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RESEARCH ARTICLE

Examining Baseline Relations Between Parent–Child Interactions and STEM Engagement and Learning

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ABSTRACT

Several studies suggest that children's learning and engagement with the content of play activities is affected by the ways parents and children interact. In particular, when parents are overly directive and set more goals during play with their children, their children tend to play less or are less engaged by subsequent challenges with the activity on their own. A concern, however, is that this directed interaction style is only compared with other styles of parent–child interaction, not with a baseline measure of engagement or learning. The present study incorporates such a baseline measure, comparing it with previously-collected data on children's engagement and learning in a set of circuit-building challenges. Regarding engagement, children were less engaged by the challenges when their parents were more directed during a free play setting (tested in Sobel et al. 2021) than when children had no prior experience playing with the circuit components. Regarding learning, children were better able to complete the circuit challenges and provided more causal explanations for how the completed challenges worked when they had experience playing with the circuit blocks with their parent. Overall, these data suggest that parent–child interaction during a STEM activity relates to both children's engagement and performance on challenges related to that activity.

1 | Introduction

Parent–child interaction during collaborative play is critical to the ways children learn (e.g., Weisberg et al. 2014). Although parent–child interaction is important for learning in many informal environments, such as the home, the grocery store, or playscapes (e.g., Gaudreau et al. 2021; Hassinger-Das et al. 2018, 2020; Köster et al. 2022; Morris et al. 2023; Ridge et al. 2015), a common way to study such interaction is by considering the ways children and parents play together in informal learning environments such as museums or zoos. For example, children's museums are often designed around the themes of interaction and exploration, and therefore provide a vibrant context to study children's learning (e.g., Callanan and Jipson 2001; Gaskins 2008; Sobel and Jipson 2015; Van Schijndel, Franse, and Raijmakers 2010). When parents and children interact at museum exhibits, parents can provide explanations, encourage children's exploration, guide children's attention to actions and the results of those actions, and generally support the ways they encode information (e.g., Benjamin, Haden, and Wilkerson 2010; Callanan et al. 2020; Jant et al. 2014; Legare, Sobel, and Callanan 2017).

Analyzing parent–child interaction in informal learning environments has also been used to study how children are engaged by the act of learning. For example, children explore more aspects of an exhibit and do so for a longer time when they are with a parent (Crowley et al. 2001). When parents generate more causal language, more STEM language, or more elaborative language to describe interaction at a museum exhibit, children explore the exhibit longer and discover more information about its content

Summary

- Identifies how parental goal-setting during play reduces children's STEM engagement compared to baseline measures.
- Provides evidence suggesting that directive parenting reduces children's engagement during a STEM activity.
- Demonstrates that parent-directed interaction during free play still benefit children's problem-solving performance in STEM challenges, separating the roles of engagement and learning efficacy.

(e.g., Chandler-Campbell 2020; Fender and Crowley 2007; Jee and Anggoro 2021; Kurkel et al. 2021; Marcus, Haden, and Uttal 2017; Van Schijndel and Raijmakers 2016).

But not all parental actions are beneficial for children's engagement with exploring an exhibit. For example, Willard et al. (2019) demonstrated that the more parents "troubleshooted" behaviors for children when they explored a gear exhibit together (i.e., engaged in behaviors that fixed the gear machines children built, instead of letting children fix those machines themselves), the less time children spent playing with a similar gear exhibit on their own. They did not observe any differences in what children learned from their play.

Callanan et al. (2020) documented differences in children's exploration during free play based on the extent to which parents or children set goals for the interaction. They coded dyads' interactions as either *parent-directed, child-directed, or jointly-directed*. Parent-directed interactions involved parents setting more of the goals for the interaction and engaging in more iterative imperatives for how the play would unfold. Child-directed interaction involved parents being more hands-off in their goal setting and allowing children to set almost all the goals for the interactions; parents often engaged in other activities during such interactions and were simply present. Jointly-directed interactions were more collaborative; parents and children set a similar number of goals, or parents actively supported the goals children set. Children in the jointly-directed dyads engaged in more exploratory actions that were related to their learning at the exhibit.

But this kind of parent-child interaction (centered around goal setting) might not relate to children's learning as much as it relates to their engagement with that learning. Medina and Sobel (2020) asked parents and children to learn about a novel set of causal relations (how objects with different features related to activating a machine) during a free play session with a novel machine. They coded the parent–child interaction using the same coding scheme as Callanan et al. (2020), and found that children in parent-directed dyads explored this setting for the least amount of time with their parents, suggesting they were less engaged by the act of learning. Children whose parents were more directive, however, learned the causal structure equivalently to children from jointly-directed dyads.

Expanding on these ideas, Sobel et al. (2021) asked parents and children to play together at a circuit exhibit, and then presented children on their own with a set of circuit-building challenges. Children in parent-directed dyads participated in the fewest number of circuit-building challenges after their free play. They also found that other behaviors on the part of parents related more to children's learning about the circuit blocks, suggesting that goal-setting behaviors on the part of parents were more related to children's engagement. Such findings are similar to those by Leonard et al. (2021), who showed that when adults take over their interaction with 3- to 6-year-olds during a challenging task, children were rated lower on measures of global persistence (see also Leonard et al., 2022).

A challenge in interpreting these findings is that children's engagement in these studies is only measured in comparison with other styles of parent–child interaction. There is no baseline measure of engagement to act as a reference for each interaction style. Providing a baseline measure would distinguish among hypotheses about the relation between parent–child interaction during play and children's engagement. One hypothesis is that because children's autonomy during a play session is important for their engagement (following Deci and Ryan 1987; Ryan and Deci 2000), parents setting too many goals during free play relates to lower engagement on the part of children (Leonard et al., 2021; Sobel 2023). This hypothesis would predict that children in the parent-directed dyads would show lower engagement than those in a baseline group, who received no parent–child interaction prior to participating in a set of challenges. Critically, this hypothesis also predicts no difference between such a baseline condition and children's engagement when their play with their parents is jointly directed or child-directed.

