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

Mariel K. Goddu (goddu@berkeley.edu)
Department of Psychology, 2121 Berkeley Way
Berkeley, CA 94720 USA

Caren M. Walker (carenwalker@ucsd.edu)
Department of Psychology, Department of Psychology, McGill Hall #0109
9500 Gilman Drive, La Jolla, CA 92093 USA

Abstract

A large literature on the development of causal reasoning characterizes early childhood as a period of curiosity, exploration, and experimentation. This suggests that a *novelty preference* may be a universal hallmark of early causal learning. Functionally, such a bias might serve to direct attention towards new opportunities for knowledge gain. An alternative possibility is that a preference for exploring novel outcomes develops over time. In three experiments with 2- to 5-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: while two-year-olds trend toward a preference for reliable over novel outcomes, older children clearly prefer novel ones. We discuss possible adaptive reasons for this developmental shift.

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

Introduction

A large literature 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, learn from evidence to 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 that drives discovery in the causal domain. However, there are at least two additional possibilities in which a preference to explore novel causal outcomes *develops* over the course of early childhood. One possibility is that younger children in fact possess the opposite preference. That is, it may be adaptive for younger children to prefer actions that are more likely to produce reliable, or invariant outcomes in order to build a basic repertoire of causal knowledge and competencies. After this initial groundwork is established, children may *shift* to prefer novel outcomes that they cannot yet explain, expanding the boundaries of their existing knowledge. Alternatively, children may not initially prefer causes that produce either reliable or novel outcomes. Instead, a novelty preference may develop with experience, as children discover that causes that generate novel outcomes afford more opportunities for learning.

In three experiments, we investigate which of these 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 the emergence of a novelty preference 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. Specifically, 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 opportunities to acquire new knowledge.

Merits of Attending to Reliable Causal Outcomes?

Despite the potential benefits of attending to novel events, there may also be merit in prioritizing attention to reliable, or invariant aspects of the environment in very early childhood. 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 mashing the keys on a piano or laptop provide fewer experiences of reliability and control, yielding complex, 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 express a novelty preference later in development. Alternatively, as detailed above, it may be the case that younger children do not prefer reliable or novel causal outcomes: if a novelty preference emerges, it does so because children learn that exploring novel causal outcomes is more likely to provide opportunities for information gain.

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 outcomes. *Experiment 1* provides evidence suggesting the emergence of a novelty preference between 2 and 3 years of age. *Experiment 2* (ongoing) demonstrates that novelty, and not mere variability, drives this preference. That is, if 3-year-olds know in advance which outcomes to expect, they no longer prefer a variable cause over a reliable one. Finally, *Experiment 3* (ongoing) provides initial evidence that 3-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 variable 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 *reliable* 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 reliable 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.

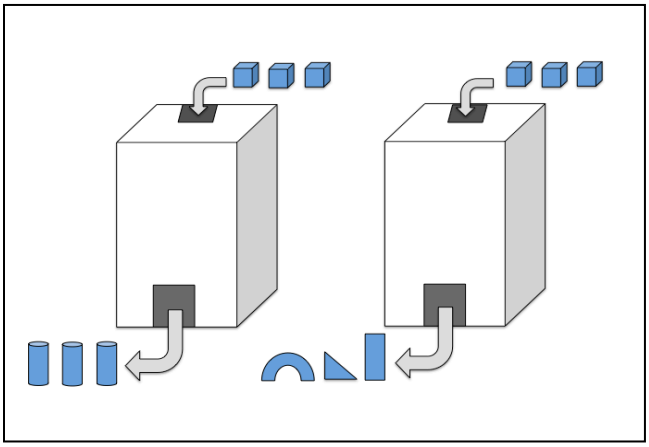

Figure 1: Schematic of the reliable (pictured left) and variable (right) change machines and their outputs.

Results and Discussion

The results of Experiment 1 provide evidence for a developmental shift from a preference for reliable 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, but not significant, preference for reliable causal outcomes, X^2 (1, 50) = 2.88, p = .09, three-, four-, and five-year-olds significantly preferred the variable machine (68%, X^2 (1, 50) = 6.48, p = .01; 66%, X^2 (1, 50) = 5.12, p = .02.; 68%, X^2 (1, 50) = 6.48, p = .01), with no difference between the older three age groups, X^2 (2, 150) = 0.06, p = .97.. There was a significant difference between two- and three-year-olds' preferences, X^2 (2, 100) = 9.03, p = .002.. 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 reliable 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 *reliable* 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

The 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, X^2 (1, 23) = 1.09, p = .30. This is significantly different from their pattern of responding in Experiment 1 (68%), X^2 (2, 72) = 5.42, p = .01. Two-year-olds again did not have a significant preference for either machine, X^2 (1, 15) = .6, p = .44, which does not differ from their performance in Experiment 1, X^2 (2, 65) = .02, p = .89. These initial findings suggest that the older children's preference for the variable over reliable 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. If older children have a genuine preference for novelty, an increase in the number of novel outcomes produced by the variable machine should also increase their preference for the cause that produces them.

