Naïve Physics – the wrong theory?

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Abstract

In this paper we examine the idea of a "naïve physics" in humans solving physics problems. This invokes the idea that people have a theory of motion in their heads that is non-Newtonian, and hence leads to systematic errors on these problems. We are able to show that, by selecting our problems carefully, it is possible to obtain answers that are consistent with this naïve physics and inconsistent with it; suggesting that it is not used to solve these problems but sometimes offered as post-hoc justification for the answers given. We offer evidence that the answers given owe more to past experience than any theory, and that a theory that postulates extrapolation on the basis of associative memory can give a good account of our results.

Keywords: Associative, Memory, Naïve Physics, Theory.

Introduction

McCloskey, Caramazza and Green (1980) and McCloskey, Washburn and Felch (1983) have proposed that people consistently make particular mistakes when asked to predict the path of an object, given certain initial conditions, because they are applying the wrong theory, an intuitive mechanics or "naïve physics", to this type of problem. Their evidence is that, when given a relatively simple physical situation and asked to extrapolate on the basis of the information supplied, people tend to make certain types of error rather than others, and justify this with verbal reports that indicate a non-Newtonian approach to the problem (even though the instructions encourage that type of approach). One example of such a problem would be for participants to be asked to imagine looking down on the curved tube (which is held horizontally) in Figure 1, while a ball bearing is inserted with some speed, v, as shown. Their task is to draw the path the ball bearing takes on exiting the tube, ignoring such factors as friction between ball bearing and tube, and any wind resistance. The plan view is intended to take gravity out of the picture for the purposes of this problem, and the correct, Newtonian solution, is to draw a straight line as shown in the figure (solid line) as the ball bearing leaves the tube. Instead, many participants draw something approximating the curved dotted line as their answer, and justify this by claiming that the ball bearing has acquired "curvy impetus" as a result of its journey through the tube and this continues to cause its path to curve on exiting the tube. A more sophisticated version of this account will claim that this impetus dissipates with time, and so the curved path will gradually straighten as the ball bearing gets further from the tube (see McCloskey et al, 1980).

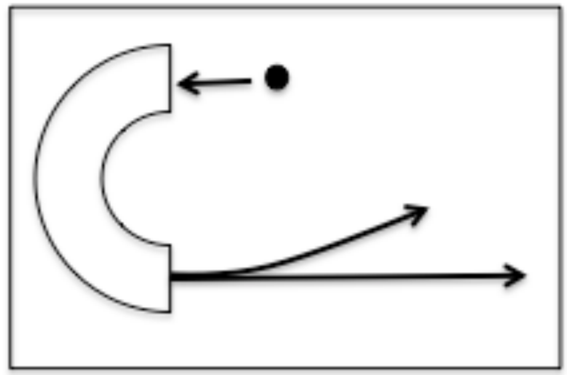

Figure 1: The ball bearing and curved tube problem.

Another classic problem studied by McCloskey and colleagues concerns what they call the "straight down belief" (McCloskey, Washburn & Felch 1983). The idea here is that people tend to predict a straight down trajectory for objects that are dropped whilst being carried, whereas they predict a parabolic path for objects that fall when moving independently. A classic example of this is a cannonball projected off a cliff. If fired horizontally from a cannon with initial velocity, v, an "out and down" approximation to the parabolic path is a typical response from participants asked to draw its subsequent path. But if carried (by some overhead conveyor belt arrangement) to the edge of the cliff with velocity, v, and then released, even though this is the identical problem in physical terms, participants are much more likely to describe the cannonball's motion as straight down. The reason they give for this is that, in the first case, the cannonball possesses its own impetus when it leaves the gun. This horizontal impetus takes it out past the cliff edge, but starts to dissipate. At the same time, gravity takes hold, and accelerates it downwards – hence the "out and down" parabolic trajectory. But, in the case of the cannonball being carried by a conveyor belt, participants think it has no impetus of its own, and so, when released, gravity takes hold immediately and it drops straight down.