This hypothesis can be contrasted with two alternatives. The first is that there is a general benefit to parent–child interaction on children's engagement, based on studies that suggest parental involvement during exploration relates to an increase in children's engagement with learning (e.g., Crowley et al. 2001; Fender Crowley 2007). However, when parents set too many goals, that benefit is simply not realized. On this view, engagement in the baseline condition will be similar to engagement in a parent-directed group, and the engagement of both of these groups will be lower than children's engagement if their play was jointly-directed or child-directed.

The second is that parental directedness might be more of a compensatory strategy on the part of parents for children's overall lower engagement with playful learning activities. Although this possibility has not been documented in young children, in college-age adults, overparenting—which can include forms of parental directedness considered here—is related to parents' perceptions of their child's autonomy and level of interest (e.g., Jiao et al., 2024). For preschoolers and early-elementary school children, this strategy might be particularly apparent in under conditions where parents believe their children are being evaluated (Shachnai et al., 2024). Parents thus might recognize that their child is less likely to engage with a novel situation or observe that their child is less engaged by the free play, so they set more goals in order to attempt to facilitate the benefits of playful learning. This suggests that children's lower engagement manifests both when tested on their own and when playing with their parent. Because any baseline condition would be inclusive of children who would be engaged differently by the activity, but who never get to play freely, this hypothesis would posit that engagement at baseline would be between the parent-directed group and the other two interaction styles.

1.1 | Parent–Child Interaction and Children's Learning

Having laid out potential hypotheses for the importance of including a baseline condition to study the relations between parent–child interaction during free play and children's engagement with the activity, we can also consider a more straightforward question about children's *learning* from this kind of play: How does children's understanding of circuits differ when they have had a chance to interact with the circuit materials with their parents in a play setting than when they do not? The present study presented children with a set of circuit building challenges—the same challenges used by Sobel et al. (2021)—without children having first been exposed to the circuit blocks in a play session with their parent. This allows us to contrast the hypotheses about children's engagement described above. But presenting children with these challenges allows us to consider an additional question, which is how children's understanding of circuits differs when they have and have not had the chance to interact with the circuit blocks in a parent–child playful learning context.

Given numerous studies showing that parental presence at museum exhibits benefited children's exploration and learning (e.g., Fender and Crowley 2007; Van Schijndel, Franse, and Raijmakers 2010), we predicted a straightforward hypothesis, which is that children's overall performance on the circuit-building challenges in the baseline condition we present here would be lower than any of the parent–child interaction styles reported in the previous paper. Importantly, this is not the same as predicting children will be more engaged with the challenges; we want to separate measures of learning from measures of engagement. Only children's performance on challenges, and not their engagement with participating in the challenges, should be reduced in the data collected here compared to all of the parent–child free play interaction conditions documented in the previous study. But, because that previous study found that children's performance on the challenges was correlated with their engagement, in all analyses, we factor out the effect of engagement on performance and vice versa.

Further, in addition to performance on the challenges, we can also consider the language children generate to explain how the circuits they built function. Glauert (2009) examined 5- and 6-year-olds' explanations of different kinds of functional and nonfunctional electric circuits. She demonstrated that the quality of the explanations children generated related to their understanding of whether the circuit would function. To this end, we asked children to generate explanations of how the circuits that they built during the challenges worked. This allows us to consider whether the quality of the explanations children generate after constructing each circuit related to their performance on the challenges. We can also consider the previous data when children were first given a play session with their parents to see if the interaction that they had with their parents related to their explanatory abilities. These exploratory analyses would shed light on the potential mechanisms through which parents might support children's learning, beyond any potential relations with their engagement. As mentioned above, language can scaffold children's causal learning (see also Alvarez and Booth 2016; Callanan et al. 2017), and in particular, the amount of causal language children hear might facilitate their reasoning (e.g., Chandler-Campbell, Leech, and Corriveau 2020; Jant et al. 2014; Leech et al. 2020). This suggests that hearing causal language during the play session would facilitate children's explanations of the circuits.

1.2 | The Present Study

In this study, we presented a group of 4- to 7-year-olds with a set of optional circuit completion challenges. These were the same building challenges presented to children in Sobel et al. (2021), where children played with the circuit components beforehand with a parent. We compared the performance and the engagement of the children we collected here to that of the previous paper. Like the previous paper, engagement was operationalized as how many challenges children participated in, and performance was operationalized as the proportion of those challenges children solved on their own, which made for ease of comparison.

One challenge we faced in conducting this research was that the data were collected when the museum reopened after the COVID pandemic. Soon after reopening—during the data collection for this study—the exhibit space used in the Sobel et al. (2021) study was closed and repurposed for office use by the museum. Soon after that, the museum was no longer able to financially support the testing partnership in favor of other programs. As such, some of the children we tested were given the same exhibit components and tested in the same exhibit. Some were tested in with those components in another part of the same museum. But some were tested with the same materials at another informal learning institution (a local zoo). The testing environments and procedures, however, were all similar, which makes the comparison to the previously-collected data feasible. This is described in more detail below.

2 | Method

2.1 | Participants

We collected responses from 68 children between the ages of 4 and 7 years old (36 girls and 32 boys, M_{age} = 70.62 months, SD = 13.65, Range 48–95 months). Data were collected between March and October of 2023. The ethnic/racial breakdown of this sample was as follows (as indicated by parental report): 39 children were White (57%), 7 children were Black/African American (10%), 12 children were Hispanic/Latine (18%), 1 child was American Indian/Alaska Native (1%), with 9 families not responding or listing "Prefer not to say" (13%).

The sample size collected here was based on conducting a power analysis for the planned analysis, comparing these data with the 111 data points collected in Sobel et al. 2021; see that paper for demographic information) for the purpose of testing the hypotheses about engagement described in the introduction. This power analysis determined the number of additional data points needed to include another condition (the baseline condition), assuming $\alpha = 0.05$, $\beta = 0.20$, and the same effect size from the group difference among the three parent–child interaction styles in that study. This resulted in our needing a total sample of 179 participants, or 68 additional children given the 111 that had been collected in the previous study. As such, the present experiment involved collecting a new sample of data, and comparing that new sample to an already-existing dataset. Of note is that all analyses presented here are novel; no analysis on the already-published data has been presented elsewhere.

