

Certain to be surprised: A preference for novel causal outcomes develops in early childhood

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Abstract

A large literature on the development of causal reasoning characterizes early childhood as a period of curiosity, exploration, and experimentation. It therefore seems plausible that a *novelty preference* is a universal hallmark of early causal learning: Such a bias would direct attention towards new opportunities for knowledge gain. An alternative possibility is that this novelty preference develops over time, with younger children prioritizing attention to stable, predictable causes, in order to build knowledge, competence, and control. In three experiments with 2- to 4-year-olds, we investigate the developmental trajectory of children's preference for causal processes that produce *reliable* versus *novel* outcomes. We find evidence for a developmental shift between ages 2 and 3: 2-year-olds display a bias to explore reliable, deterministic outcomes, whereas older children prefer novel ones. We discuss possible adaptive reasons for this shift.

Keywords: cognitive development; causal learning; exploration; novelty; determinism

Introduction

Several decades of research on the development of causal reasoning in early childhood portrays the young learner as a “little scientist.” Toddlers and preschool-aged children generate hypotheses to explain their observations, infer which of a variety of competing explanations best fits the data, and update their beliefs in light of new evidence (e.g., Gopnik et al., 2001, 2004; Gopnik & Sobel, 2000; Gweon & Schulz, 2011; Kushnir & Gopnik, 2007; Schulz, Gopnik, & Glymour, 2007 see Gopnik, 2012 and Gopnik & Wellman, 2012 for reviews). This literature also emphasizes that young children actively explore their environment (e.g., Schulz, 2012), and generate a range of novel interventions to build and revise their causal knowledge (e.g., Bonawitz et al., 2012; Cook, Goodman, & Schulz, 2011).

Given these findings across a wide range of paradigms, it seems plausible that young children have a universal, and perhaps innate preference for novelty, driving discovery in the causal domain. However, a competing hypothesis is that a preference to explore novel causal outcomes *develops* over the course of early childhood. Specifically, it may be adaptive for younger children to prioritize actions that are more likely to produce reliable, or invariant outcomes, to build a basic repertoire of causal knowledge and competencies. After this initial groundwork is established, children may then *shift* to prefer novel outcomes that they cannot yet explain—expanding the boundaries of their existing knowledge.

In three experiments, we investigate which of these competing possibilities best characterizes children's preferences for causal outcomes in early childhood. We find initial evidence that a novelty preference in the causal domain is not universal, but likely develops over time—in this task, between ages two and three. We discuss the implications of these findings for theories of early causal learning and discuss possible advantages for this preference shift for navigating and learning about variable environments.

A Universal Preference for Novelty?

Developmental psychologists have long exploited very young children's attention to novelty. Hundreds of papers rely on infant looking time as a measure of surprise to demonstrate their detection of differences between familiar (or expected) and novel (or unexpected) events (see Sim & Xu, 2019 for a comprehensive review of this literature). Recent research demonstrates that infants not only look longer at stimuli that violate their expectations, but also preferentially explore those stimuli, presumably reflecting their desire to explain an observed violation of their existing beliefs (Schulz, 2015; Sim & Xu, 2017; Stahl & Feigenson, 2015; 2017; 2019).

This vast infant literature—and particularly the most recent exploration findings—aligns with the portrait of the child-as-scientist, who preferentially explores surprising or confounded evidence, and designs novel interventions to disambiguate competing causal hypotheses (Bonawitz et al., 2012; Cook, Goodman, & Schulz, 2011; Gweon & Schulz, 2008; Schulz & Bonawitz, 2007; Schulz, Standing, & Bonawitz, 2008). One prominent theoretical account claims that the evolutionary purpose of childhood is to enable precisely this type of “high-temperature” (i.e., variable and wide-ranging) search for information in the environment. In other words, it may be adaptive for children to explore broadly because it facilitates their discovery of unexpected, or novel data (Gopnik, 2016; Gopnik et al., 2017). When viewed from this perspective, children's attention to novel causal outcomes might be expected to appear consistently across infancy and childhood, since it affords young learners with opportunities to acquire new knowledge.

Merits of Attending to Reliable, or Deterministic Causes

Despite the potential benefits of attending to novel events, there may also be merit in prioritizing attention to reliable,

invariant, or deterministic aspects of the environment in very early childhood. After all, learning from surprising or unexpected outcomes requires that a reasoner first establish a stable and well-grounded knowledge base; otherwise, new information cannot be assimilated into existing frameworks (e.g., Piaget, 1929). Young learners are faced with the challenge of navigating a variable environment in which their interactions and interventions may often yield surprising and unexpected results. In light of this, they may initially prefer to learn about reliable causal relations that they can control. For example, repeated causal intervention on a light switch is trivial, but nevertheless provides long-lasting amusement for young children. By contrast, early interactions with the keys on a piano or laptop provides fewer experiences of reliability and control: repeated mashing, rather than repeated switching, yields complex and often discordant evidence that is difficult to interpret or reproduce.

