FLEXIBLE MINDS IN CONTEXT: PEDAGOGY, VISUAL EXPECTATIONS, AND EXECUTIVE FUNCTION IN CHILDREN'S EXPLORATION

by

MEGAN SEBREE

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Approved: *Dare Baldwin, Ph.D.*
Primary Thesis Advisor

Pedagogy elicits trade-offs in children's learning, enhancing attention to target information yet also limiting broad exploration – a phenomenon known as the "double-edged sword" of pedagogy. The present study extends understanding of this phenomenon, examining how verbal pedagogy cues interact with other factors (e.g., prior expectations regarding the information presented, executive function (EF) skills) to jointly shape children's exploratory play.

220 children (3-7 years, M=59 mos, 111 female) visiting a museum were randomly assigned to one of four conditions differing in both verbal pedagogy (knowledgeable: "This is how my toy works" vs. naïve "I wonder how this toy works") and prior expectations about a demonstrated action (consistent: pressing a button to activate a light vs. violation: waving a finger in the air to activate a light). Thereafter, children played with the toy light themselves and then participated in the Head-Toes-Knees-Shoulders task assessing their EF skills. We predicted that both naive pedagogy and violation of prior expectations would elicit enhanced exploration, especially when experienced in combination. We also expected that children with strong EF skills would more flexibly modulate their exploratory activity in relation to variations in pedagogy and prior expectations than children whose EF skills were weaker.

We measured exploration via the number of unique action types children displayed (i.e., counting any action type differing from the demonstrated press or wave). As predicted, children displayed significantly increased exploration when the demonstration violated their prior expectations. Naïve pedagogy significantly amplified this exploratory response to violated expectations. Also, as predicted, EF skills mattered. Higher EF skills were associated with enhanced flexibility, as predicted. Specifically, higher EF skills were associated with greater sensitivity to variations in pedagogy and to the actions demonstrated, while also linked to discovery of new causal functionality during exploratory play.

In sum, children's prior expectations and self-regulatory skills played a key role in determining which edge of the sword they exhibited in relation to adults' pedagogical efforts. Open-ended ("naive") pedagogy produced greatest exploration when expectations were violated, and children with superior EF skills were most responsive to these factors.

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Introduction

Although one might associate experimentation with experienced scientists, children from an early age display proficiency in key aspects of scientific reasoning. In *The Scientist as Child*, Alison Gopnik (1996) explicitly likens children to little scientists whose causal learning involves forming, testing, and revising hypotheses about the world (Gopnik & Wellman, 2012). Within pedagogical encounters, or interactions in which a knowledgeable adult intentionally aims to teach, children are not passive recipients of information. Rather, they actively infer the speaker's intent and the scope of what is to be learned based on subtle communicative cues (Shah, 2021).

Children's pedagogical inferences give rise to a central tension in early learning. Pedagogical cues can efficiently guide children's attention toward relevant information, yet they may also limit broader exploration by signaling that the demonstrated information is complete and exhaustive - a phenomenon known as the "double-edged sword" of pedagogy (Bonawitz et al., 2011). As such, early learning is reframed as an active interplay between informant and child rather than either a solely adult-imposed or child-driven venture. Inferences children draw regarding adults' pedagogical goals sometimes accelerate learning but may also narrow its scope.

Put another way, which edge of the double-edged trade-off emerges depends on how children interpret the pedagogical context (Gelman et al., 2013), a process shaped by factors such as their prior expectations and their ability to flexibly regulate attention and behavior (Carlson & Moses, 2001). In practice, responses to pedagogy are therefore unlikely to reflect the influence of a single factor, but instead arise from the interaction of multiple influences, including expectations about how objects work and developing cognitive skills.

For those invested in supporting children's learning in pedagogical contexts, such as educators, tutors, and parents, a central question is how instruction can foster both efficient learning and open-ended exploration. The present thesis addresses this question by examining how adults' pedagogical cues interact with children's expectations and EF skills to shape engagement in exploratory play.

Pedagogy as a Pragmatic Phenomenon

Children are sensitive from infancy onward to adults' pedagogical engagement with them; that is, they can detect when an adult intends to communicate information for the purpose of teaching (Gergely & Csibra, 2006; Sage & Baldwin, 2012). Infants reveal clear evidence of inferring others' pedagogical intent from a variety of pragmatic cues, such as intentional eye contact and ostensive, or joint, signaling (Csibra, 2010). These inferences inform children's interpretations of pedagogical instances, influencing how they interpret the breadth and depth of the information that follows (Gelman et al., 2013).

By preschool, children have developed robust assumptions regarding pedagogical encounters, and they deploy these assumptions readily. They expect that pedagogical informants, like teachers, intend to communicate information that is relevant to the learning context, truthful, and sufficient for understanding the task at hand (Baldwin et al., 2008; Grice, 1975). As such, children often treat pedagogical demonstrations as intentionally selected and fully informative. These pragmatic inferences guide children's interpretation of instructional content and are a natural occurrence in children's hypothesis testing capabilities (Gopnik, 1996). This ability actively influences not only what children learn, but also how they explore.

Furthermore, subtle communicative cues shape how children interpret pedagogical intent. Even in the absence of explicit instructional statements, prosodic features, such as intonation and emphasis, can signal whether a question is pedagogical, guiding children's inferences about the purpose of the demonstration (Bascandziev et al., 2025). These cues are recognized by both communicators (e.g., parents and teachers), as well as learners (i.e., children). Consistent with this, Schneidman et al. (2016) found that social demonstrations can shape children's spontaneous exploratory behavior, with instructed actions guiding attention and reducing variability in children's own exploratory play. Together, this work shows that children's sensitivity to subtle communicative cues and social contexts allows pedagogy to both direct engagement and constrain exploration.

The present thesis aimed to expand our understanding of how children's pedagogical inferences interact with prior expectations and EF skills to shape exploratory play. To investigate this, I used the method originally developed to illustrate the double-edged sword of pedagogy phenomenon, which I will describe next.

The Double-Edged Sword of Pedagogy

As mentioned earlier, although children's inferences in pedagogical encounters can support efficient learning, such inferences also introduce a fundamental trade-off. Bonawitz and colleagues (2011) demonstrated that pedagogical cues can act as a "double-edged sword": instruction can streamline children's attention to relevant information but simultaneously limit broader exploration by signaling that the information is exhaustive. In this sense, pedagogy can serve to constrain children's learning instead of enhancing it.

In the double-edged sword study, children were first introduced to a novel object by an adult researcher. The object was visually complex, containing multiple manipulable components. The researcher demonstrated a single action on the toy (pulling out a tube) which unexpectedly produced a squeaking sound. In a between-subjects approach, each child experienced one of four introductory framings in association with this demonstration: a pedagogical framing ("Look at my toy! This is my toy. I'm going to show you how my toy works. Watch this!" immediately before demonstrating the action, and after the demonstration said, “Wow, see that? This is how my toy works!”); an interrupted framing (exactly the same as the pedagogical framing, except the researcher stopped after the demonstration and left the room immediately); a naïve framing (the researcher appeared to pull the tube accidentally, producing the squeak, and then said, “Huh! Did you see that? Let me try to do that!”); or a baseline framing (“Wow, see this toy? Look at this!” with no demonstration of the pulling action or squeaking). Importantly, although only one function was demonstrated, the toy had four distinct capabilities: pulling the tube produced a squeak, pressing a different tube caused a light to flash, pressing a pad played music, and looking inside two black tubes revealed mirrors.

Children in the pedagogical condition spent a greater proportion of their playtime engaging with the demonstrated function yet interacted with the toy for less time overall and performed significantly fewer unique actions than children in the other conditions. While pedagogy supported exploratory play of the target function, it diminished children’s curiosity and broad exploration. Thus, pedagogy did not simply help or hinder learning, but instead, it reorganized the distribution of children’s exploratory actions. The authors concluded that, depending on the goals of an educational context, trade-offs arising from children’s inferences about teachers’ communicative intent may yield distinct learning outcomes, making the double-edged sword of pedagogy a critical starting point for understanding how instructional cues shape children’s learning.

A growing body of research demonstrates that multiple factors influence the double-edged sword phenomenon, characterizing the extent to which instruction constrains children’s exploration. For example, when instructional contexts encourage active participation, children may engage in broader exploration while still allocating attention to relevant target functions (Yu et al., 2018). Yu and colleagues (2018) introduced a *pedagogical questioning* condition, wherein a knowledgeable teacher prompted children's engagement through questions. This approach supported efficient knowledge transmission while simultaneously promoting exploratory behavior. Similarly, Zsoldos and colleagues (2025) found that providing children with instructed exploration can preserve exploratory behavior when pedagogy does not strongly imply informational completeness.

Children's Prior Expectations and Visual Affordance

Another key determinant of children's inferences and exploratory behavior is their prior expectation about how objects work, which is often shaped by visual affordances. Interestingly, the double-edged sword of pedagogy literature thus far has not concerned itself with the operation of such object expectations, even though they might interact with pedagogical inferences to shape children's learning.

Object expectations often arise from visual affordances, which are perceptual cues that suggest possible actions based on prior experiences and inferred causal structure (Gibson, 1986). For example, a prominent button atop an object might afford pressing, leading children to expect that pressing the button will trigger an effect (see paragraph below). Such expectations guide children's hypotheses regarding both a) the actions people are likely to undertake with objects they encounter, and b) what those actions are likely to produce in terms of causal outcomes.

Even preverbal infants have been shown to be capable of registering visual affordances. From early in development, infants anticipate how an object's structure constrains possible actions, such as adjusting their grasp in advance based on the shape and orientation of an object (Barrett et al., 2008). Infants also demonstrate sensitivity to containment relations, distinguishing between objects that afford insertion or enclosure and those that do not, suggesting an early appreciation of object relationships rather than just visual features (Caron et al., 1988).

This early sensitivity to object affordances does not operate in isolation. Rather infants' expectations about how objects are used appear to be embedded within a naïve theory of rational action. In a seminal paper, Gergely and colleagues (2002) found that infants' imitation depends on whether the observed action appears rational in a given context. Infants observed an adult activate a light by touching the lamp with their forehead. When the adult's hands were visibly constrained (e.g., wrapped tight inside a blanket for warmth), infants were more likely to use their hands to activate the light, actively assuming that the adult's unusual forehead-to-light action was necessary due to context. When the adult's hands instead were free (e.g., openly visible on the tabletop), infants tended to reenact the forehead-to-lamp action, inferring that the unusual method of turning on the light must have been necessary, otherwise hands would have been used. Thus, children (even infants) do not simply copy the actions they see others undertake with objects. Instead, they appear to base their own actions on inferences about how others' actions correspond with what rational action would dictate.

