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Weighing the Evidence:
Children's Naïve Theories of Balance Affect Their Exploratory Play

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Abstract

In this paper we show that, given identical evidence, children with different naïve theories exhibit different patterns of exploratory play. Karmiloff-Smith & Inhelder (1974) demonstrated that before children develop an adult "Mass Theory" of balance, they entertain a "Center Theory", believing that all objects should be balanced at their geometric center. Younger, "No Theory" children balance blocks by trial and error. In Experiment 1 we let Mass Theorists and Center Theorists play with a block that was weighted off to one side. We then "balanced" the block on a post either at the block's geometric center or at its center of mass. (Thus evidence that was theory-consistent for a Center Theorist was theory-violating for a Mass Theorist and vice versa.) We also introduced a novel toy (a peg and rings). Children were allowed to play freely for 60 seconds. When the evidence about the balancing block was consistent with the children's theories, they showed a standard novelty preference and played mostly with the novel toy. When the evidence violated children's theories, they preferentially played with the balancing blocks. In Experiment 2, we replicated the design with younger, No-Theory children; they showed a novelty preference regardless of whether the block was balanced in its geometric center or center of mass. These results suggest that children's spontaneous exploratory play is systematically affected by the interaction of their naïve theories and the evidence they observe. We discuss these results in terms of the optimality of children's play.

Keywords: Exploratory play, theories, evidence, balance task, cognitive development, learning

Play and Learning

Since Piaget (1951), researchers have believed that children's own actions on the environment play a central role in how they learn about the world. At the heart of the Piagetian account is the idea that children "construct" knowledge (and particularly causal knowledge) by active exploration. Although this "constructivist account" is widely accepted, there is in fact little evidence for a systematic relationship between children's play and their naïve theories. In general, the only systematic finding about children's exploratory play is that children (and many other creatures) preferentially explore novel over familiar stimuli (e.g. Berlyne, 1960; Hutt & Bhavnani, 1972; Pavlov, 1927). Moreover, considerable research suggests that even older children have difficulty designing informative experiments (Chen & Klahr, 1999; Inhelder & Piaget, 1958; Koslowski, 1996; Kuhn, 1989). These results pose a problem for the Piagetian account: if children's exploratory play is largely unsystematic, how might they generate the type of evidence that could support learning?

One possibility is that although the particular actions children take in the course of play might not be systematic, children's exploratory play might nonetheless be sensitive to the ambiguity of the evidence they observe. In a recent study for instance, children were introduced to a toy and shown either confounded or unconfounded evidence about the causal structure of the toy. The toy was removed and then returned, along with a novel toy and children were allowed to play freely for 60 seconds. Children who observed unconfounded evidence showed the standard novelty preference and played primarily with the novel toy. However, children who observed confounded evidence did not show the novelty preference: they spent more time playing with the familiar toy (Schulz & Bonawitz, in press). This research was a first step in understanding how different types of evidence might lead to differential exploration.

In that study, children were shown different patterns of evidence (confounded v. unconfounded) under the assumption that all children had similar prior beliefs about how the toy might work. However, research suggests that children's theories affect their interpretation of evidence (Bonawitz, Griffiths, & Schulz, 2006; Schulz, Bonawitz, & Griffiths, in press). If theories play an important role in how children construct knowledge, then children who have different initial theories but observe identical evidence might also show different patterns of exploratory play. The current study tests this hypothesis.

Getting ahead with a theory of balance

Because the development of children's theories has been well established in the domain of balancing blocks, this domain is particularly conducive for investigating the relationship between children's folk theories and their exploratory play. In a seminal study, Karmiloff-Smith & Inhelder (1974) looked at children's understanding of balance between the ages of 4 and 9 years of age. They demonstrated that between 6 and 8 years, children first entertain a "Center Theory", believing that regardless of the center of mass, an object should be balanced at its geometric center. Center Theorists repeatedly attempt to balance unevenly weighted blocks at their geometric center.

Gradually, children develop the correct, adult theory of balance: "Mass Theory". Mass Theorists understand that in order for a block to be stable, it must be balanced over its center of mass. Children's understanding of balance has subsequently been investigated by many researchers (e.g. Halford, 2002; Janson, 2002; Normandeau, 1989; Siegler, 1976). However, much of this literature focuses on the transition between incorrect and correct rules and strategies and not on the processes, like exploratory play, that might generate the evidence that could support such discoveries.