One recent theoretical account suggests that young children may be more likely than older children and adults to search for invariance during exploration, which explains their tendency to repeatedly engage in “positive testing” (i.e., producing causal interventions that yield confirmatory evidence) (Lapidow & Walker, 2019). This account is based on a diverse set of theories in psychology and philosophy that emphasize the importance of *invariance* in causal reasoning—the extent to which a particular causal relation continues to hold over repeated instances and across conditions (Sloman, 2005). According to Lapidow and Walker (2019), establishing invariant, generalizable causal knowledge may be critical for supporting later exploration of unknown, or unexplained phenomena.

In the current study, we aim to test the related proposal that young children may initially prefer to produce reliable causal outcomes for a particular phenomenon, and then *shift* to begin expressing a novelty preference later in development.

The Current Experiments

In the current experiments, we use a simple paradigm to test whether children prefer a cause that produces novel outcomes, or a cause that produces reliable (i.e., deterministic) outcomes. *Experiment 1* provides evidence suggesting a developmental shift from a preference for reliable causal outcomes (at 2 years) to a preference for variable causal outcomes (at 3 years and older). *Experiment 2* demonstrates that older children’s preference for variable outcomes is reduced when controlling for novelty. That is, if 3-year-olds know in advance which outcomes to expect, they no longer prefer a variable cause over a reliable one. This suggests that novelty, and not variability, drives the preference observed in Experiment 1. Finally, *Experiment 3* provides initial evidence that three-year-olds’ preference for novel causal outcomes is amplified when they observe more evidence for a cause’s tendency to produce novel, rather than reliable, effects.

Experiment 1

Experiment 1 investigated two-, three-, four-, and five-year-olds’ preferences for novel versus reliable causal outcomes.

Methods

Participants and Design A total of 200 participants, including 50 2-year-olds ($M_{age} = 30.5$ months, $SD = 3.4$), 50 3-year-olds ($M_{age} = 42.66$ months, $SD = 3.59$), 50 4-year-olds ($M_{age} = 52.9$ months, $SD = 3.27$), and 50 5-year-olds ($N = 50$, $M_{age} = 65.02$ months, $SD = 3.18$) were recruited from children’s museums, where they were tested in a quiet area of the museum. Twenty-five additional children were tested but excluded from the sample due to inattention (11), experimenter error (5), failure to respond (3), parental or sibling interference (3), or language comprehension issues (3).

Materials and Procedure Participants were introduced to two “change machines,” which were composed of identical white boxes with one hole on the top and one hole on the lower portion of the box’s front face (see *Figure 1*). The experimenter said, “Look! These are my change machines. They’re called change machines because when we put something in it,” [*the experimenter gestured to the holes on the top of each box*], “it turns into something else!” [*the experimenter gestured to the holes on the front of each box*]. The experimenter then picked up one of seven identical, blue, cube-shaped blocks and said, “Look! Let’s see what happens when we put this block into this change machine!” The experimenter dropped the cube into the top hole of one of the boxes, where it was caught by a hidden shelf. The experimenter then immediately pushed a *new* block with a different shape (e.g., a cylinder) down a hidden chute and out the front hole, such that it appeared to the participant that the original block had changed identity. The experimenter said, “Cool! Let’s try another block in this change machine!” and repeated the procedure twice more, placing each outcome block to the side of the machine in a horizontal row, such that the child was able to see all of the blocks the machine had produced. The experimenter then said, “So that’s what happens when we put things in *this* change machine. Now let’s find what happens when we put blocks in this *other* change machine!” The procedure was repeated with the other box; thus, each participant saw three causal outcomes from each of the two boxes.

Critically, one of the boxes (the *deterministic* change machine) produced three identical blocks (e.g., three cylinders), while the other box (the *variable* change machine) produced a different block each time (e.g., rectangle; semicircle; triangle). The order in which the deterministic and variable change machines were demonstrated was counterbalanced across trials, as was their right-left placement and the shapes produced by each machine.

At test, the experimenter held up the seventh and final cube block. They said, “Oh! It looks like we have only one block left! Which machine do you want to put it in?” The

child was given the opportunity to respond. Participants' responses were recorded as their first point, reach, or verbal choice. The experimenter then handed the block to the child and allowed them to place the block in their chosen machine. In the handful of cases where there was a discrepancy between the child's initial response and the machine into which they subsequently inserted the block, the response was coded as the child's actual intervention choice.