Such reasoning has direct implications for the inferences children draw in pedagogical encounters. Gopnik and Sobel (2000) demonstrated that children interpret others' actions differently depending on whether those actions occur in a pedagogical context. When a pedagogical demonstration violates visual affordance expectations, children may not reject the pedagogical nature of the interaction but instead reinterpret it. That is, within a framework of rational action, a violation of expectation may prompt children to infer that the demonstrated action was performed for a reason, yielding additional inferences about the adult's intent. For example, if a child is shown that a button can be activated by waving a finger over it rather than pressing it, the child may infer that the waving is intentionally informative or privileged, rather than concluding that the interaction is non-pedagogical.

More broadly, expectation violations have been shown to elicit changes in children's exploration and hypothesis testing. Children engage in systematic and informative explorational experiments following demonstrations that violate their expectations (van Schijndel et al., 2014), and the inductive inferences they generate are shaped by both object categories and the sequence of demonstrated actions (Schulz, 2012; Yu & Kushnir, 2014). Taken together, children's responses to pedagogy are influenced by expectations regarding how objects should function and why actors opt for specific actions. Alignment with or violations to these expectations result in children actively altering their attention, inferences, and subsequent exploratory behavior.

Jumping off from such findings, the present thesis examined how violations to children's expectations about object action might influence their inferences during pedagogical encounters in ways that shape their subsequent exploratory play.

Executive Function as a Potential Moderator

Children's executive function (EF) skills – cognitive processes that support self-regulation, including working memory, cognitive flexibility, and inhibitory control – play a pivotal role in regulating how children attend to, interpret, and act on information in learning contexts. EF develops rapidly across preschool years and has extended developmental impacts (Clancy, 2016). As well, EF shows substantial individual variability across the lifespan (Benson et al., 2013; Carlson & Moses, 2001). These individual differences are especially relevant in educational settings, where children's attention, behavior, and flexibility are all intimately involved in the success of the learning enterprise.

The development of EF is closely linked to children's learning outcomes. Regardless of general intelligence, stronger EF skills in early childhood are predictive of later academic success and more adaptive learning strategies (Blair & Razza, 2007; McClelland et al., 2007). In pedagogical encounters, EF plays a critical role in inhibitory control and cognitive flexibility, potentially moderating trade-offs between instruction and exploration. When instruction highlights a specific action or function, children must inhibit the tendency to explore alternative possibilities in order to align with the implied pedagogical goal (Bonawitz et al., 2011). Children with stronger inhibitory control may be able to better suppress impulsive responses and flexibly allocate attention. As a result, they may engage more selectively with the demonstrated function or disengage from it to pursue exploratory behavior, depending on whether they interpret the demonstration as pedagogical or non-pedagogical (Kochanska et al., 1996).

Regarding visual affordances, EF may also influence how children incorporate prior expectations. For example, when an observed action aligns with prior expectations, EF would not be required to actively update knowledge of the object. However, when an encounter includes a violation of visual affordance expectations, children must inhibit their default assumptions and flexibly revise their understanding of the object's causal structure and the demonstrator's intent (Gopnik et al., 2004; van Schijndel et al., 2015). EF may moderate how children treat such violations, with pedagogy likewise playing into this relationship.

To assess individual differences in EF, the present thesis utilized the Head-Toes-Knees-Shoulders (HTKS) task, a previously validated behavioral measure of EF in early childhood (Ponitz et al., 2009). The HTKS task requires children to inhibit a prepotent response by doing the opposite of an adult's verbal command (e.g., touching their head when instructed to touch their toes), thereby offering information about children's inhibitory control, working memory, and attentional regulation. Children's performance on the HTKS task has been shown to predict academic achievement and their ability to adapt to classroom expectations (Ponitz et al., 2009).

Importantly, the HTKS task assesses EF in contexts directly resembling pedagogical interactions; children must attend to the directions of an adult, suppress a prepotent response, and flexibly apply a rule under increasingly demanding conditions. Thus, the task provides a meaningful framework for examining individual differences in EF, while keeping our chosen population of preschool-aged children fully and actively engaged in the study. Assessing EF alongside children's attentional responses allowed the present study to examine how self-regulatory skills moderate trade-offs inherent in pedagogical encounters, providing insight into why instruction may support learning for some children while constraining exploration for others.

The Present Study

Although pedagogy, action expectations, and executive function are all insightful aspects of children's learning, they have largely been examined independently. Research on the double-edged sword phenomenon has primarily focused specifically on instructional cues and their influence on exploration, while a separate line of work has examined how violations of children's expectations shape attention. Similarly, studies of EF tend to investigate how self-regulatory skills relate to learning outcomes without incorporating the interaction of these skills and pedagogical contexts.

As children typically do not experience these factors in isolation, the present study extended prior work on the double-edged sword of pedagogy by examining the interaction of the three – adult-directed pedagogy, visual affordance cues (action expectations), and children's EF skills – to examine their joint effects on preschoolers' exploration. Examining these factors together therefore provides a more complete understanding of how children's exploratory learning unfolds.

Building on research demonstrating that pedagogical cues can constrain exploration while simultaneously supporting efficient learning (Bonawitz et al., 2011), this study investigated under what conditions, and for whom, such trade-offs emerge. Specifically, I aimed to address:

Research Question 1: To what degree will verbal pedagogy, action expectations, and their interaction shape children's exploratory play activities?

Research Question 2: To what degree will executive function (EF), while controlling for age, moderate the effect of verbal pedagogy and action expectations on children's exploratory play activities?

In this paper, hypotheses examining the effects of pedagogical framing and visual affordances on children's play behavior were confirmatory. In contrast, hypotheses examining relations between EF and the other study variables were exploratory in nature and intended to generate hypotheses for future research.

Consistent with Bonawitz et al. (2011), I expected to replicate the double-edged sword pattern: children in knowledgeable pedagogical conditions would devote a greater proportion of play to the demonstrated action but engage in fewer unique actions overall relative to children in naïve verbal pedagogy conditions. However, because the present toy was intentionally simpler and contained fewer competing affordances than the original paradigm, I anticipated that the effect of verbal pedagogy on children's exploratory play might be attenuated relative to prior findings. That is, I suspected that children might have difficulty identifying things to do with the toy other than pressing and waving (when they'd seen waving demonstrated), thereby reducing the opportunity for variation in verbal pedagogy altering the breadth of exploration with the toy.

With respect to EF, I expected individual differences in EF to moderate children's sensitivity to pedagogical cues. Specifically, I hypothesized that children with lower EF skills might be less attuned to subtle differences in pedagogical framing and instead rely more heavily on their prior expectations or the most perceptually obvious affordances. In contrast, children with higher EF skills might be more sensitive to pedagogical context and therefore more likely to exhibit the trade-off characteristic of the double-edged sword phenomenon; they might selectively focus on demonstrated information in pedagogical contexts while flexibly exploring alternatives in non-pedagogical contexts.

Because prior work has not directly examined EF as a moderator of pedagogy and affordance-based expectation violations, predictions regarding EF interactions were exploratory but theoretically grounded in research linking EF to inhibitory control, cognitive flexibility, and adaptive learning in instructional settings.

Our addition of visual affordance and cognitive ability in the study of pedagogy addresses a critical gap in current understanding of how children process and respond to pedagogical interactions. In combining these variables, we aim to investigate the joint contribution of multiple mechanisms shaping children's exploration and learning. These findings have implications for designing educational interventions that accommodate individual differences in EF and support educator goals in a variety of learning environments.

Methods

This study was conducted as part of a larger dissertation project that included additional attentional measures (i.e., dwell time) that were not analyzed for the present thesis. The primary goal was to examine how children's pedagogical inferences, action expectations, and EF interact to shape exploratory play.

Participants

A total of 220 English-speaking children between the ages of 2 and 7 participated in the study (M_{age} = 58.99 months; range = 2.75-7.33 years, 111 female). Children were recruited from 2024 and 2025 at two children's science museums, the Oregon Museum of Science and Industry (OMSI) in Portland, Oregon and the Eugene Science Center in Eugene, Oregon. Across our sample, race was representative of the area (69% White, 11% Asian, 11% Biracial, 2% Black, 0.5% Alaskan Native), although 16 participants were missing data for race. Most caregivers (74%) reported having a bachelor's degree or higher. Caregivers' socioeconomic status (SES) was calculated as a composite of parent education and two subjective scores from the Macarthur Scale of Subjective Social Status (Adler et al., 2000), which was then compared to reported education levels, as seen in Figure 1.

