

Using physical simulations to predict children’s and adults’ preference for physical interactions

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Abstract

Curiosity is a fundamental driver of human behavior, and yet because of its open-ended nature and the wide variety of behaviors it inspires in different contexts, it is remarkably difficult to study in a laboratory context. A promising approach to developing and testing theories of curiosity is to instantiate them in artificial agents that are able to act and explore in a simulated environment, and then compare the behavior of these agents to humans exploring the same stimuli. Here we propose a new experimental paradigm for examining children’s—and AI agents’—curiosity about objects’ physical interactions by letting them choose which object to target when dropping a given object. We compared adults’ (N=155) and children’s choices (N=66; 3-7 year-olds) and found that adults show a strong preference for choices affording a containment relation, a preference that is also shown by children. Adults alone also make choices consistent with achieving support relations. We contextualize our results using heuristic models based on physics simulations of the same scenarios judged by participants.

Keywords: curiosity; novel objects; object interactions; intuitive physics

Introduction

Curiosity is a hallmark aspect of human intelligence. From infants exploring the objects in their environment to scientists exploring the frontiers of our solar system, humans are highly motivated to seek out new knowledge and experiences. However, although such exploratory behavior has long been recognized as a critical component of human learning (James, 1983) and cognitive development (Gopnik, Meltzoff, & Kuhl, 2009; Piaget, 1952), formal theories that explain human curiosity and how it drives exploratory behavior have remained elusive (Kidd & Hayden, 2015). Moreover, extant theories have rarely provided quantitatively precise enough predictions to be directly compared to empirical measurements of curiosity-driven behavior in humans.

The goal of the current paper is to help close this gap by proposing a novel paradigm to advance our theoretical understanding of curiosity, specifically within the domain of physical object interactions (Kubricht, Holyoak, & Lu, 2017). First, we present an empirical investigation of the pattern of actions taken by children and adults in a novel physical exploration task. We then present a set of heuristic models of curiosity based on a variety of metrics of simulated physical interactions (e.g., likelihood of a dropped object coming to rest on a target object), and test the degree to which these features predict children and adults’ behaviors in the same task.

We take inspiration from a large body of prior work in developmental psychology investigating the development of knowledge about physical objects, their properties, and how they interact (Baillargeon, 2007; Hespos & VanMarle, 2012; Smith, Jayaraman, Clerkin, & Yu, 2018). Children both spend a remarkably amount of time across exploring how different objects and surfaces interact during naturalistic play (Fenson, Kagan, Kearsley, & Zelazo, 1976) and spend longer time exploring objects that appear to violate physical laws (e.g., an object that appears to pass through a wall; Stahl & Feigenson (2015); Baillargeon (2007)). In other words, children seem to actively learn about physical interactions by intervening on the world and observing the consequences of their actions (Gopnik et al., 2009; Gureckis & Markant, 2012; Needham, 2000). However, relatively little work has examined what types of physical interactions children are most interested in testing, or linked children’s actions to formal theories of exploration or of physics learning. Instead, most work that has investigated exploratory behavior in children has done so by examining how they play with relatively complex objects – for example, documenting the number of functions discovered while playing with a novel toy (e.g., Cook, Goodman, & Schulz, 2011; Bonawitz, Schijndel, Friel, & Schulz, 2012; Gweon, Pelton, Konopka, & Schulz, 2014).

We developed a novel physical exploration task in which children, adults, or AI agents can choose which series of physical experiments to perform, and then demonstrate how this paradigm can be used to test theories of curiosity about physical interactions. First, we measured people’s choices in a novel physical exploration task, in which participants were told that they would drop a given object (e.g., a sphere, a torus; see Figure 1) onto one of two target objects (e.g., a dumbbell, a pentagonal prism; see Figure 2), with the goal of the creating the most interesting physical interaction. We recorded adults’ and children’s (3-7 years of age) choices for a set of trials in which some of the drop objects could plausibly end up *supported* by one of the target objects, and for a set of trials in which some of the drop objects could end up *contained* by one of the targets – although the other potential targets likely also offered affordances of interest. After examining the consistency of people’s preferences, we tested the predictive power of a variety of heuristic models of curiosity that operate on simulations of this task with these same objects in a 3D environment. Our results suggest that using detailed

measurement of human action selection and computational models based on simulations of the same tasks promises to lead to more robust and precise theories of human curiosity about the physical world, and how it develops.