The research reported in McCloskey *et al's* paper investigates the basis for this finding. On the one hand, it may be just as it seems and as participants in these experiments claim, i.e. that they have applied a naïve physics (or natural intuition) to the problem which is, in some sense the "wrong" theory as it is non-Newtonian, and it is this that leads to the consistent error in predicting the path of the object. On the other hand, it may be that the account given by participants of why they drew that particular path is more by way of a post-hoc rationalization of what they did, rather than an account of what caused them to do it. Instead, the causal factor in producing this consistent error could be extrapolation on the basis of experience, by which we mean to imply associatively-mediated retrieval of memories based on some surface similarity to the problem just posed. On this account, the reason why a carried object is often portrayed as taking a path straight downwards when released is because that is the perceived experience that we have, and call upon, of this situation in real life. Imagine you are cycling along and you drop a package. To a first approximation at least, the package appears to fall straight down. This is because both the package and the observer on the bicycle share a (moving) frame of reference, and in that frame of reference there is no horizontal motion with respect to one another. But a thrown package, which, in naïve physics terms, is one moving independently, does not have this property and so will follow a curved trajectory.

We realize that proponents of the naïve physics view will argue that it is exactly episodes of this kind that lead to induction of a naïve physics i.e. the incorrect theory is derived from these types of experiences, and it is only by running carefully controlled experiments that allow for friction, wind resistance, and frames of reference that the proper Newtonian theory can be arrived at. But we would differ from this view in arguing that the effect of experience is primary, and that its impact via retrieval from memory is what drives the response, not its impact via some naïve physics induced on the basis of these experiences. This stance makes the prediction that, if we are able to find scenarios where experience would predict that a carried object would follow a curved trajectory, or an object moving independently should take a path straight down, then the result of putting these problems to participants should be quite different to that predicted on the naïve physics account. If participants have a theory that drives their responses, then it should apply across different situations, as long as the particular scenario employed does not change the essential physics of the problem. Equally, if the outcome of experimental investigation of this proposition were to be that the responses made to a problem involving a carried object were to predict a path straight down (independent of considerable variation in the surface features of the scenario), then this would be inconsistent with an account in terms of associative memory (to the extent that different memories would be expected to lead to different predictions.

Experiment

Method

Participants

27 University of Exeter students with ages ranging from 18-35 participated in this experiment. All were undergraduates studying psychology, but were naïve to the hypotheses under test in this experiment.

Design

Eight physics problems, featuring falling objects, were devised. These problems all had the same underlying structure, and therefore the same answer (in terms of Newtonian physics), but different surface and contextual features. The problems were of two types: Those in which the object was carried prior to being released, and those where the object had been moving freely (independently) throughout. These two problem types were further divided to give two subsets in which the *expected answers* were either congruent or incongruent with the predictions of a naïve physics theory.

Four different types of problems were, therefore, presented to the participants in a questionnaire:

Type 1: Carried – Congruent (CC) – Problems in which objects are carried prior to release and where our predicted answer “falls straight down” is in accordance with naïve physics theory.

Type 2: Carried – Incongruent (CI) – Problems in which objects are carried prior to release and where our predicted answer is not in accordance with naïve physics theory.

Type 3: Free – Congruent (FC) – Problems in which objects are moving freely/independently and where our predicted answer “curved forwards/parabolic trajectory” is in accordance with naïve physics theory.

Type 4: Free – Incongruent (FI) – Problems in which objects are moving freely/independently and where our predicted answer is not in accordance with naïve physics theory.

Two imaginary scenarios were devised for each type of problem. These were constructed using MS Powerpoint and Word software on a Macintosh computer as follows:

Table 1

1. Carried Congruent condition (CC):
   Problem 1. Bird in flight dropping ice cream
   Problem 5. Plane dropping crate

2. Carried Incongruent condition (CI):
   Problem 2. Swinging monkey drops banana
   Problem 6. Cricket bowler drops ball at release

3. Free Congruent condition (FC):
   Problem 3. Cannonball fired off cliff
   Problem 7. Skier approaching a crevasse

4. Free Incongruent condition (FI):
   Problem 4. Skateboarder dropping in to a half-pipe
   Problem 8. Water falling over a cliff