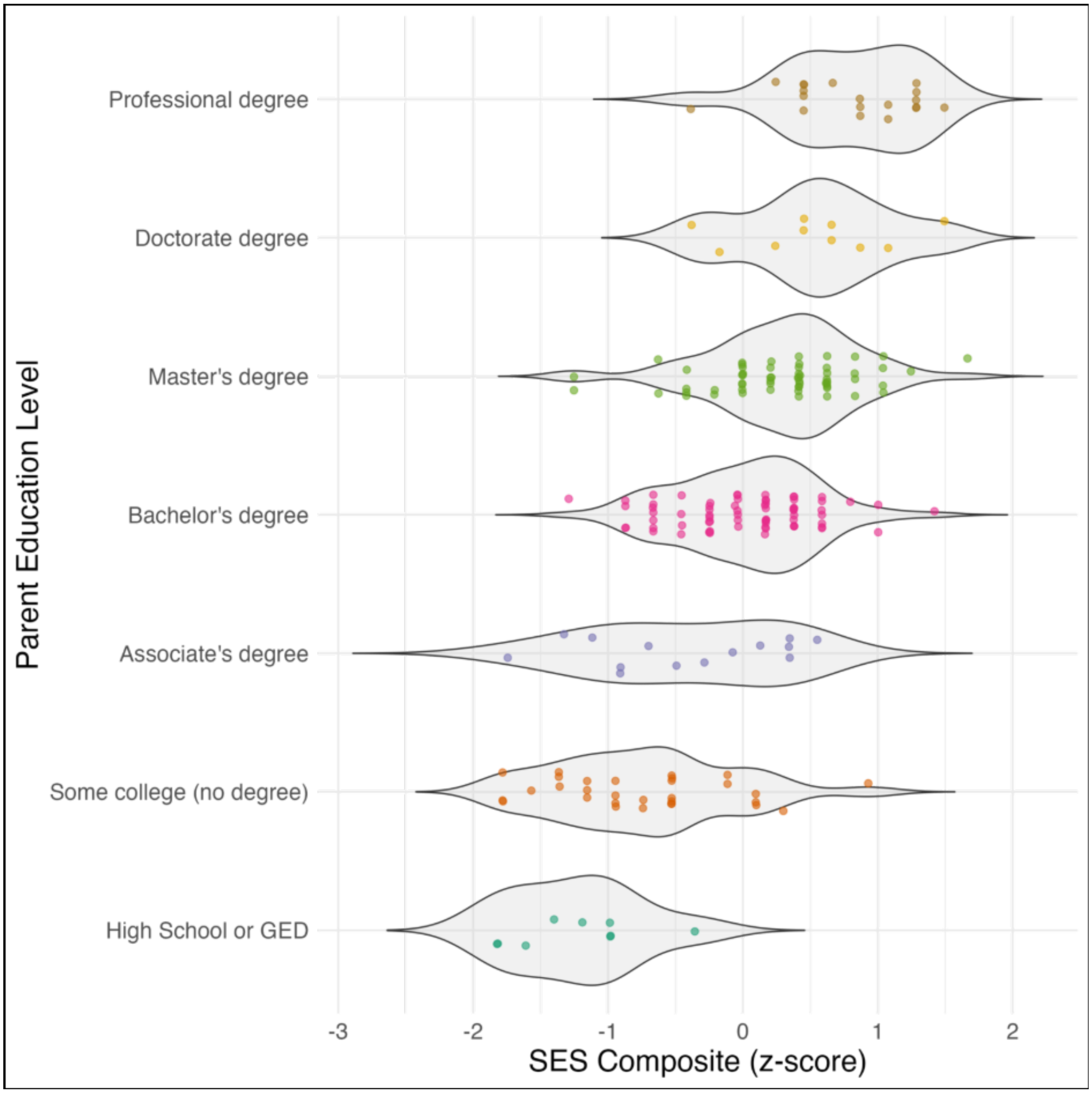

Figure 1: SES Composite vs Reported Parent Education Level

SES scores, a composite developed from parent education and two subjective scores of social standings from the Macarthur Scale of Subjective Social Status (Adler et al., 2000), were compared to parent's reported education level.

Participants were randomly assigned to one of four experimental conditions, with age and gender roughly balanced across groups. Caregivers remained present during the session to complete a demographic questionnaire and a measure of child temperament.

Materials

Novel Object

The object introduced to participants was meant to be relatively novel for children. It had a black base measuring 5.5 inches x 7.5 inches x 1 inch with a 4–inch diameter white light encasement set in the center that was roughly 1.5 inches tall. The central region of the light – approximately 3 inches in diameter – lit up red when activated. The light could only be activated remotely by research assistants, who remained out of sight. Each time a child pressed the light or waved over it, the assistants triggered the illumination. None of the participants made comments about the light being remotely controlled by one of the researchers or by trickery, suggesting that they experienced their actions on the object as being the causal source of the light turning on.

Pedagogy Manipulation Videos

Two short videos (t = 5 sec) were created to convey verbal pedagogy about the function of the novel object. Each video depicted the same person from the chest up, with the toy displayed on a table in front of them. They produced a sentence in accordance with one of the two experimental conditions: knowledgeable or naive ("This is how my toy works" and, "I wonder how this toy works" respectively). Every attempt was made to balance the person's appearance and prosody across the videos associated with the two experimental conditions. The person did not physically interact with the toy in either video, as the videos acted only as a verbal pedagogy manipulation.

Expected Action Slideshows

A visual display of the toy's functions was presented using expected action slideshows. The two slideshows were each made up of 21 images of frame-by-frame stills from a video of the same person engaging with the toy, consistent with dwell-time methodology. The original videos were 4 seconds (30 frames per second [FPS]) in length, and we extracted images at equal intervals of 5 FPS for a total of 21 images. The light was illuminated across the same 4 slides (slides 10-13) in both slideshows, so the only content that differed in the slideshows was the presented action, seen in Figure 2. To start, the object is held aloft. In the "Consistent" expected-actions video, the right hand of the actor leaves the object from the left-hand side of the screen and makes an arching motion before pressing – and turning on – the light. The right hand then returns to the right side of the object while the left hand remains stationary on the base. The "Violating" expected-actions video depicts a motion where the right hand arcs over to a little beyond the left side of the object, then changes trajectory to perform a horizontal waving motion visibly above the light encasement. The light turns on despite the finger obviously never touching it. The right-hand returns to grasping the right side of the object; the left hand holds the base throughout and never moves.

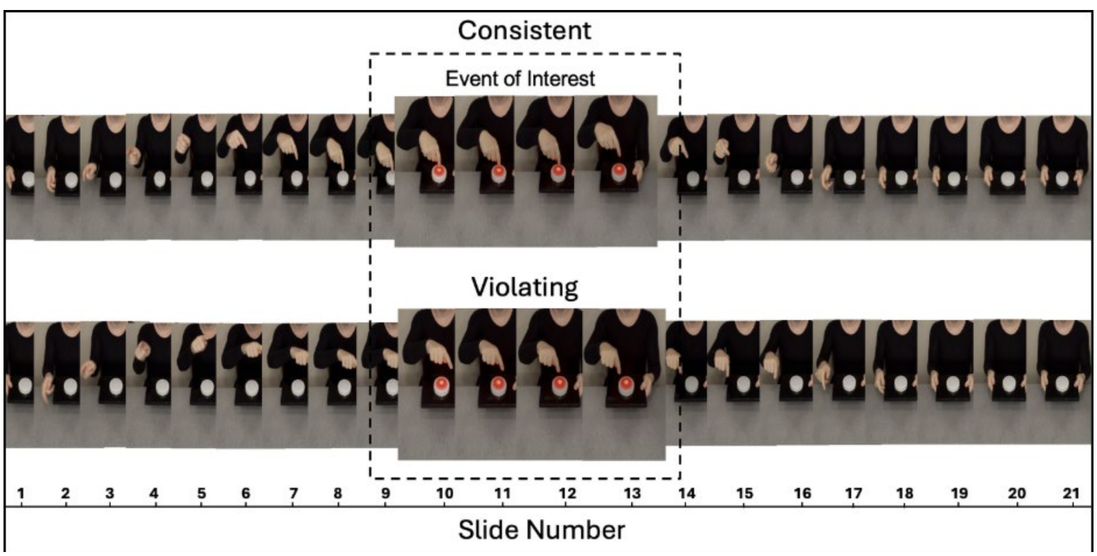

Figure 2: Expected-Action Slideshows

Slideshows consisted of 21 slides, with the same slides (10-13) introducing the action. The remaining slides were relatively similar in appearance as to not largely affect children's attention across conditions.

Head-Toes-Knees-Shoulders Task and Children's Behavior Questionnaire – Short Form

The Head-Toes-Knees-Shoulders (HTKS) HTKS is primarily a measure of inhibitory control and involves the suppression of a prepotent action (i.e., children must touch their head after being instructed to touch their toes) (Ponitz et al., 2009). Scores on the HTKS serve as the primary EF variable in subsequent analyses. See Appendix 1 for a detailed description of the HTKS task procedure and scoring.

Caregivers completed the Children's Behavior Questionnaire - Short Form (CBQ-SF; Putnam & Rothbart, 2006), a widely used parent-report measure of temperament for children aged 308 years. In the present study, we focused on two primary subscales: Extraversion/Surgency and Effortful Control. Parents rated their child's typical behavior on a 7-point Likert scale ranging from 1 ("extremely untrue") to 7 ("extremely true"), with each subscale assessed via 6–7 items. Higher scores reflect greater levels of the temperament dimension in question. Detailed information on the CBQ-SF items, subscales, and scoring procedures can be found in Appendix 2.

Dwell-Time Measures

Latency between mouse clicks advancing slideshow images was recorded via PsychoPy® (Pierce et al., 2019) to assess attentional patterns. Because dwell-time analyses were part of the larger dissertation, they are not analyzed in the present thesis.

Design

The study utilized a 2x2 between-subjects factorial design, using the following two manipulations:

1. Pedagogy: Knowledgeable vs Naive
2. Expected Action: Consistent (press) vs. Violating (wave)

Thus, each child experienced one of four possible combinations of pedagogical framing and expected action, seen in Figure 3. Additionally, children viewed their assigned dwell-time slideshow twice, creating a repeated-measures factor of viewing, nested within each child's assigned experimental condition (which will not be discussed further in the thesis, as it was not pertinent to my focus on the exploratory play aspect of the larger study).

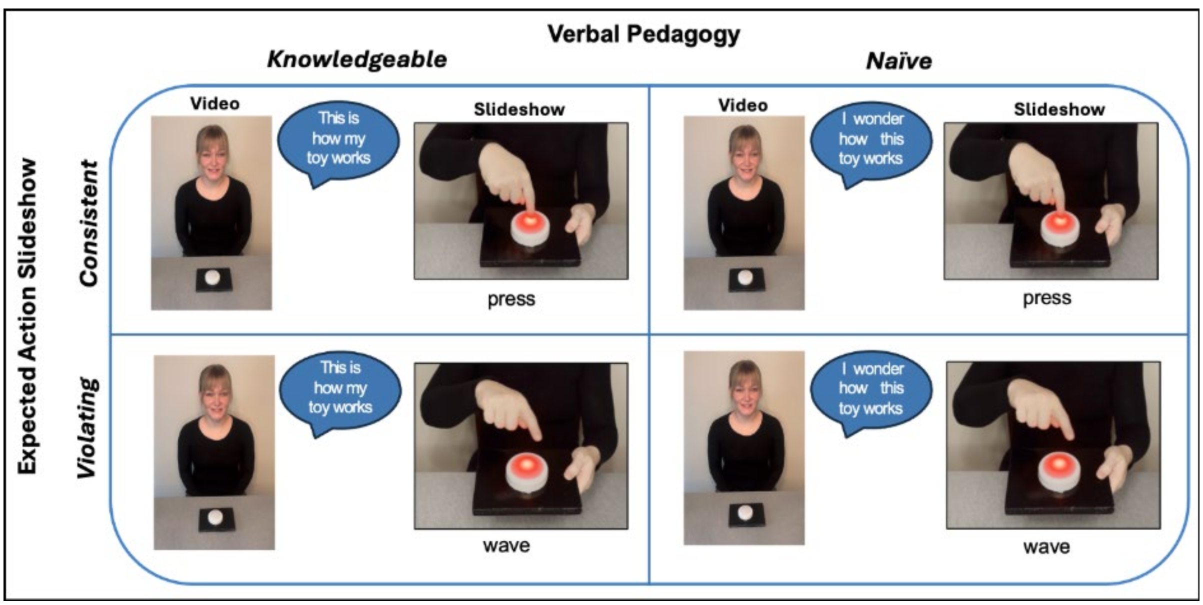

Figure 3: Experimental Conditions
Children received either the knowledgeable or naive condition's pedagogical introduction and either the low or high expected action slideshow, creating four possible combinations.