Experiment 1: Center- & Mass-theorist Play

To a Center Theorist, a block with a conspicuously heavy side balancing on its geometric center may not be surprising; however, this evidence should surprise a Mass Theorist. Conversely, to a Center Theorist, a block with one heavy side balancing under its center of mass might be surprising, but that evidence should not surprise a Mass Theorist. To investigate how children's theories affect their exploratory play, we used a method similar to the free play paradigm of Schulz and Bonawitz (in press). We presented children with evidence about the balancing blocks and then let them choose to play freely with either the balancing blocks (the familiar toy) or a peg and ring toy (the novel toy). If children are unsurprised by the evidence about the balancing blocks, they should spend most of their time playing with the novel toy; if they are surprised by the evidence, they might overcome the novelty preference and preferentially explore the familiar toy. We predict that children who observe identical evidence but have different theories will show different patterns of exploratory play.

Methods and Design

Participants Fifty-seven six and seven-year-olds (range = 72 to 96mths, M = 85mths) participated.

Materials A short, 6-page storybook (unrelated to the balancing task) about a girl who was looking for her teddy bear was used as a pretest to ensure the children were attentive. There were three theory-classification blocks, each made of Styrofoam and covered with colored tape, (see Figure 1). Additionally there were three familiarization blocks, identical blue blocks, each with a larger, heavier side. Test blocks balanced by the experimenter were identical to the familiarization blue blocks; however, the two test blocks each contained a magnet in the base located either in the center of the block or off to the side where the block would actually balance. The magnet was used throughout to make sure the stimuli and balancing attempts were equivalent across conditions. The balancing apparatus consisted of a rod inserted into a rectangular wooden base. The novel toy was comprised of

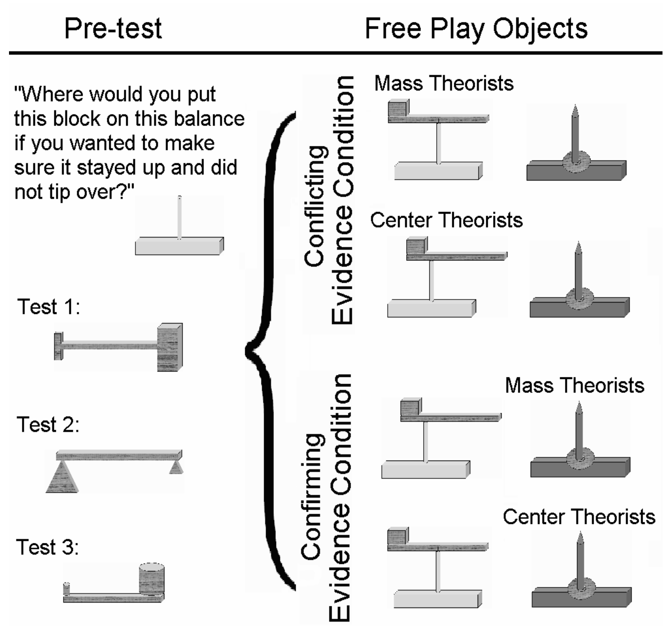

Figure 1: Methods and Design

a metal key ring with several charms; the ring was placed on a pointed rod and base similar to those of the balances. An opaque bag was used to cover the novel toy.

Procedure In order to make sure participants were attentive, children were first given the pretest book and asked two simple memory checks. If children failed the memory checks, they were discontinued from the study. Children were then given a theory-classification task. In this task, children were presented with the three classification blocks in random order and were asked to try to balance each block on the post. We coded whether the child attempted to balance the block at its geometric center or towards the center of mass. The experimenter took hold of the block before the child actually set it on the post so children never observed the outcome of their balancing attempts. The child was then shown the 3 familiarization blue blocks, given a chance to explore the blocks for a few seconds, and was then asked to point to the heavier side of each block. Throughout the classification and familiarization trials, the novel toy was on the table, covered so as to be out of the child's view, and off to the right or left side (counterbalanced).

Children were classified as Center or Mass Theorists based on where they attempted to balance the classification block on at least two of the three trials. Center balances included a 10% margin of error around the center of the block (~1 inch radius from center.) All balances towards the heavy side of the block that fell outside of this margin of error were coded as mass balances. The experimenter then randomly assigned children to either a Conflicting or Confirming condition, (see Figure 1).