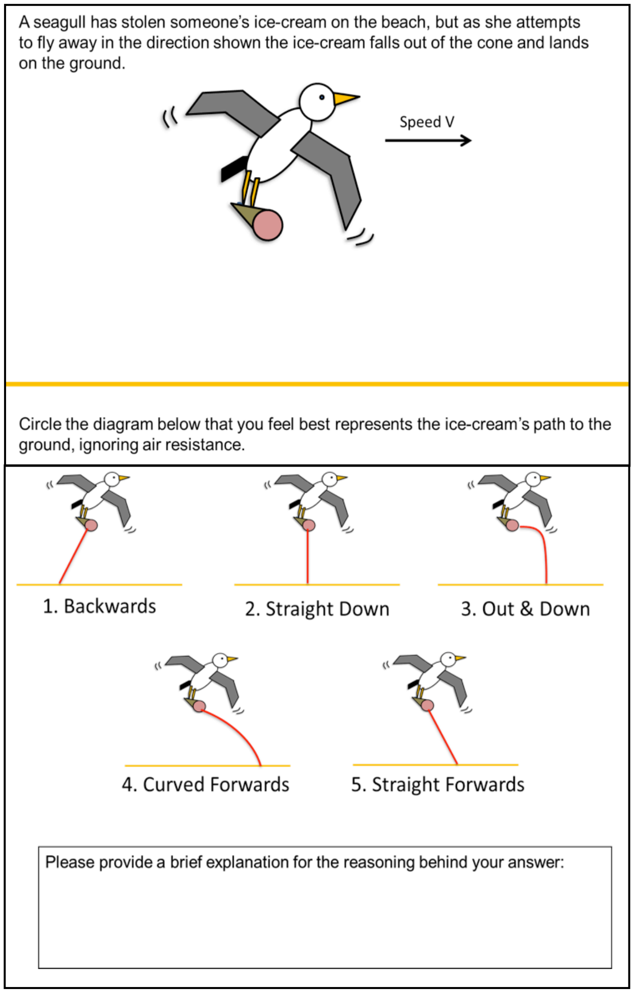

Figure 2. The figure shows one of the scenarios (Problem 1) presented for the CC condition. Participants were asked to select one of the 5 responses to indicate the trajectory of the dropped object (e.g. the ice-cream)

The problems in Table 1 were chosen so that the CC and FC examples, i.e. the congruent problems, were closely modeled on problems that have typically been used in previous experiments on naïve physics. As far as we could tell, there were no associations to events or situations that contradicted the predictions of a naïve physics theory for these examples. The incongruent problems (CI and FI) were chosen so that they conformed to the “Carried” or “Free” designation, but had associations that seemed to us to suggest that a response that was incongruent with a naïve physics theory would be given. Thus, a cricket bowler (e.g. Problem 6) is typically seen as projecting the ball forwards, not dropping it straight down. If you observe someone or something else (e.g. the monkey in Problem 2) in a state of motion carrying an object that they drop, then the typical perceived experience is for that object to continue to follow that state of motion. Because waterfalls (e.g. Problem 8) are typically seen from front-on and below, the modal experience is of them falling nearly straight down; and when