Experiment 1: Adults

To investigate the systematicity of people’s preferences for physical interactions between objects, we began by studying adults, whom we might expect to be less idiosyncratic and thus more consistent in their choices than children. Our design is motivated by the results of a pilot study conducted in-person in January, 2020, in which we asked adults to select which of a pair of 3D-printed toy blocks (see Figure 1) they would like to drop on a given target object from the set, or vice-versa: on which of a given pair of target objects would they like to drop a given object. In the pilot study (N=15), the pairs of target or drop objects were chosen essentially at random, but were the same for all participants. We were surprised to find consistency in adults’ preferences for many of the trials: especially when given a drop object and asked to choose one of two target objects, adults were quite often (75-90%) targeting that object that would either *contain* or *support* the dropped object (i.e., the pipe could contain the cone; the pentagonal prism could support the octahedron). This consistency in their choices is remarkable given that there are many other possible goals that people might choose in order to make something “interesting” happen: they might attempt to make the dropped object roll or bounce far from the target, or rebound in an unexpected direction, but in fact most people settled on attempting support or containment relations. Thus, we set out to examine the development of these preferences, first in a large adult sample, and then in young children.

Method

Participants 200 adults were recruited via Amazon Mechanical Turk and were paid \$1 for participating.

Materials Stimuli were images of 3D objects produced using Blender 3D-modeling software. The nine objects, depicted in Figure 1, were bowl, cone, dumbbell, octahedron, pentagon (pentagonal prism), pipe, pyramid, torus, triangular prism, and ball (sphere; not pictured).

Design The experiment consisted of 20 drop trials, completed by each participant in one of four pseudorandom orders. Participants were randomly assigned to each order. Each drop trial displayed an object X that is to be dropped on one of two other objects (Y or Z), as described in the following procedure. In the 20 trials, each of the above 3D objects was used twice as the drop object (X), and appeared four times as potential targets. Instead of randomly sampling the target objects (Y or Z), each trial was designed to allow for one of two goal relations (or affordances): containment, or support. That is, the target objects were chosen so that one of them would be capable of either supporting or containing the dropped object. For example, if asked to drop the cone on either the torus or the octahedron, a containment relation could be achieved between the cone and the torus, but not the octa-

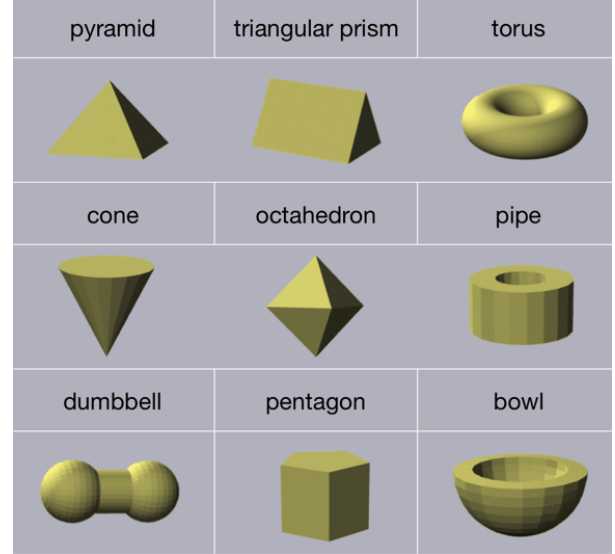


Figure 1: Nine of the 10 3D objects used for dropping and as targets (not pictured: ball).

hedron (and support is unlikely due to the small surface area of the octahedron). An example support relation is choosing to drop the pentagonal prism on the (equal diameter) pipe rather than the pyramid. 10 of the 20 trials were designed to afford containment relations, and the other 10 afforded support relations. We refer to the objects affording the designed containment and support relations as *targets*, and the alternative objects as *distractors*. Distractors for each trial were the same for all participants, and were selected to 1) not afford containment/support of the dropped object, and 2) roughly equate the frequency of appearance of all 10 objects.