2.2 | Materials

Nine custom-made electric circuit blocks were used in this study. Two blocks had LED lights that would activate in either red or green (depending on the direction of the current). Two blocks had motorized spirals (one orange and one purple, which could spin in either direction, dependent on the construction of the circuit). Two blocks were batteries (with windows revealing AA batteries). Two blocks were isolated buttons. One was a motorized red-green pinwheel block, which could also spin in either direction, depending on the construction of the circuit. Also present on the table at the start of the procedure were approximately 20 alligator clip wires, which could connect the circuit blocks. These stimuli are shown in Figure 1. These stimuli were identical to the ones used by Sobel et al. (2021). They were taken from the (now-closed) exhibit at a children's museum with the museum's permission.

FIGURE 1 | Circuit blocks used in this and the previous study.

2.3 | Procedure

The study procedures used here were approved by [Blinded for Review] IRB protocol #1701001674, *Belief revision in early childhood: Learning about learning in the lab and museum*. Children were tested in one of two informal learning environments. One is the same children's museum as the children in the previous study ($n = 30$). Twelve of those children were tested in the original exhibit. Eighteen were tested in another space after that exhibit became unavailable. The remaining children ($n = 38$) were tested at a local Zoo. Those children tested outside of the original exhibit were tested in a quiet location off of the main activity floor. Those tested at the zoo were recruited from a play area (away from all animal exhibits), and brought to a table in a quiet space, which was similar to those children tested in the museum.

Children sat at a table with the circuit blocks and alligator clips on it. No circuit blocks on the table were connected together. The researcher told the participating child, "I have some challenges for you to try." Parents were present while children were being tested (seated at a nearby table/chair). Parents were given the demographic information survey as well as a set of other questionnaires to fill out while the researcher started the procedure with the child.

The researcher presented children with a set of up to eight circuit building challenges. These challenges are described in Table 1. These were the same challenges, with the same procedure, performed in the same order as those in Sobel et al. (2021). After completing each challenge, children were asked if they wanted to try another challenge, or if they wanted to stop the task.

For each challenge, the researcher would first pose the challenge to the child (e.g., "Can you show me how to make the light turn on?") and would then wait for the child to attempt to create a circuit. If children were uncertain or hesitated after engaging in an inaccurate set of actions, they were given increasingly informative prompts until they were able to complete the challenge. First, the researcher encouraged children to continue working by saying, "It's tricky. Keep trying and see if you can figure it out." If the child stopped and asked for help, or tried the same thing, which continued not to work, the researcher provided further encouragement by saying, "try something different" or "what else can you try?" If the child stopped again, the researcher would ask whether the child wanted a hint (the exact language for each hint is shown in Table 1). At this point, the researcher would not interact with the circuit blocks or connect them; they only provided a hint. Finally, only after a hint was given and children explored further and were unsuccessful in solving the challenge, the researcher would ask whether children wanted the solution. If so, the researcher would instruct them as to how to connect the particular circuit. Importantly, after the assembly of

TABLE 1 | List of eight challenges, hints, and solutions used in the script of the study.

Challenge	Hint given (if necessary)	Solution given (if necessary)
1) Nearly complete circuit: Show a circuit with LED light, almost complete (Battery block has two alligator clips attached, LED has one side attached but not the other): "Can you show me how to make the light turn on?"	"What do you need to connect?"	"Try connecting it to the light" [Show exactly where to connect alligator clip]
2) Circuit with a new effect, from scratch: The LED Circuit used in Challenge 1 is pushed to the side of the table. Bring out the other battery block, extra alligator clips, and mechanical pinwheel effect block (not used during free play): "Now, can you make this one go?"	"What parts do you need to make it work?" or "is there a part missing?"	"Try connecting it to the battery on both sides." [Show exactly where to connect alligator clips]
3) Circuit with on-button: Once child has circuit with pinwheel going: "Great! OK, let's make it stop again." [Disconnect pinwheel from battery on both sides so it stops. Give child a button block] "Now, can you use this button to make it go?"	"What if you connect the pieces in a circle?" or "Can you put the button in between the battery and the pinwheel?"	"Try connecting this side of the battery to the button and that side to the pinwheel. Then connect the button and the pinwheel together." (showing children where to connect each clip)
4) Circuit with two effects: Once child has a circuit with a pinwheel and button: "Let's take away the button and start with the pinwheel spinning like before." [Reconnect battery & pinwheel; Give child the other LED block.] "Now, can you make the pinwheel and the light go at the same time? (using any of the pieces on the table)"	"Are both pieces connected to the battery?"	Try connecting both sides of the pinwheel to the battery and both sides of the light to the battery.[Show where to connect each clip]
5) Directional effects: [Disconnect existing circuits. Connect just the LED and battery as it was in the beginning, put pinwheel off to the side.] "Look, this light is green/orange. Can you make the light turn on in [the other color]?"	"What if you switch which sides are connected?"	"Try connecting this side of the battery to that side of the light." [Show exactly where to connect each clip.]
6) Directional effects, transferring strategies: [Push the circuit from challenge 5 off to the side, still in view. Bring out the pinwheel, a second battery, alligator clip wires.] "Let's connect this one again like you did before." [Letting child make the same pinwheel circuit again from Challenge 2.] "Look, it's spinning this way"—indicate clockwise or counterclockwise. "Can you make it spin the other way?"	"What if you switch which sides are connected?"	"Try connecting this side of the battery to that side of the light." [Show exactly where to connect each clip.]
7) Circuit with off-button: Once child has a circuit with pinwheel spinning again: "OK, now, can you use a button to make the pinwheel stop spinning?"	"What if you connect the three pieces in one line?	"Try connecting the battery to the motor on both sides and then connect the battery to the button on both sides." [Show where to connect each clip.]
8) Circuit with off-button, transferring strategies: [Bring back the circuit with the LED light from Challenge 5.] "Now can you use a button to make the light turn off?"	"What if you connect the three pieces in one line?	"Try connecting the battery to the motor on both sides and then connect the battery to the button on both sides." [Show where to connect each clip.]

the completed, functional circuit, children were prompted with an explanatory question: "How does that work?"