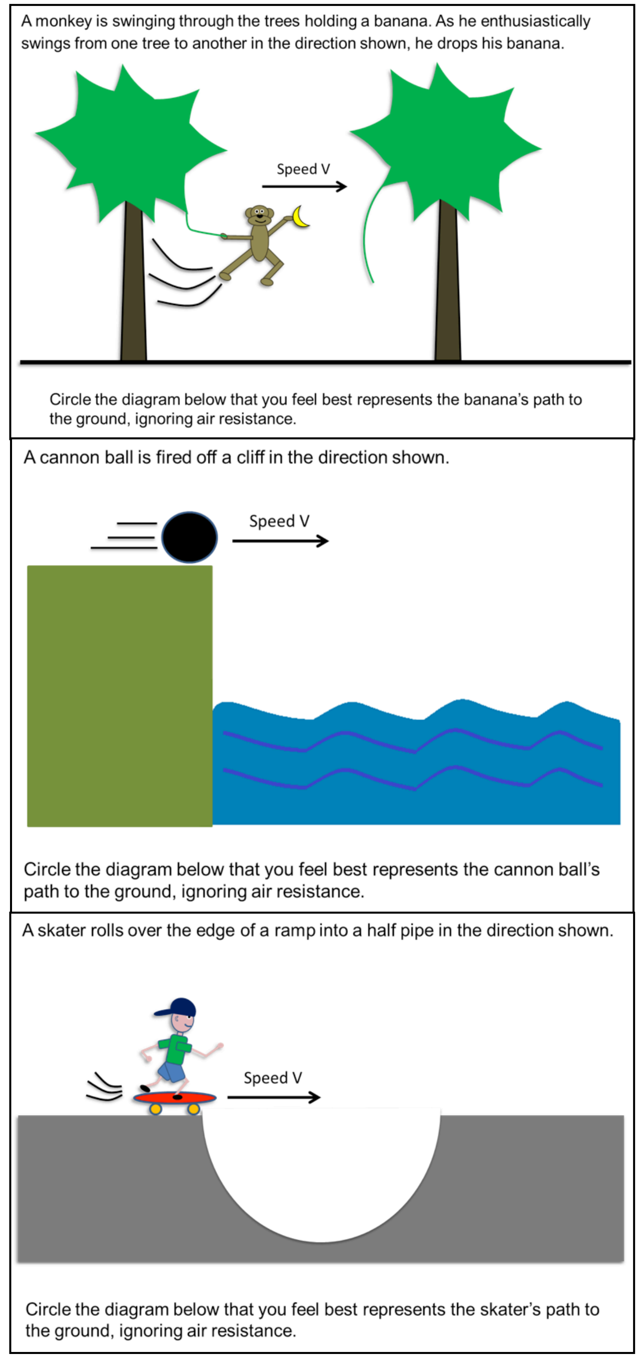

Figure 3. This shows examples of the other three types of scenario presented to our participants. The top panel is an example of a CI (Type 2 problem), the middle a FC (Type 3 problem) and the bottom a FI (Type 4 problem) example. In each case the same five response options were offered, illustrated by mini-drawings to show the path suggested (see Figure 2 for examples).

skateboarders drop in (e.g. Problem 4), they typically appear to take an initial path that is straight down. So, our hope was that these scenarios would predispose our participants to choose paths that were not expected on a naïve physics account.

Procedure

The eight problems were collated into a nine page A4 sized booklet printed in black and white using size 12 Arial font. The front page consisted of instructions to the participants, a consent form and a question asking for information about their level of physics knowledge. Each of the following eight pages featured one of the physics problems, a pictorial multiple-choice selection showing the available answers and a text box with space for participants to write an explanation of the rationale behind their selection. The presentation of the problems was randomized, with each problem appearing once, and equally likely to appear on any page.

Participants were asked to look at each problem and attempt to predict the path of the object as it fell to the ground. They were then asked to select, by circling the relevant number from the multiple choice answers, which of the five responses: 1. Backwards, 2. Straight Down, 3. Out & Down, 4. Curved forwards (Parabolic) and 5. Straight Forwards, most closely resembled the path they had thought of. Participants were also asked to write a short rationale for their choice of path to make clear the connection between their answer and their intuition. After completing all problems participants returned the booklet and were thanked for their contribution.

Results

The data of interest are the frequencies of each response (1-5) provided for a given problem. Table 2 gives these frequencies for each problem. The responses that might be considered consistent with naïve physics (NP) for a given problem are shown in green, those that are not and are better explained by an appeal to associative memory (AM) are shown in red.

Table 2

	Response				
Question	1	2	3	4	5
1	7	18	3	3	5
2	4	12	2	17	1
3	0	3	11	21	1
4	0	25	4	5	2
5	9	21	0	2	4
6	1	3	3	28	1
7	0	0	13	21	2
8	0	5	24	7	0

We took the view that for a "Carried" problem (Problems 1, 5, 2 and 6) the NP congruent response would be 2 ("Straight Down") and the AM (or NP Incongruent) response would be 3 ("Out & Down") or 4 ("Curved Forwards"). For a "Free" problem (Problems 3, 7, 4 and 8) the NP responses we allowed as congruent were either 3 ("Out & Down") or 4 ("Curved Forwards"). This was done because, in practice, distinguishing between responses 3 and 4 was difficult. The AM (or Incongruent) equivalent response for these problems was 2 ("Straight Down"). Responses 1 and 5 were relatively rarely used, so when computing Chi-Square values we collapsed responses 1 and 2 together, and responses 3, 4 and 5 together. This gave two basic classes of answer, which we can characterise as mostly straight down and certainly not forwards (1 and 2), and mostly curved forwards (3, 4 and 5).