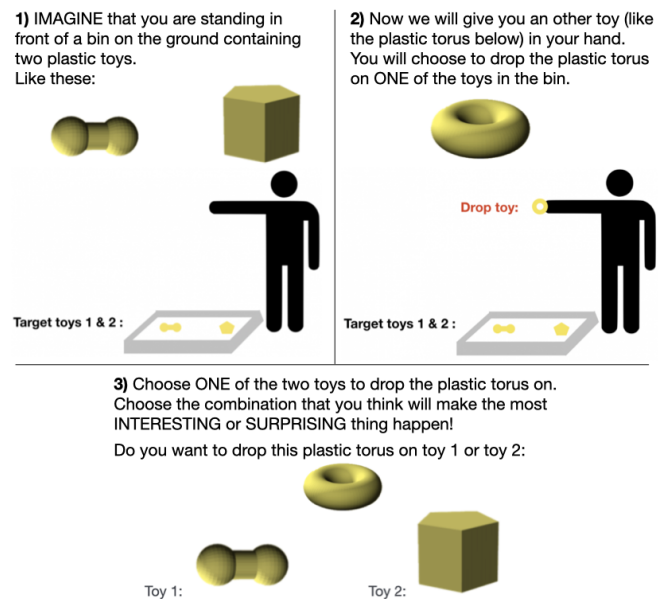


Figure 2: Example of a trial given to adults in Experiment 1.

Procedure Participants were instructed that they would be helping choose which toys to include in a new set of children’s blocks in order to make them the most interesting. Participants were then given a practice trial (see Figure 2), in which they were told that they should imagine dropping a given object (the torus) on each of two toys (the dumbbell or the pentagonal prism) in a bin. They were then asked to choose which toy to drop the torus on, and prompted to choose the most interesting or surprising combination. After making their choice on the practice trial, participants were shown a 10-second video recording of 3D-printed plastic toys carrying out their chosen interaction (e.g., if they chose the dumbbell, they would see the torus dropped on the dumbbell). This was done to ensure that they understood the consequences of the choice they made. After the video of the torus drop, participants were given a sequence of 20 more drop trials asking them to choose which toy (X or Y) they would like to drop object Z on. Four catch trials were interspersed among the 20 drop trials, which asked them to indicate which object they had just dropped on the previous trial (3-alternative forced choice). The catch trials were meant to encourage attention to the objects, and participants who were incorrect on two or more of the catch trials were excluded.

Results

We analyzed data from the 155 adults who completed the experiment and got at least 3 of the 4 catch trials correct (45 participants were excluded for not meeting this criterion). Table 1 shows the proportion of participants that chose the designed target relation for each of the 20 trials. Based on the binomial distribution, any of the trials on which more than 90 of the 155 participants agree (i.e., >0.59 or <0.41) significantly differ from chance. As can be seen in Table 1, adults participants (*adult* column) significantly preferred the target relation for all 10 of the containment trials, and significantly preferred five targets on the 10 support trials; the other five support trials did not significantly differ from chance.

Were adults more consistent in their choices on support or containment trials? Averaging each subject’s binary responses (1=target relation, 0=alternative) for each trial type revealed a stronger preference for containment relations ($M = 0.87$) than support relations ($M = 0.63$; paired $t(154) = 12.69$, $p < .001$, $d = 1.02$).