Methods

Participants and Design 10 two-year-olds (M_{age} = 27.9 months, *SD* = 3.6) and 15 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 reliable 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, X^2 (1, 15) = 11.27, 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, X^2 (1, 10) = 0.4, p = .53. Considered together with the findings of Experiments 1 and 2, these preliminary results 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, while still in progress, provide initial evidence that a preference for novel causal outcomes develops over the course of early childhood (see *Figure 2* for a summary of all results). *Experiment 1* (completed) found evidence for the emergence of a significant preference for a cause that produced 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 amplifies the 3-year-olds' novelty preference.

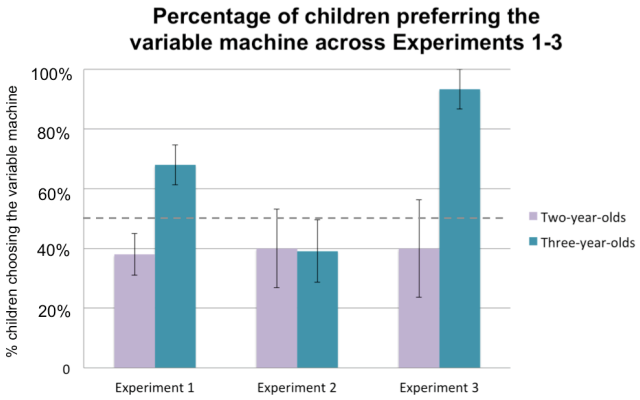

Figure 2: Results of Experiments 1–3, indicating 2- and 3-year-olds' preference for the variable change machine. Chance performance is indicated by the dashed line.

Taken together, these findings complement existing work on causal exploratory learning and explanation-seeking behavior in early childhood. The discovery that a preference for novel outcomes develops over early childhood suggests that children may *learn* what is epistemically beneficial to explore from their early experience with the causal world. Future empirical work is needed to investigate this possibility.

Additionally, the results of Experiment 1 indicate a trending, but non-significant preference for reliable causal outcomes in 2-year-olds. Once data collection for all three experiments are complete, all data from 2-year-olds will be combined (N = 150) to assess whether they indeed express a preference for reliable causal outcomes. Future work might also modify the current paradigm for use in even younger children, since it is possible that an even earlier preference for reliable outcomes was not captured by the age range included in the present experiments.

From a broader perspective, the present studies 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. Thus, 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 reliable to novel outcomes as they gain additional knowledge about a causal system. If younger children shift to preferring novel causal outcomes with increasing competence and knowledge, then we may infer that a preference for novel outcomes might also arise as a consequence of having stable causal knowledge that provides the foundation for new learning.

.

Acknowledgments

Thank you to Antonia Grunert, Anna Gruszka, Lalin Ozyazgan, and Brenna Yob for their assistance with data collection. We gratefully acknowledge Birch Aquarium, Fleet Science Center, and the New Children's Museum for allowing data collection for these projects in their facilities. We also thank the teachers and staff at Honey Bear Preschool, Maple Hill Early Learning Center, and Breezy Knoll Childcare Center for hosting data collection. Finally, we thank the participants' parents for allowing their children to take part in this research, and the participants themselves for sharing their time and attention.

References

Bonawitz, E. B., van Schijndel, T. J., Friel, D., & Schulz, L. (2012). Children balance theories and evidence in exploration, explanation, and learning. *Cognitive psychology*, *64*(4), 215-234.

Cook, C., Goodman, N. D., & Schulz, L. E. (2011). Where science starts: Spontaneous experiments in preschoolers' exploratory play. *Cognition*, *120*(3), 341-349.

Gopnik, A. (2012). Scientific thinking in young children: Theoretical advances, empirical research, and policy implications. *Science*, *337*(6102), 1623-1627.

Gopnik, A. (2016). *The gardener and the carpenter: What the new science of child development tells us about the relationship between parents and children*. Macmillan.