For all groups across experimental conditions, children were invited to participate in an exploratory play session and complete the HTKS task while parents filled out the CBQ-SF survey.

Procedure

Recruitment and Setting

Our OMSI-based recruitment followed the National Science Foundation's (NSF) Living Lab model, which hinges on a partnership between developmental scientists and children's museums that is designed to enhance communication about developmental science in children's museums. The Living Lab encourages youth participation in research, as well as clarity with children and their parents regarding the research process. The area of the museum where we recruited was meant for children ages 0-6, and our final sample included a full age range of 2.8-7. Finally, each participant and their parent/guardian received thorough debriefing, as part of the Living Lab's educational model. We maintained the standards of the Living Lab at Eugene Science Center for consistency.

After agreeing to participate and providing consent, children's caregivers were provided with a brief demographic questionnaire and the CBQ-SF to fill out during the study, which assessed temperament across dimensions such as shyness, inhibitory control, and impulsivity.

Phase 1: Training phase:

Children were seated at a table with a laptop, a child-sized tiger mouse, and noise cancelling headphones to reduce distraction. Children experienced five phases during the study: a training phase, a video phase, a slideshow phase, an exploratory play phase, and an HTKS phase.

To acquaint children with the slideshow setup, they advanced at their own pace through a brief training slideshow depicting an animated train moving across the screen. Children were encouraged to keep "click, click, clicking" through the images. A second trial of training was undertaken if the child failed to demonstrate understanding of how to advance through the slideshow on the first trial. Children then advanced at their own pace through a slideshow depicting an individual reaching over a barrier and grabbing a ball as part of a replication of previous research (Kosie & Baldwin, 2021). Thereafter, children entered the Video Phase of the present study.

Phase 2: Video Phase

Children watched one of the two pedagogy manipulation videos. Both videos consisted of the experimenter presenting the novel toy. The two conditions differed only with respect to the utterance that the experimenter produced:

1. In the *knowledgeable* condition, the adult implied knowledge of the toy's functionality ("This is how my toy works").
2. In the *naive* condition, the adult implied ignorance of the toy's functionality (I wonder how this toy works").

Phase 3: Dwell-Time Slideshows

Children's dwell times – the latency between mouse clicks that advanced one slide to the next – were recorded using PsychoPy software. Children viewed one of two slideshows, advancing at their own pace through a given slideshow twice:

1. *Consistent expected action* condition: the adult pressed the button with a finger to make the toy light up with direct contact.

2. *Violating expected action* condition: the adult waved a finger over the button to make the toy light up without direct contact.

Phase 4: Toy Exploration and Memory Check

A researcher then presented each participant with the same toy that had been depicted in the slideshow, enabling them to physically interact and play with the toy while another researcher simultaneously controlled the toy's light function remotely. The toy exploration period ended either after three minutes, if the child stopped interacting with it for five seconds, (wherein the researcher would confirm with the child if they were finished by asking "Are you done playing with the toy?" and they agreed), or if they verbally indicated that they were done. Exploratory play sessions were video recorded from both a side and frontal view to aid in *post-hoc* behavioral play coding.

Immediately after play sessions, each participant received a memory check regarding which condition they saw. The following questions were asked: "Remember before you played with the toy, you saw a person with the toy: did the light turn on when the person pressed right on the toy, or did it turn on when the person waved in the air above the toy or both?" and "Remember when you were playing with the toy: did the light turn on when you pressed right on the toy, or did it turn on when you waved in the air above the toy, or both?". These questions were both counterbalanced so that a) the subject of the question (researcher vs. participant) and b) the action (light or wave) mentioned were equally presented as first in order. The participants' responses were recorded for further analysis.

Phase 5: HTKS Executive Function Task:

Each trial ended with the HTKS task. Children stood for the task in an open area to encourage their full engagement with each movement. A new research assistant led children through the task according to the HTKS guidelines, wherein children completed only Part 1 (Head-to-Toes) or Parts 1 and 2 (Knees-to-Shoulders) depending upon their performance and age. Instructions for the HTKS task are included in Appendix A. A separate research assistant recorded the entirety of the HTKS task using a handheld video recording device.

As the HTKS task uses call-and-response-style instruction, it was administered at the end of the session to avoid influencing children's experience by contaminating their responding in the earlier portions of the study. Specifically, the HTKS task involves training children to ignore the instructions of a highly directive adult. With data related to pedagogy, action expectations, and dwell-time being most closely related to our core research questions and goals for replication, reversing the procedure could have influenced children’s responses to the pedagogy manipulation, so the HTKS was administered last to avoid contamination. That is, had children carried such training over to the video and slideshow phases of the study, their performance in those phases would have been affected. Data related to pedagogy, visual affordance, and dwell time were most closely tied to our core research questions. Additionally, to account for the total length of the trial and young children’s attention spans, we expected some attrition for the HTKS task, specifically.

Debrief

Following the components above, participants and caregivers were provided adequate time to answer their questions regarding the nature of our research and the potential impact of our findings on the current understanding of children’s cognitive development. Children were also able to select a sticker as a reward for participating.

Coding and Dependent Measures

To capture detailed behavioral data from the exploratory play sessions and the HTKS task, we implemented a *post-hoc* video-based coding system to provide reliable measurement beyond what is possible in real-time scoring. Coders were blind to participants' assigned conditions, and inter-rater reliability was assessed throughout coding.

Exploratory Play

Videos from exploratory play sessions, recorded from both frontal and side views, were coded along multiple dimensions:

1. Press: Any intentional contact with the button component of the toy using one or more fingers, a full hand, both hands, or other body parts, in any orientation.
2. Wave: Any intentional motion above the button component using fingers, hands, or other body parts.
3. Unique Actions: Interactions that differed substantially from the demonstrated action, including picking up, flipping, spinning, or inspecting the toy (e.g., looking underneath). The number of unique actions served as the primary index of exploratory breadth.
4. Total Actions: A sum of all discrete actions performed, including presses, waves, and unique actions.
5. First Action: The initial interaction with the toy, categorized as press, wave, or other.
6. Proportion Measures: Onset and offset times for each action episode were recorded, with an episode defined as the period from the start of an action until the child either switched actions or paused for ≥ 2 seconds; the proportion of time spent on the demonstrated action type was then calculated relative to total playtime.

The coding system was adapted from Bonawitz et al. (2011) and expanded to include first action. Each video was coded by a minimum of two trained researchers, with regular consensus meetings to resolve discrepancies. Krippendorff's alpha exceeded 0.90 for all exploratory play measures, indicating excellent inter-rater reliability.

Executive Function and Temperament Coding

Children's performance on the Head-Toes-Knees-Shoulders (HTKS) task was assessed via *post-hoc* video coding to ensure precise measurement of inhibitory control. While the task was scored live during administration (necessary for task progression), video coding allowed verification of initial responses. Each training and test item was scored 0 (incorrect), 1 (self-corrected), or 2 (correct). Two coders independently scored all videos, with Krippendorff's alpha = 0.96, indicating excellent inter-rater reliability. Scores were missing for 24 participants who did not complete the initial training portion, yielding a final HTKS sample of $N = 199$.

Caregivers completed the Children's Behavior Questionnaire Short Form (CBQ-SF; Putnam & Rothbart, 2006), focusing on Extraversion/Surgency and Effortful Control subscales. Each item was rated on a 7-point Likert scale (1 = "extremely untrue," 7 = "extremely true"). We initially aimed to create a composite EF score made of participants' HTKS scores and Effortful Control from the CBQ; however, we ultimately decided to use HTKS scores as the sole measure of EF. The primary reason for this decision hinged on the finding that the correlation between HTKS and Effortful Control scores was weak, $r(179) = .25$, $p < .001$, supporting evidence that behavioral EF tasks and parent-report EF measures assess related but distinct constructs (Eycke & Dewey, 2016; Silver, 2014; Nagar & Gupta, 2017; Vriezen & Pigott, 2002; Dekker et al., 2017).

Dwell-Time

As described above, dwell times, measuring latency between mouse clicks during slideshow viewing, were recorded to assess attentional patterns. This measure was part of the larger research project as an extension of prior research (Kosie & Baldwin, 2021); however, analysis of dwell times falls outside the scope of the present thesis.

Memory Check

Similarly, memory checks were excluded from the final analysis. Investigating the relationship between memory accuracy and play outcomes required data parsing that substantially reduced the available sample size, so memory accuracy was not incorporated into the study's results.

Results

This section presents analyses examining how preschoolers' exploratory play behaviors varied as a function of verbal pedagogy and action expectations, and whether these effects were moderated by executive function (EF), controlling for age. Two primary outcomes were analyzed: (a) the proportion of time children devoted to the demonstrated action, reflecting fidelity to the modeled behavior, and (b) the number of unique actions produced during the play period, indexing exploratory breadth beyond the demonstrated function.

Analyses proceeded in two stages. First, 2×2 factorial ANOVAs tested the effects of verbal pedagogy (knowledgeable vs. naïve) and expected action condition (consistent vs. violating) on each outcome. Because the proportion outcome was non-normally distributed, it was transformed prior to ANOVA. Second, EF (measured via HTKS) and age were added to the models to examine whether EF moderated the effects of pedagogy and action expectations. For the proportion outcome, zero-one beta regression models were used to accommodate the bounded distribution of the dependent variable. For the unique actions outcome, linear regression models were fit using a log-transformed outcome due to positive skew. All analyses were conducted in R.