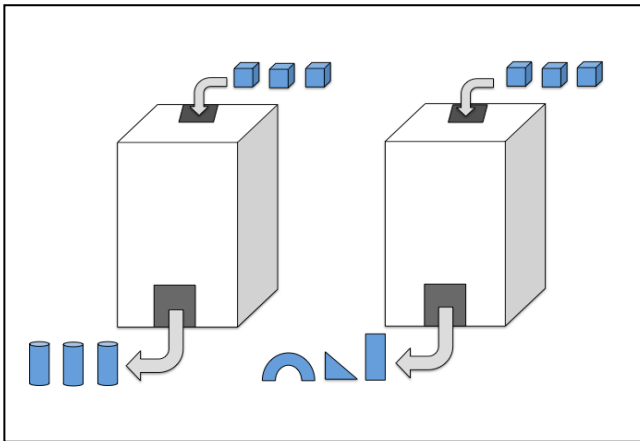


Figure 1: Schematic of the deterministic (pictured left) and variable (right) change machines and their outputs.

Results and Discussion

The results of Experiment 1 provide evidence for a developmental shift from a preference for deterministic causal outcomes to a preference for variable outcomes between ages two and three in this task. While only 38% of two-year-olds chose to observe the final block placed in the variable machine, indicating a trending preference for deterministic causal outcomes, $t(49) = -1.73, p = .09$, three-, four-, and five-year-olds significantly preferred the variable machine (68%, $t(49) = 2.70, p < .01$; 66%, $t(49) = 2.36, p = .02$; 68%, $t(49) = 2.70, p < .01$), with no difference between the older three age groups, $F(2,147) = 0.03, p = .97$. There was a significant difference between two- and three-year-olds' preferences, $t(88) = -3.34, p = .001$. These results provide initial evidence that a preference for novel causal outcomes is not stable across early childhood, but rather develops—in this task, appearing between the ages of two and three.

However, this paradigm leaves open the possibility that the older children's preference is for *variability*, rather than for *novelty*. That is, it may be that the older children simply have a preference for greater perceptual entropy—or an aversion to uniformity—that the younger children do not share. In Experiment 2, we control for novelty to investigate whether three-year-olds' preference in Experiment 1 is due to a preference for variability.

Experiment 2

Experiment 2 (ongoing) investigates the effect of controlling for novelty by showing participants all of the possible outcomes in advance. If the older children's preference for the machine that produced variable outcomes in Experiment 1 is due to a genuine preference for novelty, then this preference should disappear when the causal outcomes of each change machine are known in advance. If, on the other hand, older children are simply attracted to variability, then they should continue to prefer the variable machine over the deterministic machine.

Given the uniformity of responses in 3-, 4-, and 5-year-olds in Experiment 1, Experiment 2 (and Experiment 3) only include children aged 2- and 3-years, in order to further explore this developmental shift.

Methods

Participants and Design Fifteen two-year-olds ($M_{age} = 29.8$ months, $SD = 4.25$) and 23 three-year-olds ($M_{age} = 41.3$, $SD = 3.86$) of a planned sample of 100 total participants (50 per age group) have participated thus far.

Stimuli and Procedure. The stimuli and procedure in Experiment 2 were identical to those in Experiment 1, with one exception: the range of causal outcomes of each machine were shown to participants in advance.

The experimenter first introduced the change machines in the same manner as in Experiment 1. However, following this introduction, the experimenter attached a laminated image to the front of each change machine with Velcro. The images included an illustration of the three blocks that would be produced for each machine—one with three identical blocks (to be attached to the *deterministic* machine) and one with three unique blocks (to be attached to the *variable* machine).

After affixing the first image to the front of one of the machines, the experimenter said, "Look! Here are the things that *this* machine makes. So, when we put things in this machine, this is what comes out [*gesturing to the shapes on the image*]." They then affixed the second image to the front of the other machine, saying, "And look! Here are the things that *this* machine makes [*gesturing to the shapes on the image*]." So, when we put things in this machine, this is what comes out [*gesturing to the shapes on the image*]." Thus, all participants were knowledgeable of the causal outcomes of each machine prior to the demonstration. The remainder of the procedure was identical to that of Experiment 1.

Results and Discussion

Initial results of Experiment 2 suggest that removing the novelty of the causal outcomes also removes older children's preference to intervene on the variable machine: only 9 of the 23 three-year-olds (39.1%) preferred the variable change machine, $t(22) = -1.04, p = 0.31$. This is significantly different from their pattern of responding in Experiment 1 (68%), $t(40.6) = -2.34, p = 0.02$. Two-year-

olds continued to prefer the deterministic machine, with 6 of the 15 participants choosing the variable machine (40%), which does not differ from their performance in Experiment 1, $t(23.4) = 0.34$, $p = 0.74$. These initial findings suggest that the older children’s preference for the variable over deterministic machine in Experiment 1 is likely driven by a true preference for novelty, rather than a preference for variable outcomes.