Gopnik, A., Glymour, C., Sobel, D. M., Schulz, L. E., Kushnir, T., & Danks, D. (2004). A theory of causal learning in children: causal maps and Bayes nets. *Psychological review*, *111*(1), 3.

Gopnik, A., Griffiths, T. L., & Lucas, C. G. (2015). When younger learners can be better (or at least more open-minded) than older ones. *Current Directions in Psychological Science*, *24*(2), 87-92.

Gopnik, A., & Sobel, D. M. (2000). Detecting blickets: How young children use information about novel causal powers in categorization and induction. *Child development*, *71*(5), 1205-1222.

Gopnik, A., Sobel, D. M., Schulz, L. E., & Glymour, C. (2001). Causal learning mechanisms in very young children: Two-, three-, and four-year-olds infer causal relations from patterns of variation and covariation. *Developmental psychology*, *37*(5), 620.

Gweon, H., & Schulz, L. (2011). 16-month-olds rationally infer causes of failed actions. *Science*, *332*(6037), 1524-1524.

Gopnik, A., & Wellman, H. M. (2012). Reconstructing constructivism: Causal models, Bayesian learning mechanisms, and the theory theory. *Psychological bulletin*, *138*(6), 1085.

Gopnik, A., O'Grady, S., Lucas, C. G., Griffiths, T. L., Wente, A., Bridgers, S., Aboody, R., Fung, H., & Dahl, R. E. (2017). Changes in cognitive flexibility and hypothesis search across human life history from childhood to adolescence to adulthood. *Proceedings of the National Academy of Sciences*, *114*(30), 7892-7899.

Gopnik, A., & Wellman, H. M. (2012). Reconstructing constructivism: Causal models, Bayesian learning mechanisms, and the theory theory. *Psychological bulletin*, *138*(6), 1085.

Gweon, H., & Schulz, L. (2008, July). Stretching to learn: Ambiguous evidence and variability in preschoolers' exploratory play. In *Proceedings of the 30th annual meeting of the Cognitive Science Society* (pp. 570-574).

Lapidow, E., & Walker, C. M. (2020). The Search for Invariance: Repeated Positive Testing Serves the Goals of Causal Learning. In *Language and Concept Acquisition from Infancy Through Childhood* (pp. 197–219). Springer, Cham.

Lewis, D. (1974). Causation. *The Journal of Philosophy*, *70*(17), 556–567.

Lombrozo, T., & Carey, S. (2006). Functional explanation and the function of explanation. *Cognition*, *99*(2), 167–204. https://doi.org/10.1016/j.cognition.2004.12.009

Pearl, J. (2009). Causal inference in statistics: An overview. *Statistics surveys*, *3*, 96-146.

Piaget, J. (1929). The child's concept of the world. *Londres, Routldge & Kegan Paul*.

Schulz, L. (2015). Infants explore the unexpected. *Science*, *348*(6230), 42-43.

Schulz, L. (2012). The origins of inquiry: Inductive inference and exploration in early childhood. *Trends in cognitive sciences*, *16*(7), 382-389.

Schulz, L. E., & Bonawitz, E. B. (2007). Serious fun: preschoolers engage in more exploratory play when evidence is confounded. *Developmental psychology*, *43*(4), 1045.

Schulz, L. E., Gopnik, A., & Glymour, C. (2007). Preschool children learn about causal structure from conditional interventions. *Developmental science*, *10*(3), 322-332.

Schulz, L. E., Standing, H. R., & Bonawitz, E. B. (2008). Word, thought, and deed: the role of object categories in children's inductive inferences and exploratory play. *Developmental psychology*, *44*(5), 1266.

Sim, Z. L., & Xu, F. (2017). Infants preferentially approach and explore the unexpected. *British Journal of Developmental Psychology*, *35*(4), 596-608.

Sim, Z. L., & Xu, F. (2019). Another look at looking time: Surprise as rational statistical inference. *Topics in cognitive science*, *11*(1), 154-163.

Sloman, S. A. (2005). *Causal models : how people think about the world and its alternatives*. Oxford; New York: Oxford University Press.

Stahl, A. E., & Feigenson, L. (2015). Observing the unexpected enhances infants' learning and exploration. *Science*, *348*(6230), 91-94.

Stahl, A. E., & Feigenson, L. (2017). Expectancy violations promote learning in young children. *Cognition*, *163*, 1-14.

Stahl, A. E., & Feigenson, L. (2019). Violations of core knowledge shape early learning. *Topics in cognitive science*, *11*(1), 136-153.