Finally, we examined the split-half reliability of adults’ choices by repeatedly splitting the samples in half and testing the correlation between the halves. Based on 100 random samples, the split-half reliability for adults is $r = 0.95$ ($sd=0.02$).

relation	drop	target	child	adult
contain	bowl	pyramid	0.72	0.96
contain	cone	torus	0.73	0.94
contain	dumbbell	pipe	0.67	0.92
contain	octahedron	pipe	0.58	0.90
contain	pentagon	bowl	0.69	0.88
contain	pipe	cone	0.58	0.88
contain	pyramid	torus	0.71	0.87
contain	sphere	bowl	0.80	0.86
contain	torus	cone	0.67	0.81
contain	trig prism	bowl	0.65	0.71
support	bowl	torus	0.71	0.85
support	cone	trig prism	0.45	0.82
support	dumbbell	pentagon	0.38	0.74
support	octahedron	pentagon	0.45	0.64
support	pentagon	pipe	0.57	0.62
support	pipe	torus	0.60	0.56
support	pyramid	trig prism	0.52	0.55
support	sphere	pipe	0.58	0.54
support	torus	bowl	0.70	0.53
support	trig prism	pentagon	0.62	0.46

Table 1: Children’s and adults’ target preferences per trial.

Experiment 2: Children

Experiment 1 demonstrated that adults show consistent preferences for dropping objects on target objects that afford containment relations, and to a lesser extent support relations. Experiment 2 investigates whether these strong preferences are present even in young children, recognizing that children may find different types of physical interactions (e.g., rolling, bouncing, unpredictability) of greater interest.

Method

We adapted the same materials and procedure used in Experiment 1 for use in an online experiment with children, in order to directly compare the results for children and adults.

Participants Participants were 73 children recruited online via outreach through a local nursery school and targeted Facebook ads. Participant exclusions were made based on cases where i) the participant did not complete more than half of the study play session or ii) the parent did not consent for video recording of study. After exclusions, results from 66 were analyzed, including 17 3-year-olds, 15 4-year-olds, 16 5-year-olds, 16 6-year-olds, and 2 7-year-olds.

Materials The materials were the same as those used in Experiment 1, except that the trials were adapted for presentation via Zoom in a slide presentation as shown in Figure 3.

Procedure After the parent provided informed consent, children were assigned to one of two pseudorandom trial orders in counterbalanced order. A video recording was taken of the online session. To accompany the practice trial, children were shown 3D-printed instances of the three physical objects held by the researcher, to ensure that children understood their physicality. Children were asked to verbally se-

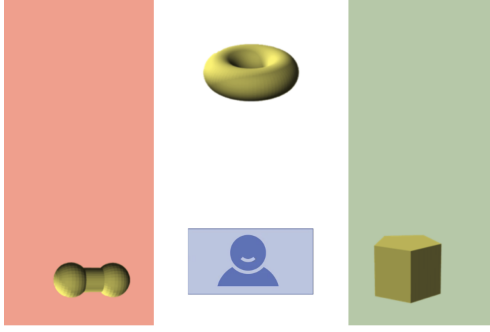


Figure 3: Zoom screen configuration for children in Experiment 2. Parents were asked to place the experimenter’s video feed in the bottom center so the experimenter could point up to the drop object and left and right at each target choice.

lect target object Y or Z, and then asked to confirm whether they wanted to select the object on the red or green side of the screen, in order to prevent left/right confusion. The sides on which target objects and colors appeared were counterbalanced across trials.

Results

We examined children’s choice of target objects to determine if children were choosing randomly, or had consistent preferences for some objects. Table 1 shows the proportion of children (“child” column) choosing the designed target relation for each of the 20 trials, alongside the adult choice proportions from Experiment 1. Based on the binomial distribution, any of the trials on which more than 41 of the 66 participants agree (i.e., >0.64 or <0.36) significantly differ ($p < .05$) from chance. Children significantly preferred the designed relation on eight of the 10 containment trials, while only significantly preferring two of the 10 support relation choices. On the remaining two containment trials and the other eight support trials, children’s preferences also did not significantly differ from chance against the designed relation.