Our goal in reproducing the challenge phase of this study was to compare the results of children's engagement with and performance on the challenges with the previous data collected by Sobel et al. (2021). To that end, we used the same dependent measures: Children's engagement on the challenges was measured as the number of challenges children participated in volitionally (for a dependent measure with a range of 1–8). Children's performance on the challenges was measured as the proportion of challenges that children solved either on their own with no further instruction or only with encouragement on the part of the experimenter. We then consider two novel aspects of the previous experiments and the data we collected described in the results section below.

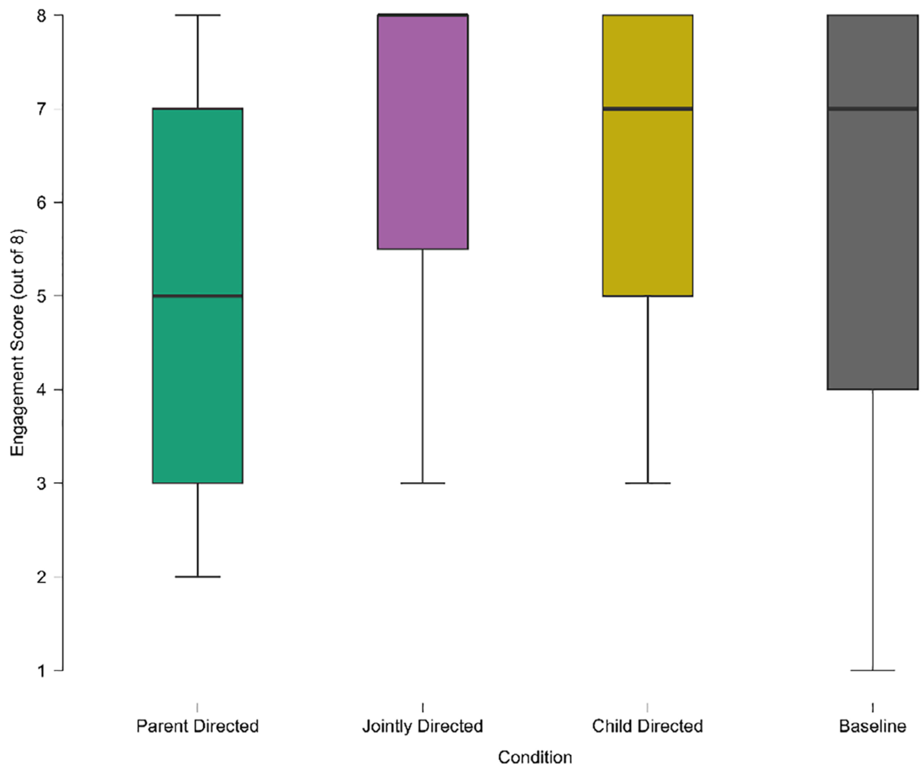

FIGURE 2 | Number of challenges children participated in (engagement score) for the baseline group and three parent–child interaction groups (lines show median scores).

3 | Results

All deidentified summary data files and data analysis code are available at http://osf.io/9a8nz/?view_only=84e67cea058e40399bdc55aed2dd8d7d. We present our results in three sections. First, we examined children's engagement and performance on the challenges collected here with the data collected by Sobel et al. (2021). Second, we reexamined the previously collected data, which included parents and children playing together with the circuit blocks before the challenges were administered. Our goal was to supplement our analysis of children's engagement on the challenges by considering how parents and children initially played at the exhibit together. Third, we considered the language children generated when they built the circuits during the challenges.

Although this study was not preregistered, the power analysis that we conducted was specifically designed to consider the analysis of children's engagement and performance in the previous study compared to the baseline condition collected here. These analyses are reported in the next section. As a result, we consider these analyses to be more confirmatory and all other analyses reported in the subsequent sections more exploratory in nature.

3.1 | Baseline Measures of Engagement and Performance

The results from the baseline condition, as well as the three parent-child interaction styles from Sobel et al. (2021) are shown in Figures 2 and 3. We first contrasted the number of challenges children participated in (our measure of engagement) and the proportion of challenges children solved on their own (our measure of performance) among the three parent-child interaction styles and the baseline condition. This revealed a main effect for engagement, Kruskal–Wallis $H(3) = 13.62$, $p = 0.003$, $\eta^2 = 0.06$, and a main effect of performance, Kruskal–Wallis $H(3) = 24.01$, $p < 0.001$, $\eta^2 = 0.12$.

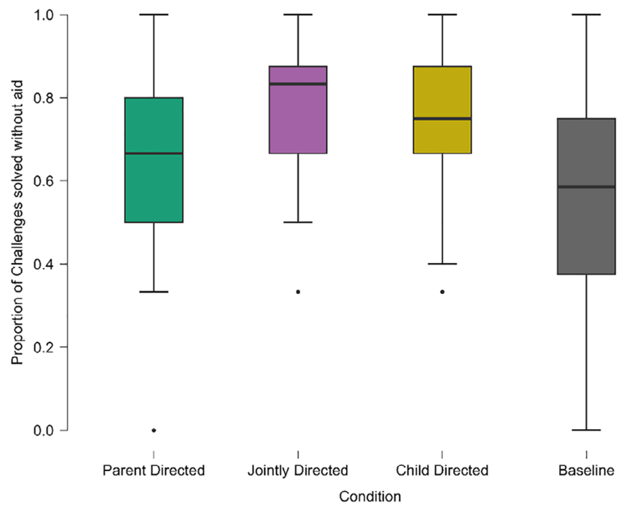

FIGURE 3 | Proportion of challenges children solved on their own (performance score) for the baseline group and three parent–child interaction groups (lines show median scores).