Prior to analysis, three participants were excluded because parental consent for video recording was not obtained, which was necessary for behavioral coding. The resulting analytic sample consisted of $N = 217$ children. For models including age as a covariate, analyses were restricted to children between 36 and 83 months of age (3–6 years), yielding $N = 214$. Age was treated as a continuous variable in all inferential analyses.

Analyses proceeded in two stages:

1. Using 2 × 2 factorial ANOVAs to examine the main and interactive effects of verbal pedagogy and expected action condition on (a) proportion of time spent with the demonstrated action and (b) number of unique actions produced during exploratory play.
2. Adding EF, while controlling for age, to the models to test whether EF moderated the effects of verbal pedagogy and expected action condition on (a) proportion of time spent with the demonstrated action (via zero-one beta regression) and (b) number of unique actions (via linear regression with a log-transformed outcome).

RQ 1: To what degree will verbal pedagogy, action expectations, and their interaction shape children's exploratory play activities?

1.1: Proportion of Time Engaged with the Demonstrated Action

To examine whether verbal pedagogy, action expectations, and their interaction influenced children's engagement with the demonstrated action, a 2 × 2 factorial ANOVA was conducted (see Table 1).

	df	*Sum Sq*	*Mean Sq*	*F value*	*partial* η^2	η^2 *90% CI*	*p*
Verbal Pedagogy	1	0.13	0.13	0.80	0.00	[0.00, 0.03]	.371
Expected Action	1	36.12	36.12	226.45	0.52	[0.44, 0.58]	< .001
Verbal Pedagogy × Expected Action	1	0.00	0.00	0.02	0.00	[0.00, 0.01]	.877
Residuals	213	33.97	0.16				

Table 1: Factorial ANOVA Results Examining Proportion of Time with Demonstrated Action

There was no significant main effect of verbal pedagogy on the proportion of time children engaged with the demonstrated action, $F(1, 213) = 0.80$, $p = .371$, partial $\eta^2 = .00$, 90% CI [0.00, 0.03]. Children in the knowledgeable (pedagogical) and naïve conditions did not differ significantly in the amount of time they spent engaging with the demonstrated function.

In contrast, there was a large and statistically significant main effect of expected action condition, $F(1, 213) = 226.45$, $p < .001$, partial $\eta^2 = .52$, 90% CI [0.44, 0.58] (see Figure 4). The effect size indicates that approximately 52% of the variance in children's engagement with the demonstrated action was attributable to whether the demonstrated action was consistent with or violated action expectations. Children in the consistent condition spent substantially more time engaging with the demonstrated action (*Mprop* = 0.83, *SD* = 0.19) than children in the violating condition (*Mprop* = 0.24, *SD* = 0.35). The interaction between verbal pedagogy and expected action was not significant, $F(1, 213) = 0.02$, $p = .877$, partial $\eta^2 = .00$, 90% CI [0.00, 0.01], indicating that the effect of action expectations on engagement with the demonstrated action did not differ as a function of pedagogical framing.

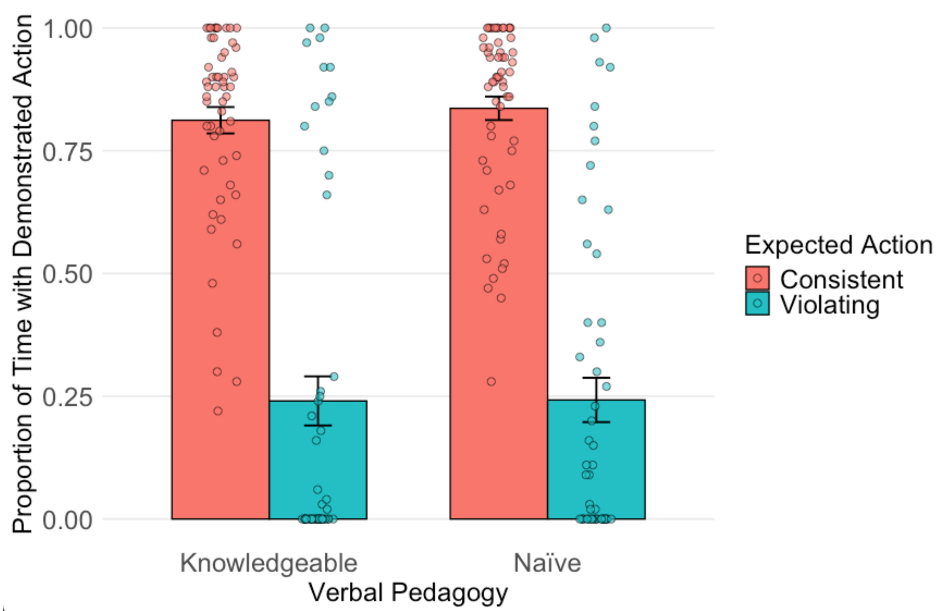

Figure 4: Proportion of Time with Demonstrated Action by Verbal Pedagogy and Expected Action Condition

Mean proportion of time children spent engaging with demonstrated acions across verbal pedagogy (knowledgeable vs. naïve) and expected action (consistent vs. violating) conditions. Individual data points are displayed to illustrate variability within groups.

1.1 Summary

Taken together, these findings indicate that children's engagement with the demonstrated action was driven almost entirely by their expectations for action rather than by verbal pedagogical framing. Whether the action aligned with children's expectations about how the object should function strongly shaped their exploratory behavior, whereas the presence or absence of explicit pedagogical language did not significantly alter time spent engaging with the demonstrated outcome.

1.2: Number of Unique Actions

To examine the extent to which verbal pedagogy, action expectations, and their interaction influenced the number of unique actions children generated during exploration, a 2 × 2 factorial ANOVA was conducted (see Table 2).

	df	*Sum Sq*	*Mean Sq*	*F value*	*partial* η^2	η^2 *90% CI*	*p*
Verbal Pedagogy	1	1.52	1.52	8.26	0.04	[0.01, 0.09]	.004
Expected Action	1	1.83	1.83	9.95	0.04	[0.01, 0.10]	.002
Verbal Pedagogy × Expected Action	1	0.74	0.74	4.04	0.02	[0.00, 0.06]	.046
Residuals	213	39.23	0.18				

Table 2: Factorial ANOVA Results Predicting Number of Unique Actions

There was a significant main effect of verbal pedagogy, $F(1, 213) = 8.26$, $p = .004$, partial $\eta^2 = .04$, 90% CI [0.01, 0.09]. Collapsing across expected action conditions, children in the naïve pedagogical framing condition generated significantly more unique actions ($M = 0.67$, *SD* = 0.09) than children in the knowledgeable condition (*M* = 0.38, *SD* = 0.06). There was also a significant main effect of expected action, $F(1, 213) = 9.95$, $p = .002$, partial $\eta^2 = .04$, 90% CI [0.01, 0.10], indicating that, overall, children in the violating condition generated more unique actions (*M* = 0.68, *SD* = 0.09) than those in the consistent condition (*M* = 0.38, *SD* = 0.07).

However, these main effects were qualified by a significant verbal pedagogy × expected action interaction, $F(1, 213) = 4.04$, $p = .046$, partial $\eta^2 = .02$, 90% CI [0.00, 0.06]. Follow-up Tukey HSD comparisons (Table 3) revealed that differences in unique action generation were concentrated in the violating condition. Children in the consistent x knowledgeable and the consistent x naïve conditions performed fewer unique actions than those in the naïve x violating condition (*M*-diff = −0.36, $p < .001$); (*M*-diff = −0.30, $p = .002$). Additionally, within the violating condition, children in the naïve framing produced significantly more unique actions than those in the knowledgeable framing (*M*-diff = −0.29, $p = .003$). In contrast, knowledgeable and naïve framings did not differ within the consistent condition ($p = .896$; see Figure 5).

Comparison	**Difference**	*Lower CL*	*Upper CL*	*SE*	*p (adj)*
Consistent: Knowledgeable vs. Consistent: Naïve	-0.06	-0.27	0.15	0.08	.896
Consistent: Knowledgeable vs. Violating: Knowledgeable	-0.07	-0.28	0.15	0.08	.853
Consistent: Knowledgeable vs. Violating: Naïve	-0.36	-0.57	-0.14	0.08	< .001
Consistent: Naïve vs. Violating: Knowledgeable	-0.01	-0.22	0.20	0.08	1.000
Consistent: Naïve vs. Violating: Naïve	-0.30	-0.51	-0.09	0.08	.002
Violating: Knowledgeable vs. Violating: Naïve	-0.29	-0.51	-0.08	0.08	.003

Table 3: Tukey HSD Pairwise Comparisons for Unique Actions (2 × 2 ANOVA)

Tukey HSD post hoc pairwise comparisons examining differences in the number of unique actions across expected action and verbal pedagogy conditions in the 2 × 2 factorial ANOVA.

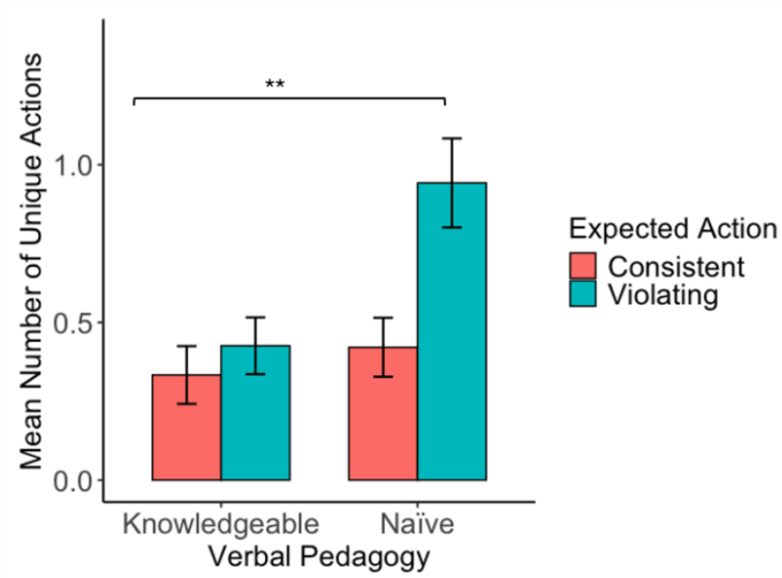

Figure 5: Mean Number of Unique Actions by Expected Action and Verbal Pedagogy

Mean number of unique actions performed across expected action and verbal pedagogy conditions. Error bars represent standard errors. “**” indicates $p < .01$ for pairwise comparisons.