Were children more consistent in their choices on support or containment trials? As for adults, averaging each child’s binary responses for each trial type revealed a stronger preference for containment relations ($M = 0.68$) than support relations ($M = 0.56$; paired $t(154) = 12.69$, $p < .001$, $d = 1.02$). Overall, children did not show a significant preference for choosing the support relation. Figure 4 shows the proportion of participants’ choice of the designed target relation broken down by relation type and age group, showing a preference for the designed relations that increased with age, and that was stronger for containment.

Comparison of Children’s vs. Adults’ Preferences

Finally, we compare the trial-level preferences of children and adults. Figure 5 shows adults’ (Experiment 1) vs. children’s (Experiment 2) choice proportions for the target relations, colored by relation type (visualizing the same data presented in Table 2). If they corresponded perfectly, they

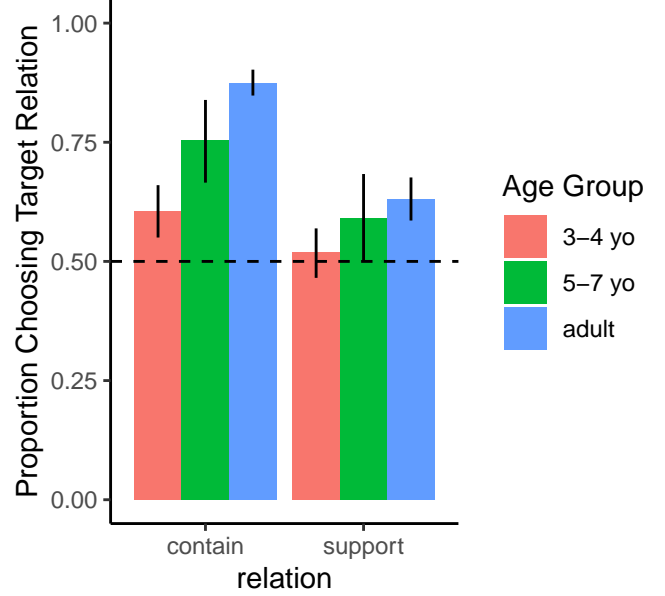


Figure 4: Children’s vs. adults’ choices for each type of trial, with bootstrapped 95% confidence intervals.

would fall along the dotted $y = x$ line, but children’s preferences mostly fall short of that line, lying closer to $y = 0.5$. At a glance, this seems to support the hypothesis that “children are noisy adults.” We will re-examine this hypothesis with model-based predictions for each trial.

The split-half reliability for children’s choices is $r = 0.61$ ($sd=0.09$). The overall split-half reliability of children and adults on containment trials is $r = 0.82$ ($sd=0.07$), and on support trials is $r = 0.76$ ($sd=0.09$).

Comparison to Physical Simulations

Using a physics engine (Gan et al., 2020) and 3D models of the objects that were shown to participants, we constructed a simulation of for each drop interaction in the experiment and attempted to predict children’s and adults’ choices using a variety of heuristic models based on the simulated physical interactions. For each trial’s two possible drop object choices, we ran 250 simulated drops, and for each drop calculated a variety of features measuring the state of the model after the drop was completed. We selected features that we thought may provide good metrics for what people could find interesting, for instance, the mean length of time before both objects come to rest, as well as the standard deviation (SD) of that time. Some features were calculated separately for drop and target objects, such as the SD of each object’s final position, the mean and maximum final distance of each object from the drop location, and the normed velocity of each object after first collision. We also tested a variety of features based on the likelihood of the dropped object coming to rest atop the target object— $Pr(support)$ —and the robustness of this likelihood to small perturbations in drop position. Note that the model’s definition of support does not distinguish support from containment.