To analyze these findings further, we constructed a Generalized Linear Model assuming an ordinal distribution on children's engagement scores (i.e., the number of challenges they participated in), treating age, condition, and children's performance score as independent variables. The overall model was significant, Likelihood $\chi^2(5) = 52.25$, $p < 0.001$. There was a main effect of age, $\beta = 0.05$, SE = 0.01, 95% CI [0.03, 0.07], Wald $\chi^2(1) = 17.81$, $p < 0.001$, odds ratio = 1.05, such that as children got older, they participated in more challenges. There was also a main effect of performance score, $\beta = 2.24$, SE = 0.70, 95% CI [0.87, 3.62], Wald $\chi^2(1) = 10.27$, $p = 0.001$, odds ratio = 9.39, such that children had participated in more challenges as the proportion of the challenges they solved increased.

Looking at the differences between the parent-child interaction groups, children in the parent-directed dyads participated in fewer challenges than children in the baseline group, $\beta = -0.77$, SE = 0.39, 95% CI [−1.53, −0.02], Wald $\chi^2(1) = 4.04$, $p = 0.05$, odds ratio = 0.46. The differences in the engagement score between the jointly-directed group and the baseline group and between the child-directed group and the baseline group were not significant, $\beta = 0.13$ and 0.03 respectively, SE = 0.41 and 0.41, Wald $\chi^2(1) = 0.11$ and 0.01, $p = 0.75$ and $p = 0.94$.

We constructed a similar Generalized Linear Model to consider children's performance on the challenges, looking at age, condition, and engagement score as independent variables. This analysis resulted in a main effect of age, with children solving a higher proportion of challenges on their own as they got older, $B = 0.04$, SE = 0.01, 95% CI [0.01, 0.06], Wald $\chi^2(1) = 9.61$, $p = 0.002$, odds ratio = 1.04. There was also a main effect of engagement score, with children solving a higher proportion of the challenges on their own as they participated in more challenges, $B = 0.24$, SE = 0.07, 95% CI [0.09, 0.38], Wald $\chi^2(1) = 10.49$, $p = 0.001$, odds ratio = 1.27. Finally, the proportion of challenges children solved on their own in each of the parent–child interaction groups was higher than that of the baseline group, $B = 1.23$, 1.63, and 1.41 for the parent-, jointly-, and child-directed groups respectively, SE = 0.38, 0.37, and 0.38, 95% CI [0.48, 1.98], [0.90, 2.37], and [0.67, 2.15]. Wald $\chi^2(1)$-values = 10.38, 18.91, and 14.05, all p values ≤ 0.001, all odds ratios >3.42.

3.2 | Activity During First 30s of Free Play

The previous section suggested that when parents were overly directed during the free play, children's level of engagement with the challenges were lower than a baseline condition in which children did not receive any previous parent–child interaction. We suggest these findings are more consistent with the hypothesis that parent directedness results in lower engagement on the part of children in the subsequent related challenges. However, because children in the baseline condition did not receive the previous experience of playing with the circuit blocks with their parents, we do not know what their interaction style would have been. As such, we must revisit one of the alternative hypotheses—that parent-directedness is a more compensatory strategy on the part of parents for children being less engaged by the act of the playing with the circuits.

Parents presumably want their children to obtain the benefits of parent–child interaction, so they set more goals for children during play when they know that their children are less engaged. Because the baseline condition randomly sampled dyads from each possible interaction style, the present study cannot completely discount the possibility that many children in the baseline condition were simply less engaged by the challenges, and would have been coded as parent-directed if they and their parents had first been allowed to interact with the circuit blocks in a free play environment.

We went back to the 111 dyads who participated in the free play sessions collected by Sobel et al. (2021). We recoded these data to consider the ways parents and children engaged with each other during the first 30 s of their free play. If parents were more directed and set more goals because they observed lower levels of engagement from their children, we might also observe children being less engaged during the initial part of the play session. Coding the ways parents and children initially play together in the previous dataset allows us to provide an exploratory analysis that supplements what the addition of a baseline condition can do to discern among the hypotheses about parent-directedness outlined above.

Two undergraduate research assistants, blind to the hypotheses of the coding and to the other coding of the data (such as the parent–child interaction style or performance on the challenges), watched the first 30s of the free play session between parents and children. They coded the parent and the child (separately) for the way they interacted with the exhibit for the majority of this time frame. This was coded as (1) Not looking at or engaging with the exhibit materials, (2) Observing the materials without physically touching the exhibit, (3) Passively exploring the exhibit, which consisted of touching the exhibit materials without clear intention or purpose for building a circuit. Typically, this involved handing a circuit block or wire to their partner, or helping them accomplish a goal like connecting two blocks together. (4) Actively exploring the exhibit, by engaging in goal-directed behavior toward building a circuit. Agreement was calculated on their results of a subset of the data (20% of the children and a different 20% of the parents). Agreement was 89% (Kappa = 0.82). Disagreements were resolved by the second author. The coders then independently coded the rest of the dataset. The results of this coding are shown in Table 2.

The hypothesis in question was whether children's distribution of activity differed among the three interaction groups. It did not, $\chi^2(6) = 2.38$, $p = 0.67$, $\phi = 0.15$. Children in all three interaction groups were mostly coded as actively engaging with the exhibit materials. We constructed a multinomial model in which we tried to predict children's activity category from their parent's activity, the parent-child interaction style, and children's age. This model was not significant, Likelihood $\chi^2(6) = 7.07$, $p = .32$, and no individual independent variable significantly predicted children's activity during the first 30 s of the interaction.

This set of null results suggest that parents were not reacting to their children, but rather engaging in their own actions from the beginning of the interaction as opposed to reacting to their children initially[1]. There was a significant difference in the distribution of activity codes for the parents among the three interaction groups, $\chi^2(6) = 29.85$, $p < 0.001$, $\phi = 0.52$. Within the parent-directed dyads, the observed behavior predominantly involved parents engaging actively with the exhibit in collaboration with their children. In contrast, within the dyads where the goal-setting was jointly shared, parents were

TABLE 2 | Percentage of parent's and children's type of exploration during the first 30s of free play at the exhibit across the interaction groups.