Experiment 3

Experiment 3 (ongoing) investigates whether the emerging novelty preference is amplified when older children observe a larger quantity of evidence to suggest that a cause reliably produces novel outcomes.

Methods

Participants and Design 10 two-year-olds ($M_{age} = 27.9$ months, $SD = 3.6$) and 12 three-year-olds ($M_{age} = 42.3$ months, $SD = 3.8$) of a planned sample of 100 total participants (50 per age group) have participated thus far.

Stimuli and Procedure. The stimuli and procedure used in Experiment 3 are identical to those used in Experiment 1, with one exception: each change machine was demonstrated *nine* times, for a total of 18 unique outcomes. Thus, the deterministic machine produced nine identical blocks, and the variable machine produced nine unique blocks. At test, just as in Experiments 1 and 2, participants once again had the opportunity to choose a machine in which to place a final block.

Results and Discussion

Initial results suggest that Experiment 3 replicates and extends the findings of Experiment 1. Increasing the number of novel outcomes produced by the variable change machine increased older children’s novelty preference: 14 out of 15 three-year-olds (93%) preferred the variable machine, $t(14) = 6.5$, $p < .001$. By contrast, only 4 out of the 10 two-year-olds (40%), chose to see the final block placed in the variable change machine, $t(9) = -0.61$, $p = 0.55$. Coupled with the findings of Experiments 1 and 2, these provide converging evidence for the emergence of a novelty preference for causal outcomes between ages two and three on this task.

General Discussion

The present experiments provide initial evidence that preferences for causal outcomes may change over the course of early childhood (see *Figure 2* for a summary of all results). *Experiment 1* found evidence for a shift from a trending preference for reliable, deterministic causal outcomes to a significant preference for variable causal outcomes between ages two and three, and continuing through 5 years of age. *Experiment 2* (ongoing) provides initial evidence that this shift in preference is truly due to

novelty, and not to mere variability: 3-year-olds’ preference for variable outcomes disappears when they know the outcomes in advance. Finally, *Experiment 3* (ongoing) demonstrates that increasing the amount of evidence provided amplifies these preferences.

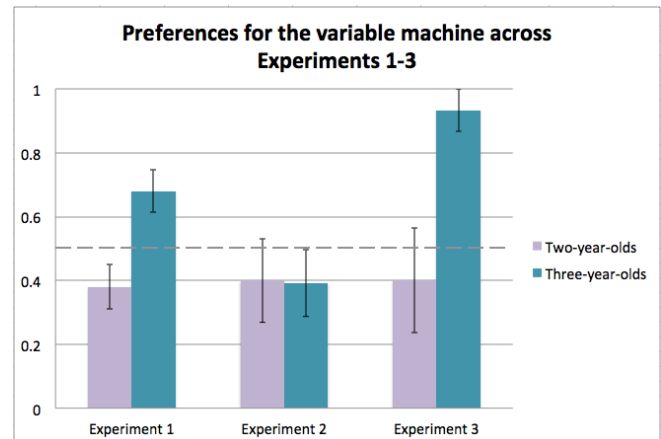


Figure 2: Results of Experiments 1–3, indicating 2- and 3-year-olds’ preference for the variable change machine. Chance performance is indicated by the dashed line.

Taken together, results are anticipated to yield important findings for ongoing research in early causal reasoning—informing work on exploratory learning and explanation-seeking behavior. In addition to completing data collection on all current experiments, future work will explore the circumstances under which two-year-olds’ preferences might shift from deterministic to novel outcomes as they gain additional knowledge about a causal system.

From a broader perspective, the present findings may shed light on an understudied aspect of early causal learning: the benefit of establishing a strong base of prior knowledge before exploring novel outcomes. Younger children are, after all, newer to the world. Their challenge is not only to learn the causal structure of their environment, but also to discover their own capabilities.

Modern empirical investigations of causal learning have drawn heavily on theoretical and computational accounts from probabilistic models, which represent causal knowledge as networks of variables related to one another by causal dependencies (e.g., Gopnik et al., 2004; Pearl, 2009). However, these accounts do not (and cannot) address the phenomenological implications—and motivations—of the epistemic uncertainty that characterizes early childhood, or children’s efforts to cope with that uncertainty. The present findings suggest that early causal reasoning may emerge, at least in part, from a motivation to achieve certainty and control, in addition to the desire discover the true causal structure of the world. Future developmental work may benefit from integrating these two powerful—and complementary—engines of causal learning.

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