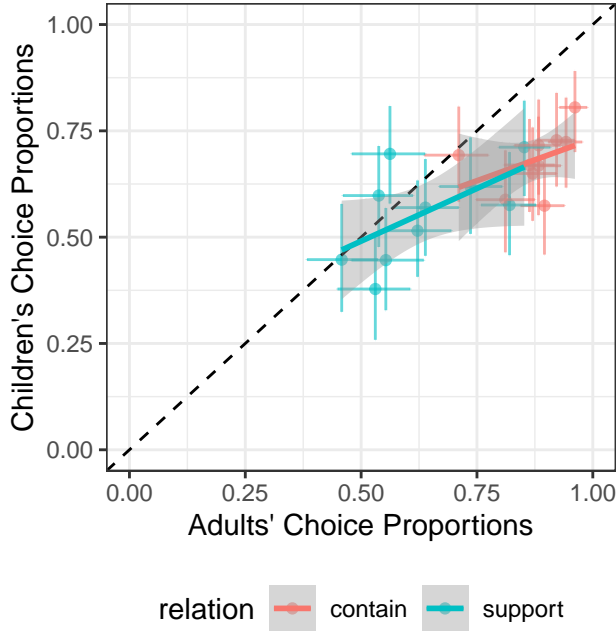


Figure 5: Comparison of children’s vs. adults’ preferences on each trial (dot), with bootstrapped 95% confidence intervals.

We measured each of these features in 250 simulations of each possible drop in the experiment, and then used the resulting values to generate relative preferences for the drop choices on each trial. A model’s preference on any given trial was assumed to be proportional to the relative magnitude of the feature values for the possible physical interactions on that trial, scaled by a softmax parameter β . For each model (feature), we optimized β separately to find best-fitting values for children’s and adults’ drop preferences, with the objective of minimizing mean squared error (MSE) between model and human choice proportions across all 20 trials.

Results The best-fitting feature was $Pr(support)$ for both children ($\beta = 0.5$, $MSE = 0.015$) and adults ($\beta = 1.18$, $MSE = 0.034$).¹ Figure 6 shows this model’s fitted preferences plotted against those of children and adults. Although the model captured people’s overall mean preference for the target relations, the trial-level correlation with human behavior was negative (adults $r = -0.35$, children $r = -0.49$, with similar values for $\beta = 1$). The support response sharpness model fit slightly worse (children $\beta = 0.81$, $MSE = 0.016$) and adults ($\beta = 1.94$, $MSE = 0.054$), but its responses were positively correlated with people’s (adults $r = 0.45$, children $r = 0.4$).²

Discussion

This study aimed 1) to measure the consistency of children’s and adults’ preferences for particular object interactions, and 2) to determine whether people’s interest was predicted by

¹For $\beta = 1$, adult $MSE = 0.035$, child $MSE = 0.026$ for $Pr(support)$.

²For $\beta = 1$, adult $MSE = 0.059$, child $MSE = 0.016$ for support response sharpness, with very similar correlations.