	Parent-directed group	Jointly-directed group	Child-directed group
Parents			
No engagement	5%	8%	40%
Observing without touching exhibit	32%	64%	29%
Passive exploration	5%	3%	0%
Active exploration	57%	26%	31%
Children			
No engagement	0%	0%	0%
Observing without touching exhibit	8%	5%	6%
Passive exploration	5%	3%	0%
Active exploration	87%	92%	94%

more inclined to adopt a role of observation, focusing on both the exhibit and the manner in which their children interacted with it. Conversely, in scenarios where the dyads were more child-directed, parental engagement with the exhibit was notably minimal. These findings suggest that children's activity did not predict the way parents interacted with them, suggesting that parents' goal-setting behaviors were not a compensatory strategy for children's lack of engagement with the play activity.

3.3 | How Children Explained the Circuits They Built

Finally, in addition to considering how children performed on the circuit challenges in the absence of previous parent-child free play with the materials, we also considered an unexplored facet of the Sobel et al. (2021) data, compared with the baseline condition: how children talked about each challenge in response to the question "How does this work?" after the challenge was completed (either on the child's own or with help/instruction). The coding scheme is shown in Table 3. Note that one participant in the baseline condition had completely inaudible explanations and was not counted in the analysis. Two undergraduate research assistants, blind to the hypotheses, coded 45 randomly-selected participants. Agreement was 98% with disagreements resolved by the first author. The undergraduate students then coded the remainder of the data independently, asking questions of the first author if necessary.

We performed three exploratory analyses with this coding[2]. The first examined whether there were differences between the parent–child interaction conditions and the baseline condition in children's explanations. Table 4 shows the mean percentage of unobservable causal explanations and causal explanations more generally (defined as children generating either an unobservable mechanism or an observable feature). As shown in the table, there was no difference among the four groups regarding the number of causal explanations that involved unobservable mechanisms, but there was an difference in the number of causal explanations they generated overall, Kruskal–Wallis $H(3) = 16.69$, $p < 0.001$, $\eta^2 = 0.08$.

To analyze these factors in more detail, we constructed two Generalized Linear Models assuming an Ordinal Response, looking at the role of age (in months), PCI condition (parent-directed, joint-directed, child-directed, and baseline) and the proportion of challenges children solved on their own. In the first model, we considered the number of unobservable causal mechanistic explanations children generated as the dependent variable. This model showed only a significant effect of age, with older children generating more unobservable causal mechanistic explanations, $\beta = 0.04$, SE = 0.01, 95% CI [0.02, 0.07], Wald $\chi^2(1) = 10.97$, $p < 0.001$. When we considered causal mechanisms overall as the dependent variable (combining both observable and unobservable mechanisms), the results were different. There was no significant effect of age, Wald $\chi^2(1) = 2.65$, $p = 0.11$. Instead, there was a significant effect of the proportion of challenges children solved on their own, $\beta = 1.69$, SE = 0.71, 95% CI [0.30, 3.08], Wald $\chi^2(1) = 5.64$, $p = 0.02$, and a main effect of condition, Wald $\chi^2(3) = 7.77$, $p = 0.05$, with children generating significantly more causal explanations in the child-directed, $\beta = 1.14$, SE = 0.45, 95% CI [0.26, 2.03], Wald $\chi^2(1) = 6.39$, $p = 0.01$ and the jointly-directed groups, $\beta = 0.89$, SE = 0.43, 95% CI [0.04, 1.74], Wald $\chi^2(1) = 4.16$, $p = 0.04$, than the baseline group. This suggests that participating in the free play session with the parent was not related to an increased likelihood of explaining the circuits based on an unobserved causal property. The play sessions with parents, however, were related to a higher likelihood of generating causal explanations in general, particularly when the interaction style was not parent-directed.

The second analysis examined whether there were relations between children successfully solving the challenge on their own and their explanation of how the circuit works. We constructed a Generalized Linear Mixed Model assuming a Binomial dependent variable on whether children generated an unobservable causal mechanistic explanation for each challenge, with children's age, parent-child interaction condition (including Baseline), challenge number, and whether children solved the challenge on their own (our measure of performance) as independent variables. This analysis indicated a significant main effect of age, $\beta = 0.15$, SE = 0.06, $t(2.74) = 2.74$, $p = 0.006$, suggesting again that older children were more likely to provide an explanation that involved unobservable causal mechanisms. No other significant main effects or interactions were observed.

A second GLMM was constructed with children generating any causal explanation (combining the observable and unobservable mechanisms) as the dependent variable, with the same independent variables. This analysis also revealed a significant main effect of age, $\beta = 0.17$, SE = 0.06, $t(4.18) = 4.18$, $p < 0.001$, with no other significant effects or interactions. This analysis suggests that there is not a significant relation between solving a challenge on one's own and generating a causal explanation for how the completed circuit works.

Finally, given that the children who engaged in free play with their parents sometimes generated more causal explanations overall, we can ask whether any factor of the parent-child

TABLE 3 | Coding scheme for "How does it Work?" question.

Code	Description
Unengaged/no response	The child appears to be not focusing on anything or anyone and is not displaying active scanning or interest in the external setting. The child appears involved with any other person, object, or activity, although he or she is obviously actively scanning or avoiding looking at or engaging with a parent or other child (e.g., the child continues to play with the toys, the child looks toward parent for the answer, the child plays/talks with another child in the room)
Outcome-based/labeling	The child provides an answer/description and/or behavior that focuses only on the outcome (e.g., "It just works" or points to ONLY a non-battery circuit block). Or the child provides a label or a description of the stimuli that is non-descriptive of the actions involved within the challenge ("It goes green" or "It's spinning"). This could also be a demonstrative action on the part of the child of connecting and disconnecting the circuit.
Non-causal mechanism	The child provides a description that is noncausal and is outside of reality (e.g., "The battery talks to the light"; This is magic).
Causal explanation based on observable feature	The child provides a description of how the circuit blocks work that is observable. This includes responses that involve words or word groups such as connections, circle, parts, battery, spinner, and wires (e.g., "The battery makes the light turn on."). This would also include when a gesture of connection is made with a verbal response.
Causal explanation based on an unobservable mechanism	The child provides a description of how the circuit blocks work that is unobservable to the researcher (e.g., Electricity, energy, force, positive/negative, flow: "Using the wires, we created a circuit", "The energy flows through the wires in order for the light to turn on.").