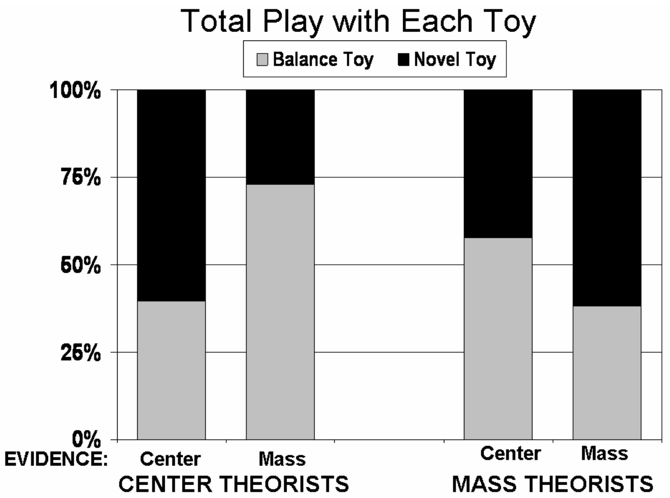

Figure 2: Experiment 1 children's total play with each toy.

The experimenter said, "I'm going to try to balance my block here very carefully," and 'balanced' the test block either in the geometric center of the block or over the center of mass. Then the experimenter uncovered the novel toy and told the child, "Go ahead and play with which ever toy you want until I come back." After 60 seconds of free-play, the experimenter returned to the table and covered up the novel toy. She returned the test block to its original balanced position and asked, "Why is this block staying up? How come it's not falling over?"

Results of Experiment 1

Three children were dropped from the study: one child for failing the pretest; two for parental interference. Of the remaining 54 children, 32 were classified as Center Theorists and 22 were classified as Mass Theorists. Of the Center Theorists, 87% of children attempted to balance the block at the geometric center on all three trials, the remaining 13% of children did so on two of the three trials. Of the Mass Theorists, 59% attempted to balance the block at the center of mass on all three trials; the remaining 41% did so on two of the three trials. Sixteen Center Theorists were randomly assigned to the Confirming condition; 16 to a Conflicting condition; 12 Mass Theorists were assigned to the Confirming Condition; 10 were assigned to the Conflicting Condition.

Children were counted as playing with the toys as long as they were touching the toys and we coded the total amount of time each child played with each toy. We analyzed children's play by looking at how long, on average, children played with the balance block. Data were coded by both the first and second author.

Children were more likely to explore the familiar toy (the block) when the evidence conflicted with their theories than when it confirmed their theories (See Figure 2). To compare the amount of time playing with the blocks, we ran a two-way-between subjects ANOVA with theory and type of evidence as the between subjects variables and time spent playing with the blocks as the dependent measure. Comparisons between conditions revealed no main effect of theory (averaging across the two conditions, Center theorists and Mass theorists played for equal amounts of time) and no main effect of evidence type (averaging across the two conditions by theory, children who saw the block balancing at the geometric center played as long as children who saw the block balancing at the center of mass). However, comparisons revealed a significant interaction: children spent more time playing with the block when the evidence conflicted with their theories than when the evidence confirmed their theories ($F(1, 53) = 5.38$, $p = .024$).

Discussion of Experiment 1

The results of Experiment 1 support the claim that children's prior beliefs shape their choices in play, suggesting that young children's spontaneous exploratory play is sensitive not just to the perceptual novelty of an object, but also to whether or not observed evidence is consistent with the child's theoretical predictions. Although children observed identical evidence, they showed distinctive patterns of exploratory play. Two variables seemed to drive the effect: the initial theory and the observed evidence.

Experiment 2: No-balance-theory

The results of Experiment 1 support the idea that children's theories play a pivotal role in their exploratory play. However, what happens when children don't have strong theoretical commitments? In the original balancing studies of Karmiloff-Smith and Inhelder (1974), the researchers suggested that children between 4 and 6 have not yet developed a theory of balance. If younger children do not have robust theories of balance, neither a conspicuously weighted block balancing at its center of mass nor a block balancing at its geometric center should be particularly surprising; children should show a novelty preference throughout.

Methods and Design

Participants Thirty-five 4 and 5-year-olds (range = 51mths to 68mths, M = 62mths) participated.

Materials Blocks, books, and novel toy were identical to those in Experiment 1.

Procedure/Design The procedure was identical to the procedure in Experiment 1. However, because children's initial predictions were not seen as theory-driven, children were randomly assigned to either the Geometric Center or Center of Mass conditions.