1.2 Summary:

Together, these findings indicate that both pedagogical framing and action expectations shaped the diversity of children's exploratory behaviors, and that their effects were interdependent. When the demonstrated action violated expectations, children generated the greatest number of unique actions when pedagogical framing indicated naiveté. Thus, exploratory breadth was highest when children encountered unexpected outcomes and were not constrained by explicit instructional cues.

RQ2: To what degree will executive function (EF), while controlling for age, moderate the effects of verbal pedagogy and action expectations on children's exploratory play activities?

2.1: Proportion of Time with Demonstrated Action

To examine whether EF moderated the effects of verbal pedagogy and expected action on children's fidelity to the demonstrated action, a zero-one beta regression predicting the proportion of time spent performing the demonstrated action was performed. The model included expected action condition, verbal pedagogy condition, EF, with age as a covariate, along with interactions between EF, verbal pedagogy, and expected action (see Table 4).

	Estimate	*SE*	*z*	*95%CI Lower*	*95%CI Lower*	*p*
Intercept	1.50	0.37	4.08	0.78	2.21	< .001
Expected Action	-3.44	0.51	-6.71	-4.45	-2.44	< .001
Verbal Pedagogy	-0.18	0.41	-0.45	-0.98	0.61	.655
EF (HTKS score)	-0.01	0.01	-1.11	-0.04	0.01	.268
Age	0.18	0.13	1.42	-0.07	0.43	.157
Expected Action x Verbal Pedagogy	0.86	0.66	1.29	-0.45	2.16	.197
Expected Action x EF (HTKS score)	0.06	0.01	4.31	0.03	0.09	< .001
Verbal Pedagogy x EF (HTKS score)	0.01	0.01	0.90	-0.01	0.04	.369
Verbal Pedagogy x Expected Action x EF (HTKS score)	-0.04	0.02	-2.05	-0.08	0.00	.040

Table 4: Zero-One Beta Regression Predicting Proportion of Time with Demonstrated Action

Zero-one beta regression output with expected action, verbal pedagogy, EF (HTKS score) and age as a covariate predicting the proportion of time with demonstrated action outcome.

Although there was a significant main effect of expected action, $\beta = -3.44$, $SE = 0.51$, $z = -6.71$, $p < .001$, and no significant main effect of verbal pedagogy, $\beta = -0.18$, $SE = 0.41$, $z = -0.45$, $p = .655$, these lower-order effects must be interpreted in light of higher-order interactions in our analyses. EF was not a significant main effect on its own, $\beta = -0.01$, $SE = 0.01$, $z = -1.11$, $p = .268$, and age was also not significant, $\beta = 0.18$, SE = 0.13, $z = 1.42$, $p = .157$. However, a significant interaction emerged between expected action and EF, $\beta = 0.06$, SE = 0.01, $z = 4.31$, $p < .001$, and, critically, this two-way interaction was qualified by a significant three-way interaction between expected action, verbal pedagogy, and EF, $\beta = -0.04$, $SE = 0.02$, $z = -2.05$, $p = .040$.

Because higher-order interactions alter the interpretation of main effects and lower-order terms, my interpretation centers on this three-way interaction. As illustrated in Figure 6, EF was associated with the proportion of time spent engaging with the demonstrated action specifically in the violating expected action condition. In this condition, children with higher EF scores showed substantially greater proportional engagement with the demonstrated action than children with lower EF scores. Importantly, this EF-related differentiation was strongest in the knowledgeable pedagogy condition relative to the naïve condition. In contrast, in the consistent expected action condition, EF was not meaningfully associated with fidelity to the demonstrated action.

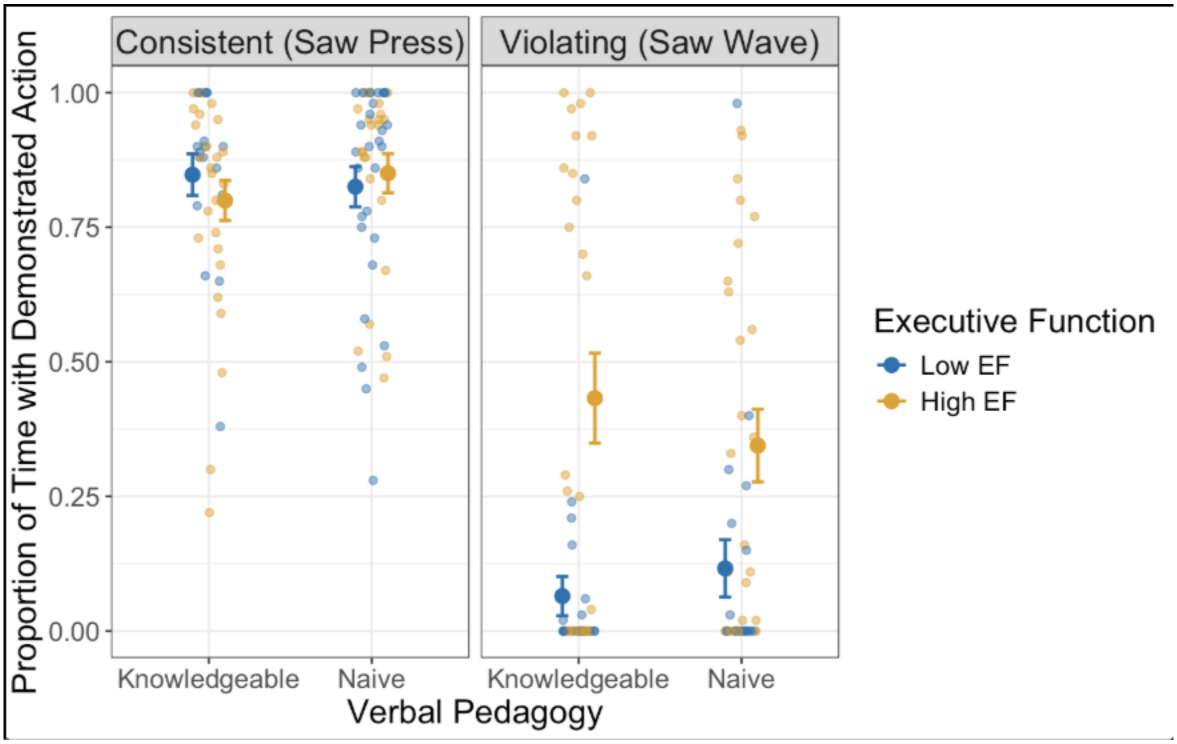

Figure 6: Proportion of Time with Demonstrated Action by Pedagogy, Visual Affordance, and Executive Function

Comparison of proportion of time with demonstrated action by verbal pedagogy, visual affordance, and EF group, with error bars. The HTKS scores range from 0-52, with the cutoff of 26 to distinguish participants who scored well on training and Part 1 of the task and moved on to Part 2 (designated High EF) from those who scored poorly on Part 1 or failed to complete it (designated Low EF).

Thus, when the demonstrated action violated children's prior expectations, children with higher EF displayed an enhanced focus on that action, particularly when the adult's framing signaled epistemic authority. For children higher in EF, the predictions of the double-edged sword of pedagogy framework were confirmed within the context of experiencing a demonstration that violated children's action expectations.

2.1 Summary

Taken together, these findings indicate that higher EF allows for enhanced sensitivity to knowledgeable pedagogy under conditions of expectancy violation. When children observed an action that contradicted their prior expectations, those with stronger EF were more likely to align their exploratory behavior with the adult's pedagogical cues, devoting greater proportional time to the demonstrated action. In other words, higher EF promoted greater fidelity in children's exploratory responses in accordance with the quality of verbal pedagogy provided.

2.2: Number of Unique Actions

To examine whether EF moderated the effects of verbal pedagogy and expected action on children's exploratory breadth, a linear regression predicting the log-transformed number of unique actions was performed. Because the unique actions outcome was positively skewed, it was log transformed prior to analysis. The model included expected action condition, verbal pedagogy condition, EF, and age as a covariate, along with interactions between EF, verbal pedagogy, and expected action (see Table 5).

	Estimate	*SE*	*t*	*95%CI Lower*	*95%CI Lower*	*p*
Intercept	0.33	0.03	10.30	0.26	0.39	< .001
Expected Action	-0.10	0.03	-3.35	-0.17	-0.04	< .001
Verbal Pedagogy	-0.10	0.03	-3.05	-0.16	-0.03	.003
EF (HTKS score)	0.00	0.00	-0.39	-0.01	0.00	.694
Age	0.00	0.00	0.39	-0.01	0.01	.697
Expected Action x Verbal Pedagogy	0.06	0.03	1.92	0.00	0.12	.057
Expected Action x EF (HTKS score)	0.00	0.00	-0.32	0.00	0.00	.753
Verbal Pedagogy x EF (HTKS score)	0.00	0.00	-0.50	0.00	0.00	.619
Expected Action x Verbal Pedagogy x EF (HTKS score)	0.00	0.00	1.97	0.00	0.01	.050

Table 5: Linear Regression Predicting Number of Unique Actions

Linear regression output with expected action, verbal pedagogy, EF (HTKS score) and age as a covariate predicting the number of unique actions outcome.

Although both expected action ($\beta = -0.10$, $SE = 0.03$, $t = -3.35$, $p < .001$) and verbal pedagogy ($\beta = -0.10$, $SE = 0.03$, $t = -3.05$, $p = .003$) emerged as significant predictors, these lower-order effects were qualified by a three-way interaction between expected action, verbal pedagogy, and EF, $\beta = 0.00$, $SE = 0.00$, $t = 1.97$, $p < .050$ (note: p-value was recorded as $p = 0.050$ in Table 5 due to rounding). In models containing higher-order interactions, interpretation of main effects and two-way terms must be considered in context; accordingly, the three-way interaction is the focal point of interpretation.

Seen in Figure 7, EF-related differences in unique action generation were concentrated in the violating expected action condition. When children observed a demonstration that contradicted the object's apparent affordances, EF differentiated how children responded to pedagogical framing. Specifically, children with higher EF generated more unique actions under naïve pedagogy than under knowledgeable pedagogy. In contrast, EF was not significantly associated with unique action production in the consistent expected action condition, nor did it substantially differentiate responses when pedagogical cues implied informational completeness.