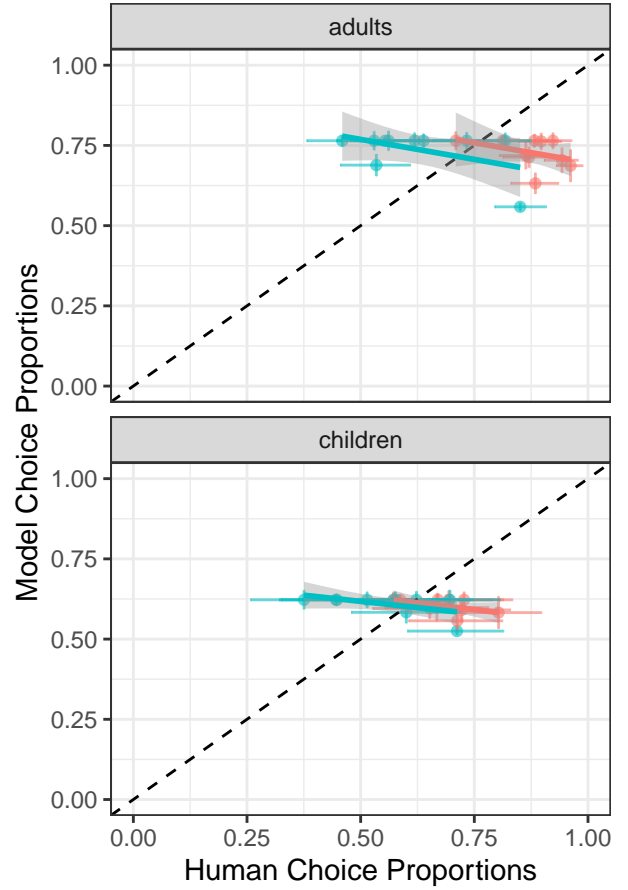


Figure 6: Comparison of $Pr(support)$ model’s vs. participants’ choices for each type of trial, with 95% CIs.

particular features of the imagined physical interactions between objects. In an online study that gave adults the opportunity to make drop choices that could result in either a likely support or likely containment relation on each trial, we found that adults consistently chose targets likely to contain the dropped object, and to a lesser degree chose target objects that were likely to support the dropped object. Experiment 2 found the same pattern in children, but with greater noise – even to the extent that younger children were at-chance at choosing the support relation on most trials. In sum, our behavioral study found that infant’s early-emerging interest in containment (Casasola, Cohen, & Chiarello, 2003) may extend through childhood and persist into adulthood, along with a weaker interest in support relations.

Given the high split-half reliability of choices on this task, particularly for adults ($r = .95$, children’s $r = .61$), we tested how well heuristic models of curiosity based on simulations of the physical interactions could predict participants’ preferences of target objects on each trial. We tested a wide range of features that we thought might be proportional to people’s interest in particular object interactions (e.g., how far a dropped object might end up from the drop location), but the feature that best predicted both children’s and adults’

responses was the probability that a dropped object would come to rest atop a target object ($Pr(\text{support})$). However, on a trial level this model's choices were negatively correlated with people's. One of the next best-fitting models was the sensitivity of $Pr(\text{support})$ to perturbations in the initial starting conditions, which broadly was able to capture people's stronger preference in *contain* condition trials relative to *support* condition trials, but still did not capture item-level variation in people's choices within condition. On balance, although much of the variation in this dataset is unexplained, it is encouraging that people's interest in physical interactions can be in part accounted for by simple heuristic models based on simulations of the same physical task we asked participants to merely imagine.

We suggest that these results can fruitfully serve as a test set for evaluating more complex computational theories of curiosity such as the proposal that learners prefer to explore stimuli that are “moderately discrepant” in relation to their current knowledge state, thereby providing an opportunity to learn (Kinney & Kagan, 1976), and that curiosity will change as the gap between the learner's knowledge develops and the state of the world closes (Loewenstein, 1994). These theories are starting to be implemented in deep neural networks, which have recently been shown to be capable of learning forward and inverse physical dynamics (i.e., “intuitive physics”) from images when given the ability to “poke” the objects in the scene (Agrawal, Nair, Abbeel, Malik, & Levine, 2016). Haber, Mrowca, Fei-Fei, & Yamins (2018) created a deep reinforcement learning model to drive intrinsically-motivated artificial agents, using two interacting neural networks: a *world-model* and a *self-model*. These networks are trained simultaneously to solve different problems: the world-model attempts to predict the consequences of the agent's actions (either the forward or inverse dynamics), while the self-model attempts to learn to predict the errors of the world-model. The agent can use the predictions of the self-model to implement a variety of curiosity policies for choosing actions, for example to pick actions that it believes will challenge its world-model. In future work, we aim to examine the development of curiosity in such curious artificial agents, and compare these agents' behavior to people's in the same tasks. Curiosity has inspired curiosity in researchers for decades, but only recently have the tools come along that make these theories testable.

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