TABLE 4 | Percentage of explanation type generated on the challenges across conditions.

	Parent-directed	Jointly-directed	Child-directed	Baseline	Difference among groups
Unobservable mechanisms only	20 (32)	21 (23)	23 (34)	14 (25)	No. Kruskal–Wallis $H(3) = 2.22$, $p = 0.53$
Any causal mechanism (unobservable + observable feature)	81 (31)	88 (17)	93 (13)	66 (37)	Yes. Kruskal–Wallis $H(3) = 16.69$, $p < 0.001$

interaction related to the kind of explanations children generated in the challenges. Because numerous studies suggest links between the causal language parents generate and children's learning (e.g., Chandler-Campbell, Leech, and Corriveau 2020; Jant et al. 2014; Leech et al. 2020), we considered the proportion of causal language children heard from their parents during the free play. This was significantly correlated with the proportion of unobservable mechanistic explanations they generated, $r_s(108) = 0.20$, $p = 0.03$, but not the overall proportion of causal explanations (unobservable + observable features) they generated, $r_s(108) = -0.12$, $p = 0.21$. Children's own causal language, however, did not significantly correlate with the proportion of unobservable causal explanations they generated, $r_s(108) = 0.10$, $p = 0.30$, but their age did so, $r_s(108) = 0.33$, $p < 0.001$. When controlling for age, the proportion of causal language children heard from their parents during the free play marginally correlated with the frequency of unobserved causal explanations they generated, $r_s(107) = 0.18$, $p = 0.06$.

4 | Discussion

The present study compared children's engagement and performance on a set of circuit building challenges given no previous exposure to the circuit block materials with a group of children, initially described in another paper, who had previously received a free-play session with the circuit blocks with their parents. We also reexamined this previously published data to ask novel questions about children's engagement with the circuit challenges and their learning from the free play. The results have implications for hypotheses related to the relation between parent–child interaction during play and children's engagement and learning. We described these implications in the sections below.

4.1 | Implications for Engagement

We described three hypotheses explaining how parent-directedness during play might be related to children's engagement with the circuit building challenges they were given. The first was that parent-directedness during an activity related to lower engagement on the part of children when challenged on their own. The second was that parent-directedness prevented a benefit of parent-child interaction. The third was that parent-directedness was a reaction to children's own lower engagement with the play (and hence also the challenges).

We suggest these findings are more supportive of the first hypothesis than the other two, with one important caveat. It is plausible that parent directedness relates to children's lower engagement and is also a reaction to children's lower overall engagement with novel situations. That is, these possibilities are not necessarily mutually exclusive. Although we did not observe any differences in children's activity level when they started playing among the parent-child interaction styles, this analysis was exploratory. Further studies, for example, could measure aspects of children's temperament, like surgency, which might relate to how they would explore a novel environment without any other information. This is a possibility for future investigation.

However, our speculative conclusion that parent directedness relates to children's lower levels of engagement when tested on their own parallels findings by Sobel and Stricker (2022). They introduced parents and children to a home-based activity centered around the importance of soap. They had dyads engage in the activity remotely, and coded their interaction using the same parent-directed, jointly-directed, and child-directed coding system. However, they also included a condition in which dyads did not participate in the demonstration, but rather watched the demonstration on a video without ever doing it themselves. This condition could be seen as similar to the baseline condition used here. They found that children in the parent-directed dyads were less engaged with using soap in related handwashing activities during the subsequent week, not only compared to the jointly-directed dyads, but to this video group as well (whose engagement was no different from the jointly-directed group).

Why might parent-directedness reduce children's engagement with the challenges? Some researchers (Leonard et al. 2021; Sobel 2023) suggest that when parents take over actions for their children or set too many goals for children's play, they become less engaged by the activity specifically because children come to recognize that the parent believes they must be present for the child to accomplish goals. More generally, parent-directedness might correspond to overparenting (e.g., Grolnick and Pomerantz 2009). Obradović et al. (2021) found significant relations between overparenting and parental scaffolding (parents' support of children's goals). When parents set the majority of goals for children during a play session, they might implicitly communicate to their children that they (i.e., the parent) must be involved in the activity. Indeed, Sobel et al. (2021) found that parents in the parent-directed dyads made many more statements in which they talked specifically about what they wanted to do (or wanted their child to do) when building the circuits. This could communicate to children that their parent has to be present for them to participate in the activity. Children are indeed sensitive to the broader interactive environment created by parents, which affects their beliefs about their own competence (e.g., Skinner et al. 2005). Parental directedness, therefore, could result in children coming to think that the activity is not for them, and when they are tested on their own in the challenges, they are less engaged to participate in an activity. Although this is a speculative explanation, it is an important consideration for future studies.

4.2 | Implications for Learning

Across all the parent-child interaction styles, the proportion of challenges that children solved on their own was greater than children in the baseline condition presented here. This is an unsurprising finding, given the more straightforward hypothesis that parents promote both explanation and exploration during free play in museum exhibits (Legare, Sobel, and Callanan 2017), and that numerous studies suggest parent-child interaction promote children's learning from exhibits (e.g., Andre, Durksen, and Volman 2017; Fender and Crowley 2007; Puchner, Rapoport, and Gaskins 2001). Parents' knowledge of the exhibit informs the learning process during such interactions (e.g., Acosta et al. 2021; Franse, Van Schijndel, and Raijmakers 2020). Additionally, Vandermaas-Peeler, Massey, and Kendall (2016) found that parents who were instructed in ways to provide guidance to their children about learning from the exhibit had children who answered more questions correctly about the exhibit after they played at it than parents who were only instructed to talk to their children. All of these findings suggest that parent-child interaction promotes children's learning, which is consistent with our findings regarding children's performance on the challenges without previous interaction at the exhibit.

In addition to examining children's performance on the challenges, we also considered the explanations they generated for how the circuits worked. Overall, children generated fewer causal explanations of the circuits they built during the challenges in the baseline condition than in the previous study. This suggests that parent-child interaction during free play benefitted children's understanding of the circuits.