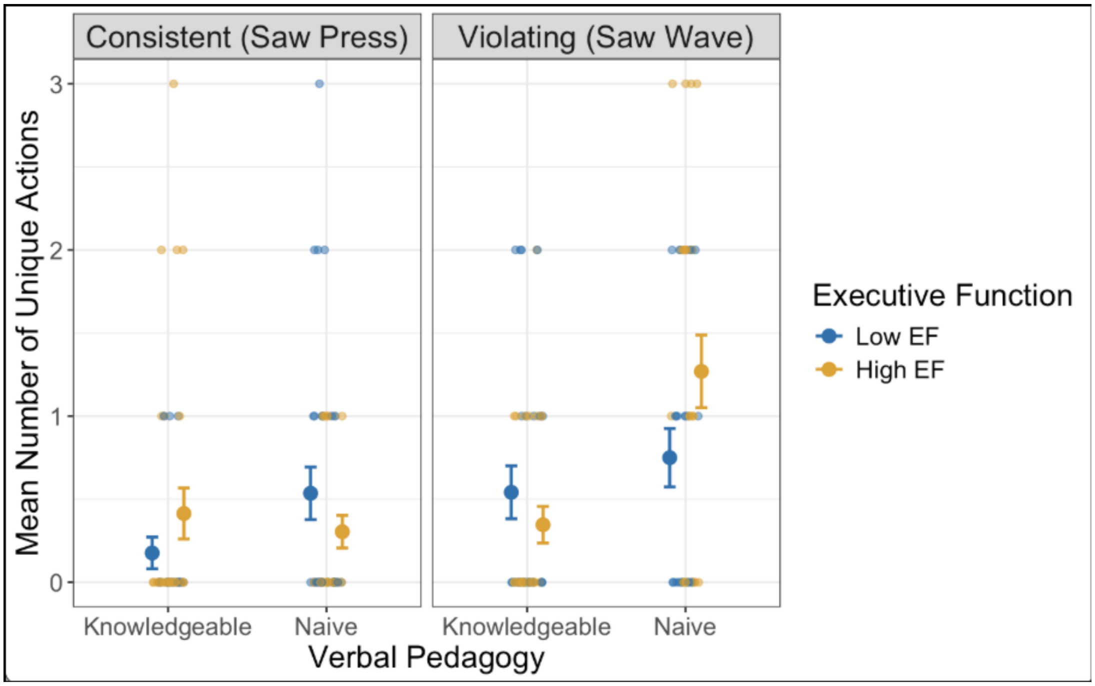

Figure 7: Unique Action Generation Across Pedagogical Framing, Expected Action Condition, and EF Group

A comparison of unique actions by verbal pedagogy, visual affordance, and EF group, with error bars. The HTKS scores range from 0-52, with the cutoff of 26 to distinguish participants who scored well on training and Part 1 of the task and moved on to Part 2 (designated High EF) from those who scored poorly on Part 1 or failed to complete it (designated Low EF).

In other words, EF did not simply increase exploratory diversity across contexts. Instead, it shaped how children calibrated their exploration when faced with expectancy violation. High EF children expanded their behavioral repertoire when the adult's framing signaled uncertainty, yet showed reduced breadth when pedagogy suggested epistemic authority.

2.2 Summary

These findings suggest that higher EF enhances children's sensitivity to naïve pedagogy in contexts of expectancy violation. When a demonstrated action conflicted with prior expectations, children with stronger EF responded to naïve pedagogy by broadening their exploration. Thus, rather than functioning as a general driver of exploration, EF appears to promote context-sensitive alignment between children's exploratory breadth and the informational signals conveyed by adults.

Discussion

The present thesis investigated how children's exploratory play is shaped by the interaction of verbal pedagogy, action expectations, and EF. Building on prior work demonstrating the "double-edged sword" of pedagogy (Bonawitz et al., 2011), this study queried the extent to which pedagogical framing and children's expectations about an object jointly influence exploration, and whether these effects are further moderated by children's EF skills.

Across analyses, three primary findings emerged. First, children's action expectations strongly shaped proportional engagement with the demonstrated action, independent of pedagogical framing. Second, naïve pedagogical framing increased exploratory breadth, particularly when the demonstrated action violated children's expectations. Third, EF moderated children's sensitivity to the combined context of pedagogy and expectation violation, with higher-EF children showing responses that were more closely aligned with the informational cues provided rather than simply exhibiting greater exploration overall.

Importantly, the present study examined these influences simultaneously. Whereas prior research has often investigated pedagogy, expectation violation, or EF in isolation, children encounter these influences together in real-world learning environments. By examining their joint effects, the present work provides a more integrated account of how pedagogical contexts shape children's exploratory behavior.

Pedagogy, Action Expectations, and Exploratory Play

Consistent with prior research (Bonawitz et al., 2011; Sobel et al., 2022; Zsoldos & Király, 2025), naïve pedagogical introductions encouraged children to engage in broader exploration, as reflected in the number of unique actions they produced during play. However, this effect was not uniform across conditions. Rather, the present findings highlight that the impact of pedagogy on exploration can be contingent on children's prior action expectations. Specifically, naïve introductions were particularly effective in eliciting high levels of exploration when children observed an expectation-violating action.

This pattern both replicates and extends the "double-edged sword" account of pedagogy: knowledgeable instruction did not uniformly suppress exploration, but its constraining effects were most apparent when paired with expectation violation. When children encountered evidence that conflicted with their expectations, an inquiry-oriented pedagogical frame (e.g., "I wonder how this toy works") appeared to license and encourage deeper exploration.

Importantly, violations of expectation did not universally lead to increased exploration. Rather, heightened exploration emerged most when expectation violation occurred in conjunction with an inquiry-oriented pedagogical context. This finding suggests that expectation violations create uncertainty, and children's responses to that uncertainty depend on the cues they receive about how to engage with the object. Inquiry-oriented pedagogical statements may signal that exploration is both appropriate and valuable in moments of uncertainty, thereby amplifying exploratory behavior.

Taken together, these results underscore the importance of considering pedagogy and action expectations jointly. The present work contributes to the literature by demonstrating that pedagogical framing and expectation violation interact to shape exploratory play, rather than exerting independent or additive effects.

Executive Function as a Moderator of Exploratory Behavior

EF did not universally predict exploratory behavior when controlling for age; rather, it moderated children's responses specifically in contexts where pedagogical framing and expectation violation intersected. This pattern is consistent with theoretical accounts of EF as supporting inhibitory control, cognitive flexibility, and the updating of behavior in response to changing information (Diamond, 2013).

Notably, EF moderated children's responses differently depending on the outcome measured. For proportional engagement, higher EF amplified sensitivity to knowledgeable pedagogy under expectation violation, leading to intensified focus on the demonstrated action. In contrast, for exploratory breadth, higher EF amplified sensitivity to naïve pedagogy under violation, leading to greater production of unique actions. Thus, EF did not simply increase exploration or fidelity; it enhanced children's alignment with the epistemic signals conveyed by the adult.

These findings align with prior research demonstrating that pedagogical cues shape children's exploratory behavior (Bonawitz et al., 2011) and that violations of expectation increase children's attention to surprising evidence and subsequent exploration (Stahl & Feigenson, 2015). However, the present results extend this literature by demonstrating both that children respond to these factors jointly, and that EF moderates these effects. Specifically, EF appears to influence children's ability to calibrate their responses to pedagogical cues when expectations are disrupted.

At the same time, the model accounted for only a modest proportion of variance in unique actions, indicating that exploratory breadth is likely influenced by many additional factors. Variables such as temperament, prior experience, interest in the object, or situational features of the testing context may also play important roles (Rothbart et al., 2001; Poli et al., 2025). Thus, EF should be understood as likely just one contributing factor among many that shape children's exploratory behavior.

One interpretation is that higher EF enables children to inhibit prepotent responses (such as pressing the button given that button-pressing was expected), attend to novel evidence, and update their behavior accordingly. In contrast, children with lower EF were more likely to persist in pressing, suggesting difficulty shifting away from visually afforded actions when expectations were violated. Importantly, this does not imply that lower-EF children are incapable of exploration, but rather that their behavior may be less responsive to contextual cues that invite inquiry.

Interpreting Proportional Engagement Measures

The proportion-of-time measure yielded a more complex pattern of results and requires nuanced interpretation. In the violated expected action condition, spending time pressing does not necessarily reflect a failure to explore. Instead, children may press precisely because they are attempting to determine whether the toy responds exclusively to the wave action or whether pressing remains effective. From this perspective, pressing in the violation condition may reflect hypothesis testing rather than perseveration.

High-EF children appeared particularly adept at using perceptual information to guide their exploratory efforts across measures. They were sensitive to the demonstrated action, the pedagogical framing, and the affordances of the toy, adjusting both their proportional engagement and their production of unique actions accordingly. In contrast, low-EF children's behavior was dominated by pressing, limiting opportunities to observe exploration of alternative actions. Although the present measures do not allow us to definitively infer children's intentions during play, the converging patterns across proportional engagement, action attempts, and unique actions support the conclusion that EF plays a key role in enabling children to flexibly respond to complex learning contexts.

Limitations

Several limitations should be considered when evaluating generalizability of the results. First, data were collected in a museum environment, which may have introduced variability related to distraction, time constraints, and self-selection. Although museum-based research provides valuable opportunities to observe children's play and learning in diverse, naturalistic contexts, such informal environments may differ in important ways from more controlled laboratory settings (Weisberg et al., 2023; Sobel et al., 2022). These contextual features should be considered when considering the generalizability of the results.

Second, sample sizes were reduced for some analyses, particularly those involving interactions with EF, due to missing EF data and subgrouping by experimental condition. This reduction in sample size may have limited statistical power to detect smaller or more nuanced effects. As a result, EF-related findings should be interpreted cautiously and would benefit from replication in larger samples.

Third, executive function was operationalized using the Head-Toes-Knees-Shoulders (HTKS) task, which primarily captures inhibitory control and behavioral regulation. Although HTKS is a well-validated measure for preschool-aged children, it may not fully reflect the broader range of executive processes that support learning in naturalistic and classroom-based contexts, such as working memory, cognitive flexibility, or sustained goal-directed planning (Heinze et al., 2025; Deodhar & Bertenthal, 2023). Accordingly, the present findings should be interpreted as speaking most directly to inhibitory control rather than EF more broadly.

Finally, the present study focused on a single object with a specific action structure. Although this design allowed for controlled manipulation of pedagogical cues and expectation violation, it limits generalizability. Exploratory behavior is likely shaped by the affordances, familiarity, and complexity of the materials themselves, which were held constant in the present design.