Results from Experiment 2: No-balance-theory

Six children were removed from the study for failing the pretest. Of the remaining 29 children, 15 were assigned to the Geometric Center Condition; 14 were assigned to the Center of Mass condition. Results for the No-Theory children were analyzed as in Experiment 1. In both conditions, children were more likely to explore the novel toy by all measures. We compared how long the children played with each toy in each condition by doing a 2 x 2 mixed ANOVA with play time on each toy as the within-subjects variable and condition as the between-subjects variable. Comparisons between the Conflicting Condition and Confirming Condition revealed a main effect of play time (averaging across the two conditions, children significantly preferred the novel toy over the balance toy, ($F(1, 28) = 11.09$, $p < .01$)), but no main effect of condition (overall, children played for the same amount of time in each condition), and no interaction: children spent the same amount of time playing with the balance toy in the Geometric Center Condition as in the Center of Mass Condition. Additionally, individual children were no more likely to prefer the balance toy in the Geometric Center Condition than in the Center of Mass Condition (χ^2 (1, $N = 28$) = .05, $p = ns$).

Children were marginally more likely to play with the novel toy than the balance in the Geometric Center Condition ($t(14) = 1.68$, $p = .057$) and significantly more likely to play longer with the novel toy than the balance ($t(8) = 2.09$, $p < .05$) in the Center of Mass Condition. In both conditions, a non-significant majority of children played most with the novel toy.

Other measures of children's theories

Several of the No-Theory children necessarily balanced the classification blocks consistently on two of three trials, so why believe that these children did not have an initial theory that differentially predicted whether the block would balance on the geometric center vs. the center of mass? We suggest that there are three reasons to believe these children were genuinely pretheoretical with respect to the center/mass distinction. First, the ages of these children align with the ages of children in the original Karmiloff-Smith & Inhelder studies. In these studies, the 'non-theorists' were classified between 4-6yrs, the Center Theorists between 6-7.5yrs, and the Mass Theorists beginning at 7.5yrs. Our mean ages were similarly 5;2 for the No-Theory children, 6;10 for the Center Theorists, and 7;4 for the Mass Theorists.

Secondly, the initial predictions of the No-Theory children were significantly more variable than the Center and Mass Theorists, with 69% of the No-Theory children generating inconsistent predictions in the classification trials (e.g., picking the same location on two out of three rather than three out of three trials) compared to only 13% of the Center Theorists and 41% of the Mass Theorists, (No-Theory vs. Center: (χ^2 (1, $N = 59$) = 20.3, $p < .01$); No-Theory vs. Mass: (χ^2 (1, $N = 49$) = 5.37, $p < .05$)). When we specifically coded for predictions that were inconsistent with both Mass and Center theories (such as balancing towards the lighter side of the block), we found that 34% of the No-Theory children made such predictions at some point in the classification trials, while only 1 of the 49 older children made such a prediction.

As a final test of children's theoretical commitments, we looked at children's explanations for why the block was balancing after their free play period. Children's explanations uniquely and unambiguously fell into one of four categories: Center Theory consistent explanations (e.g. "It balances because it's in the middle; there's the same length on both sides"); Mass Theory consistent, (e.g.. "There's equal amount of weight on both sides"); appealing to the hidden cause, the magnet, (e.g. "There's something sticky there holding it up, like a magnet"); or Other (e.g. "It's flat"; "You balanced it slowly and carefully"). After the free play period, only 6% of the Center Theorists offered a Center Theory consistent explanation for why the block balanced; 28% offered a Mass Theory consistent explanation; 53% appealed to the magnet; and 12% of the explanations were classified as Other. The results were similar for the Mass Theorists: 6% offered a Center Theory consistent explanation; 41% offered a Mass Theory Consistent explanation; 41% appealed to the magnet and 12% were classified as Other.

The scarcity of Center Theory consistent explanations among the children classified as Center Theorists is perhaps surprising. Clearly the magnet attracted many of the children's attention. However, we think it is also possible that some of the children were at a liminal stage between Mass and Center theories. The play period may have given some of the children classified as Center Theorists more familiarity with the way the weight was distributed in the block. It is worth noting that in Karmiloff-Smith & Inhelder's study as well, many Center Theorists changed to Mass Theorists over the course of the play period. Critically however, while 88% of Center and Mass Theorist explanations appealed to one of the first three classification schemes, the majority of No-Theory (52%) children gave explanations that were classified as Other. Children were significantly more likely to give Other explanations in the No-Theory condition than in the Center Theory condition (χ^2 (1, $N = 59$) = 10.9, $p < .01$) or the Mass Theory condition (χ^2 (1, $N = 44$) = 7.35, $p < .01$), suggesting that the No-Theory children genuinely had less developed beliefs about the relevant dimensions of this task than the other groups of children.

