)*	4.18 (0.36)*	4.23 (0.36)*
B_{01} *Condition*			0.32 (0.37)	-0.27 (0.43)	-0.33 (0.44)	-0.32 (0.44)
B_{02} *Age*					-0.25 (0.12)*	-0.24 (0.12)*
B_{03} *Gender*					0.73 (0.34)*	0.67 (0.33)*
B_{10}		-0.04 (0.01)*	-0.04 (0.01)*	-0.07 (0.01)*	-0.07 (0.01)*	-0.07 (0.01)*
B_{11}				0.04 (0.02)*	0.04 (0.02)*	0.04 (0.02)
r_0	1.30 (1.70) *	1.33 (1.76)*	1.33 (1.77)*	1.34 (1.79)*	1.24 (1.54)*	1.27 (1.62)*
r_1						0.05 (0.00)*
e	3.29 (10.80)	3.26 (10.6)	3.26 (10.65)	3.26 (10.61)	3.26 (10.62)	3.23 (10.42)
Deviance	10117.91	10090.23	10091.47	10090.00	10084.04	10074.77

Table 15. HLM Models to Predict Autonomy Support Hypothesis 5

	Model A Null model	Model B STEM	Model C STEM + behavior	Model D STEM + emotion	Model E STEM+ story	Model F STEM + minutes	Model G Model F age, gender	Model H Model G + random slope
B_{00} (SE)	3.68 (0.18)*	3.33 (0.17)*	3.45 (0.18)*	3.37 (0.18)*	3.33 (0.18)*	3.97 (0.22)*	3.64 (0.32)*	3.72 (0.31)*
B_{01} *Age*							-0.27 (0.11)*	-0.26 (0.11) *
B_{02} *Gender*							0.63 (0.33)	0.57 (0.32)
B_{10} *STEM*		0.37 (0.07)*	0.36 (0.07)*	0.38 (0.07)*	0.37 (0.07)*	0.31 (0.07)*	0.31 (0.07)*	0.31 (0.07)*
B_{20}			-0.11 (0.06)	0.10 (0.11)	-0.01 (0.11)	-0.04 (0.01)*	-0.04 (0.01)*	-0.04 (0.01)*
r_0	1.30 (1.68)*	1.25 (1.57)*	1.25 (1.56)*	1.26 (1.58)*	1.25 (1.57)*	1.29 (1.66)*	1.18 (1.40) *	1.22 (1.49)*
r_1								0.05 (0.00)*
e	3.29 (10.82)	3.27 (10.71)	3.27 (10.71)	3.27 (10.71)	3.27 (10.72)	3.25 (10.57)	3.25 (10.57)	3.22 (10.36)
Deviance	10117.91	10091.95	10094.57	10095.44	10096.37	10077.92	10071.49	10060.30

Table 16. HLM Models to Predict Control Hypothesis 4

	Model A	Model B	Model C	Model D	Model E
Predictors	Null model	Minutes	Minutes + condition	Minutes * condition	Model B + random slope
B_{00} (*SE*)	2.29 (0.18)*	1.76 (0.19)*	2.01 (0.26)*	2.05 (0.25)*	1.76 (0.19)*
B_{01}			-0.53 (0.37)	-0.60 (0.38)	
B_{10}		0.03 (0.01)*	0.03 (0.01)*	0.03 (0.02)*	0.03 (0.01)*
B_{11}				0.00 (0.02)	
r_0	1.34 (1.80)*	1.37 (1.87)*	1.35 (1.84)*	1.35 (1.83)*	1.10 (1.21)*
r_1					0.06 (0.00)*
e	2.97 (8.81)	2.95 (8.69)	2.95 (8.69)	2.95 (8.70)	2.89 (8.35)
Deviance	9736.20	9715.60	9715.56	9720.29	9677.14

Table 17. HLM Models to Predict Control Hypothesis 5

	Model A	Model B	Model C	Model D	Model E	Model F
Predictors	Null model	Minutes	Minutes + STEM	Minutes + emotion	Minutes + behavior	Minutes + story
B_{00} (*SE*)	2.29 (0.18)*	1.76 (0.19)*	1.88 (0.22)*	1.72 (0.19)*	1.71 (0.19)*	1.69 (0.2)*
B_{10}		0.03 (0.01) *	0.03 (0.01)*	0.03 (0.01)*	0.03 (0.01)*	0.03 (0.01)*
B_{20}			-0.09 (0.06)	0.15 (0.07)*	0.08 (0.06)	0.20 (0.09)*
r_0	1.34 (1.80)*	1.37 (1.87) *	1.36 (1.85)*	1.36 (1.86)*	1.37 (1.88)*	1.37 (1.87)*
e	2.97 (8.81)	2.95 (8.69)	2.95 (8.69)	2.95 (8.69)	2.95 (8.69)	2.95 (8.68)
Deviance	9736.20	9715.60	9719.08	9718.00	9719.61	9715.97

Table 18. HLM Models to Predict Feedback Hypothesis 5

	Model A	Model B	Model C	Model D	Model E	Model F	Model G	Model H
Predictor	Null Model	Emotion	Emotion + STEM	Emotion + behavior	Emotion + story	Emotion + time	Model F +random emotion slope	Model F + random time slope
B_{00} (*SE*)	1.07 (0.08)*	1.00 (0.07)*	0.93 (0.07)*	0.95 (0.07)*	0.98 (0.07)*	0.78 (0.09)*	0.77 (0.09)*	0.76 (0.09)*
B_{10} *Emotion*		0.17 (0.06)*	0.17 (0.06)*	0.17 (0.06)*	0.17 (0.06)	0.15 (0.06)*	0.12 (0.07)	0.14 (0.06)*
B_{20}			0.08 (0.04)*	0.05 (0.03)	0.06 (0.05)	0.01 (0.00)*	0.02 (0.00)*	0.02 (0.00)*
r_0	0.53 (0.28)*	0.52 (0.27)*	0.51 (0.26)*	0.51 (0.26)*	0.51 (0.26)*	0.53 (0.28)*	0.46 (0.22)*	0.45 (0.20)*
r_1							0.28 (0.08)*	0.01 (0.00)
e	1.55 (2.42)	1.55 (2.40)	1.55 (2.40)	1.55 (2.40)	1.55 (2.40)	1.54 (2.38)	1.53 (2.35)	1.53 (2.35)
Deviance	7230.06	7213.12	7215.07	7217.67	7217.85	7207.50	7198.30	7202.00

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