Children's ability to build the circuit on their own, however, did not significantly relate to the way they explained how the circuit worked. This is slightly different from Glauert's (2009) results, who found that children's explanations about how circuits worked related to their correct predictions about novel circuit's efficacy. Because we did not want children to become frustrated by any challenge, they participated in each challenge until the circuit was built using a system of scaffolded guidance. It might be that once children saw the completed circuit, they could generate an explanation of how the circuit worked, regardless of whether they could build it on their own or needed more direct instruction. Thus, our procedure was not a direct replication of the Glauert study, and the hypothesis that children's explanations relate to their causal knowledge might hold. Indeed, several studies have shown that children's explanations of a phenomenon are related to their causal knowledge in that domain more generally (e.g., Legare 2012; Schult and Wellman 1997; Sobel 2004), which is generally consistent with the hypothesis that explanatory abilities tap into their abstract, coherent, domain-specific causal knowledge (e.g., Gopnik et al. 2004). This might inform museum practice moving forward; consistent with explanation-based learning (Basch and Wang 2024), encouraging children to explain how exhibits function might be more conducive to facilitating better understanding of the exhibit content (e.g., Attisano, Nancekivell, and Denison 2021; De Witt 2008; Pagano, Haden, and Uttal 2020).

This finding more generally raises the question of how to define learning from free play (e.g., Hein 2002; Hooper-Greenhill 2007) as well as how to define learning itself (e.g., Barron et al. 2015; De Houwer 2013; Sobel and Letourneau 2015). Solving challenges on one's own considers children's ability to demonstrate knowledge—that is, whether children can engage in a particular behavior and whether that capacity changes over time (e.g., Perner 1991). Generating explanations, in contrast, is more about linguistic competence and a mechanistic understanding of the relations that underlie the generation of that behavior (e.g., Legare and Lombrozo 2014). One might be able to solve challenges through trial and error or through an exploratory process, whereas generating explanations of how the parts of the circuit are related to one another requires a more explicit representation of the underlying causal structure.

Because there was a marginal correlation between the proportion of causal language parents generated and children's causal explanations that involved unobservable mechanisms, we might hypothesize that parents could be introducing such mechanistic language to their children during the play. But to isolate whether parents' language relates to the explanations children generate, or if other facets of their interaction with the circuit blocks relates to their learning, what is necessary is to contrast the present study with a condition in which children could play with the circuit blocks first without their parent, and then participate in the same circuit-building challenges used here. If parental interaction facilitates children's explanations, then one might expect similar results to our current baseline condition—no difference in overall causal explanations, but a reduction of explanations that appeal to unobservable mechanisms, which are presumably mechanisms that are more difficult to figure out without an adult's input. Such a novel baseline condition might also relate to the hypotheses about children's engagement described above. If parents overly setting goals relates to a reduction in children's engagement, we might see similar levels of engagement as our baseline condition here. However, if parental goal setting is more of a reaction to children's lower engagement, then we might expect that children's engagement during the play on their own to relate to their engagement with the circuit-building challenges. This is a question for a future investigation.

4.3 | Limitations and Conclusion

The motivation of this study was to compare the novel baseline data we collected with the previous data collected in the same environment. However, because of the COVID pandemic and its effects on the museum, this proved not to be possible during the course of data collection. Although some children in our baseline condition were tested in the same exhibit, others were tested in a different part of the museum, while others were tested with the same components, but in a different environment. Critically, in all cases, families were brought out of the main exhibit area (the museum floor or a play space at the zoo) and into a more private area, where they could interact with the experimenter and the materials in a fairly distraction-free space. Post hoc analysis revealed no difference in engagement or learning in baseline children tested in the museum ($N = 30$) and children tested at the zoo ($N = 38$).

Another difference is that children who participated in the baseline condition without prior exposure to the circuits may have approached the challenges with a different level of familiarity than those in the parent–child interaction groups from Sobel et al. (2021). This was by design. To differentiate between the hypotheses about the relation between parent-child interaction and children's engagement, we wanted a condition in which children had no exposure to the circuit blocks. That we found similar levels of engagement between the baseline condition and some of the parent-child interaction groups suggests that this lower familiarity with the exhibit components does not generally affect children's engagement. Rather, it supports the hypothesis that parent-directedness is related to children being less engaged. That we found that all of the parent-child interaction styles supported better performance on the challenges than the baseline condition was also not surprising, as these learning outcomes should be related to the degree of familiarity children have with the circuit block components.

To conclude, the present study found that children who were given a set of circuit construction challenges without any prior exposure to the circuit block materials were similarly engaged by the challenges as children who had previous exposure to the materials with their parents in a free play setting, as long as their parents were not overly directive in setting goals for that play. Children in this baseline group, however, were not as good at solving the challenges on their own. They were also generally less likely to explain how the completed circuits built during the challenges worked with causal explanations. Overall, this suggests the possibility that overly directive goal-setting during children's play might relate to children's engagement, but not necessarily their learning during a STEM activity.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are openly available in OSF at https://osf.io/9a8nz/?view_only=84e67cea058e40399bdc55aed2dd8d7d.

Endnotes

[1] Because this analysis was exploratory, it is important to consider whether it is sufficiently powered. We conducted an a priori power analysis assuming the same effect size as that of the previous study ($\omega = 0.37$). Assuming this chi-squared analysis with $\alpha = 0.05$, $\beta = 0.20$, this power analysis suggested that 102 participants were needed. Thus, the sample of 111 participants seems appropriately powered. Moreover, we did a post-hoc power analysis on the existing analysis reported above to calculate the approximate power. That analysis found that $\beta = 0.54$ for this finding, which we consider higher than what would be appropriate.

[2] Like the analyses in the previous section, because of the exploratory nature of these analyses, it is important to consider whether they are sufficiently powered. Critically, the analysis strategy described in this section is the same as the analysis strategy in the first section, which was the basis of our power analysis. As such, we believe that these analyses are also sufficiently powered.

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