Broader Implications and Future Directions

The present findings reinforce the idea that children are active learners who form and test ideas about how the world works. In this study, children's exploration was shaped not just by what adults said or demonstrated, but by the interaction between pedagogical framing, their prior expectations, and their EF skills. Learning did not operate as a one-way transfer of information; children interpreted cues, evaluated evidence, and adjusted their behavior accordingly. At the same time, the model predicting unique actions explained a modest portion of variance, suggesting that exploratory breadth is influenced by many additional factors. Future research should examine other contributors, such as temperament, curiosity, prior experience, and contextual features of the learning environment. It will also be important to test whether these findings generalize across different settings, age groups, and populations.

These results also have practical implications for educational contexts. The double-edged sword framework highlights a central tension in early education: instruction can efficiently guide attention, but it may also narrow exploration if children interpret it as complete or exhaustive. The present findings suggest that inquiry-oriented framing may be especially effective when children encounter information that challenges their expectations. Language that signals curiosity ("I wonder what will happen if…") may encourage broader exploration, particularly in moments of uncertainty. However, these effects were not uniform across children.

EF played a moderating role, with children who had stronger EF skills showing greater sensitivity to pedagogical framing in contexts of expectation violation, whether expressed as intensified fidelity under knowledgeable framing or expanded breadth under naïve framing.

Children with lower EF tended to rely more heavily on prepotent, visually afforded actions. Because EF difficulties are common among children with learning and attentional challenges (Biederman et al., 2004), these findings highlight the importance of designing learning environments that are responsive to individual differences. Inquiry-based approaches may be highly beneficial, but some children may require additional structure or support to fully engage in exploratory learning. Such support might include more explicit prompts to consider alternative actions (e.g., “What else could we try?”), structured opportunities to pause and reflect before acting, visual cues that reduce reliance on dominant affordances, or guided exploration that incrementally releases responsibility. However, the present study did not directly test specific supports, and future research is needed to determine which forms of scaffolding most effectively promote flexible, context-sensitive exploration among children with a range of EF skills. Understanding how pedagogy, expectations, and self-regulatory skills interact can help educators, parents, and caregivers create environments that support a wide range of learners while preserving opportunities for meaningful exploration.

Conclusion

Altogether, this thesis demonstrates that children's exploratory play is shaped by the dynamic interplay of pedagogy, action expectations, and EF. By examining these factors in concert, this work provides a more integrated account of how children navigate learning contexts. Specifically, the findings show that pedagogical framing and expectation violation jointly shape exploration, while EF determines how children align their behavior with these cues. In doing so, this work clarifies when and for whom exploration is most likely to emerge. More broadly, these findings contribute to ongoing efforts to characterize how children learn from both instruction and discovery, offering insight into how educational contexts can better support meaningful exploration.

Appendices

A. Head-Toes-Knees-Shoulders Task

This task evaluates a participant's ability to inhibit a prepotent motor response similar to a go-no-go task (Ponitz et al., 2009). Children will be habituated with two verbal commands ("touch your head", "touch your toes") in which they are instructed to respond with the opposite movement (i.e., when asked to touch their head, the correct response is to touch their toes, and vice versa). There will be 10 trials of this type, after which children will be introduced to an additional two commands ("touch your knees", "touch your shoulders") for which the "touch your shoulders" command is for children to touch their knees, and vice versa. Each correct response is worth 2 points; if children make a movement to the incorrect location but self-correct and end in the correct location, they earn 1 point; incorrect movements earn 0 points. There are a total of 20 trials and scores ranging from 0 to 40, with an additional range of 0 to 12 points on training trials (full scores range from 0-52).

HTKS TASK SCRIPT

Now we're going to play a game. The game has two parts. First, I want you to copy what I do. Touch your head. Wait for the child to put BOTH his/her hands on head.

Good! Now touch your toes. Wait for the child to put his/her hands on toes.

Good! Repeat the two commands with motions again, or until the child imitates you correctly. *(keep having child copy)* **Touch your head. Touch your toes.**

Now we're going to be a little silly and do the opposite of what I say. When I say to touch your head, *instead* of touching your head, you touch your toes. When I say to touch your toes, you touch your head. So you're doing something different from what I say.

> **If a child says an answer say:**
>
> **Show me**

A1. What do you do if I say "touch your head"?

Circle child's response on the code sheet.

If s/he hesitates or responds incorrectly, say:

Remember, when I say to touch your head, you touch your toes, so you are doing something different from what I say. Let's try again. Repeat A1 again.

If s/he responds correctly, say and proceed to A2: **That's exactly right.**

A2. **What do you do if I say "touch your toes"?**

If s/he hesitates or responds incorrectly, say:

Remember, when I say to touch your toes, you touch your head, so you are doing something different from what I say. Let's try again. Repeat A2 again.

If s/he responds correctly, say and proceed to B2: **That's exactly right.**

PART I PRACTICE:

Circle child's response on the code sheet.

.

B1. **Touch your head**
B2. **Touch your toes**
B3. **Touch your head**
B4. **Touch your toes**

> You may use any of the remaining retraining (up to 3 total on both rules and practice) on the practice:
>
> **Remember, when I say to touch your toes (head), you touch your head (toes), so you are doing something different from what I say.**
>
> **Let's try again.**

PART I TESTING:

We're going to keep playing this game, and you keep doing the opposite of what I say.

Give Commands on the Part I Testing Section:

1. **Touch your head**
2. **Touch your toes**
3. **Touch your toes**
4. **Touch your head**
5. **Touch your toes**
6. **Touch your head**
7. **Touch your head**
8. **Touch your toes**
9. **Touch your head**
10. **Touch your toes**

HTKS TASK SCRIPT

PART II TRAINING:

Ok, now that you've got that part, we're going to add a part. Now, you're going to touch your shoulders and your knees. First, touch your shoulders.

Touch your shoulders; wait for the child to touch his/her shoulders with both hands.

Now, touch your knees.

Touch your knees; wait for the child to touch his/her knees with both hands.

If a child says an answer say:
Show me

Repeat with four alternating commands (no demo) until the child has imitated you correctly or it is clear the child does not comprehend the task. **Touch your shoulders. Touch your knees. Touch your shoulders. Touch your knees**

Ok, now we're going to be silly again. You're going to keep doing the opposite of what I say like before. But this time, you're going to touch your knees and shoulders. When I say to touch your knees, you touch your shoulders, and when I say to touch your shoulders, you touch your knees.

C1. **What do you do if I say "touch your knees?"**

If the response is incorrect, say and proceed to D1:

Remember, when I say to touch your knees, *instead* of touching your knees, you touch your shoulders. I want you to do the opposite of what I say. Let's try again. Repeat C1 again.

If response is correct, say and proceed to D1: **Good job! Let's practice**

PART II PRACTICE:

D1. **Touch your knees**
D2. **Touch your shoulders**
D3. **Touch your knees**
D4. **Touch your shoulders**

You may use any of the remaining retraining (up to 3 total on both rules and practice) on the practice:

Remember, when I say to touch your knees (shoulders), you touch your shoulders (knees), so you are doing something different from what I say. Let's try again.

If the child gets two or fewer correct, say: Remember, I want you to keep doing the opposite from what I say, but this time, touch your knees and shoulders.

Proceed to Part II test section. Do not explain any parts of the task again. **PART II TESTING:**

Now that you know all the parts, we're going to put them together. You're going to keep doing the opposite from what I say to do, but you won't know what I'm going to say.

There are four things I could say. If I say to touch your head, you touch your toes. If I say to touch your toes, you touch your head. If I say to touch your knees, you touch your shoulders. If I say to touch your shoulders, you touch your knees.

Are you ready? Let's try it.

11.. Touch your head
12. Touch your toes
13. Touch your knees
14. Touch your toes
15. Touch your shoulders
16. Touch your head
17. Touch your knees
18. Touch your knees
19. Touch your shoulders
20. Touch your toes

After the child completes the task, say:
Thank you for playing this game with me today!

B. CBQ-SF

We chose the following sub-scales from the CBQ-SF due to their relatedness to executive functioning: Activity Level, Approach, Attentional Focusing, Impulsivity, Inhibitory Control, and Shyness. Each sub-scale had 6-7 items reported on a Likert scale from 1-7, with some items being reverse scored. These appeared as follows, with R indicating a reverse-scored variable:

1. Activity Level
    a. Seems always in a big hurry to get from one place to another.
    b. Tends to run, rather than walk, from room to room.
    c. R. When outside, often sits quietly.
    d. Moves about actively (runs, climbs, jumps) when playing in house.
    e. R. Prefers quiet activities to active games.
    f. Is full of energy, even in the evening.
    g. R. Likes to sit quietly and watch people do things.
2. Approach
    a. Gets so worked up before an exciting event that s/he has trouble sitting still.
    b. Gets very enthusiastic about the things s/he does.
    c. Becomes very excited while planning for trips.
    d. Becomes very excited before an outing (e.g., picnic, party).
    e. R. Remains pretty calm about upcoming desserts like ice cream.
    f. R. Looks forward to family outings, but does not get too excited about them.
3. Attentional Focusing
    a. R. When practicing an activity, has a hard time keeping her/his mind on it
    b. R. Will move from one task to another without completing any of them.

c. When drawing or coloring in a book, shows strong concentration
d. When building or putting something together, becomes very involved in what s/he is doing, and works for long periods
e. R. Is easily distracted when listening to a story
f. Sometimes becomes absorbed in a picture book and looks at it for a long time

4. Impulsivity
    a. Usually rushes into an activity without thinking about it.
    b. Often rushes into new situations.
    c. R. Takes a long time in approaching new situations.
    d. R. Is slow and unhurried in deciding what to do next.
    e. Tends to say the first thing that comes to mind, without stopping to think about it.
    f. R. Is among the last children to try out a new activity.
5. Inhibitory Control
    a. Can wait before entering into new activities if s/he is asked to.
    b. Prepares for trips and outings by planning things s/he will need.
    c. R. Has trouble sitting still when s/he is told to (at movies, church, etc.).
    d. Is good at following instructions
    e. Approaches places s/he has been told are dangerous slowly and cautiously
    f. Can easily stop an activity when s/he is told “no."
6. Shyness
    a. R. Seems to be at ease with almost any person
    b. Is sometimes shy even around people s/he has known a long time

c. Sometimes seems nervous when talking to adults s/he has just met.

d. Acts shy around new people.

e. R. Is comfortable asking other children to play.

f. Sometimes turns away shyly from new acquaintances.

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