Of course, it is unlikely to be the case that these younger children have no theories at all about balance. These children would certainly be surprised to see a block floating in mid-air, or a block 'balanced' on an extreme edge. In fact, the explanations of many of these children seem to suggest that children might have a theory that contact between flat surfaces is required for balance. Many children gave explanations such as, "It stays up because it's flat", and "You set it on the circle part which is smooth", and "It's even on the bottom." Importantly however, both the geometric center and center of mass evidence are equally consistent with this 'flat surface theory' and thus equally uninteresting to the youngest children, enabling exploration of the novel toy.

Additionally, work on children's predictions about balance scales (e.g. see Siegler, 1976) suggest that even these younger children may be able to employ rules to help make balancing predictions. Indeed, Siegler (1976) found that 5-6-year-old children had difficulty attending to more than one dimension of the blocks, but could at least make the prediction that as more weight is added to one side of the block, the balance may start to tip. However, this task is importantly different from our task because it draws attention to weight as a probable variable which will lead to change. In our task the children must notice that the block is weighted, and use this knowledge to make a prediction about where along the fulcrum the block will balance.

Overall, the findings of Experiment 2 support the well-established finding that children preferentially explore novel objects over familiar ones. They also support the idea that these younger children do not have a strong (evidence differentiating) theory of balance. Contrasting these results with Experiment 1 suggests the influence that children's theories can have in overcoming a preference for stimulus novelty and affecting children's play. Not only do the older children have strong theories, but these theories selectively support children's spontaneous exploration of theory-violating evidence.

General Discussion

Theories seem to play a critical role not only in supporting causal inferences, helping make predictions, and explaining the world, but also in guiding children's exploratory play. Such theory-guided play is arguably a form of optimal exploration: it suggests that children may play more where there is indeed something to be learned: either a) there is a hidden variable that can explain the surprising evidence, or b) something about the theory is incorrect. If theories support effective exploration, then children may spontaneously discover evidence that can help them revise their causal beliefs.

Do children actually learn novel causal relationships from the evidence of their own interventions (as suggested by the constructivist account)? Our experiment does not address this directly, though other research does suggest that children's spontaneous play can generate evidence that supports accurate causal learning (Schulz, Glymour, & Gopnik, in press). Here, children were arguably unable to learn much about their initial theories because we provided children with an alternative explanation for the evidence: the magnet. It is interesting to note, however, that despite the fact that the magnet was completely hidden (that is, it was observable only in its effects), most children discovered it in the course of their free play and almost half the children in Experiment 1 (49%) spontaneously appealed to it as an explanatory variable. It is also noteworthy that in Inhelder & Karmiloff-Smith's study (where there were no hidden magnets) many children did change their beliefs in the course of exploratory play. Future work may extend our understanding of the relationship between children's naïve theories, patterns of evidence, and their learning.

These results may also appear to conflict with previous work that argues that children have a relatively impoverished ability to learn from evidence, revise their beliefs, and construct informative interventions (e.g. see Kuhn, 1989). However, the demands of the Kuhn et al. studies required children to be meta-cognitively aware of their theories. While children (and even lay adults) may lack such metacognitive awareness (and thus be unable to design controlled experiments), children may nonetheless, at least implicitly, recognize when evidence conflicts with their prior beliefs. This research suggests that when children do perceive a conflict between their theories and patterns of evidence, they are motivated to explore.

Looking time paradigms (where infants look longer at novel or surprising events) may also seem somewhat analogous to the work here. For instance, one might be puzzled by the finding that infants as young as 12 months will look longer at an object whose center of mass is not supported (Baillargeon, Needham, DeVox, 1992), yet our subjects, who are more than 6 years older, do not seem to perceive a violation. In this respect, our study is consistent with many that have found a distinction between children's performance on looking-time and action-oriented tasks (e.g. see Onishi & Baillargeon, 2005). One key difference between the paradigms may be whether evidence is surprising because it is novel or whether evidence is surprising because it violates prior beliefs. An event might be uncommon in the course of everyday experience and lead to longer looking, without requiring the subject to posit any theory of how things *should* be.

A complete understanding of the processes that support theory development and theory change remains a challenge to the field. However, we believe theory-guided exploration may play an important role in helping children generate relevant evidence. Although processes as complex and noisy as children's play have rarely seemed amenable to formal principles, we hope our work suggests that even in play, there are rational relationships between theory, evidence, and exploration. We hope future work may help bridge the gap between formal theories of learning and children's play.

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