We first of all collapsed over the two problems per condition, and then ran a χ^2 as a 4 x 5 contingency table (4 conditions by 5 responses) to see if there was any effect of condition on responding. The resultant χ^2=157, 12df, p<.005 suggests that there is. We then collapsed further so that there were only two response classes as already detailed (to ensure that the expected values in each cell were sufficiently high), and carried out a series of χ^2 analyses to investigate the basis of this effect. A 2 x 2 contingency table (hence, 1df) analysis of congruency by response gave a χ^2=0.95, p=ns, indicating no main effect of this factor. Analysis of "Free" vs. "Carried" by response gave a χ^2=26.13, p<.001, showing that this factor exerted a strong influence over choice of response, with, as expected, "Free" problems tending to produce mostly curved forwards responses and "Carried" problems mostly straight down responses. If we break this down further, then the χ^2=3.06, p=ns for the Incongruent data suggested that there was no significant difference in the distribution of responses caused by this factor in these problems, but the χ^2=78.06, p<.001 for the Congruent data indicates that it is these problems that drove the strong tendency for the two types of problem to lead to different responses.

The data of main interest, however, are how the Congruency factor influences performance on the "Free" and "Carried" problems. Taking the "Free" problems first, a 2 x 2 contingency table analysis with congruency as a factor, and collapsed response as the other, produced a χ^2=28.66, p<.001, with Congruent problems favouring a curved forwards response over straight down answers, and Incongruent problems significantly reducing this tendency. The "Carried" data show an even clearer effect, with Congruent problems favouring straight down responses and Incongruent data reversing this effect to show a strong tendency to elicit curved forwards responses, χ^2 =34.09, p<.001. It seems that we were successful in our attempt to select problems that either favoured the response expected on the basis of naïve physics (Congruent), or were not congruent with this prediction and instead owed more to associative memory (Incongruent). This effect was particularly marked for the "Carried" problems, where there is essentially a pure interaction, with the Congruent problems behaving exactly as naïve physics would predict and the Incongruent problems showing quite the opposite pattern. The results corresponding to these analyses are shown in an easily interpretable form in Figure 4.

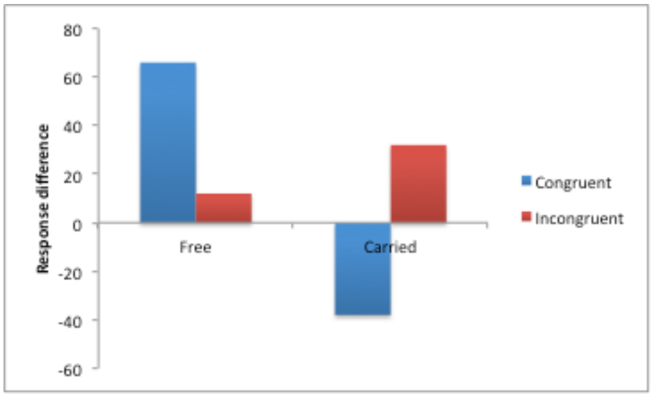

Figure 4. This shows the response difference score for each of the four conditions in our experiment. This score is simply the difference between the aggregated responses, (3+4+5)-(1+2), and measures preference for one response class over the other, with a positive score denoting a bias in favor of the curved forwards class over the straight down alternative.

In essence, Figure 4 demonstrates that whilst it is entirely possible to get the pattern of results predicted by a naïve physics model for how people solve this type of problem, it is also possible to choose problems such that the effect is eliminated.

General Discussion

What are we to conclude from these findings? Perhaps the first, and most obvious conclusion, is that a simple naïve physics theory that predicts the "straight down effect" because carried objects do not have any impetus of their own is not going to be able to explain these results. Either the theory is wrong, or it is not being applied in these situations. And this last is a real possibility. By giving considerable context to the problems, we have definitely biased participants in the way that they approach them, perhaps they do not invoke a naïve physics in these circumstances because the problems are not abstract enough?

Our objection to this analysis would be that naïve physics is exactly that which should be able to deal with these "real world" situations. And furthermore, there is as good qualitative evidence for naïve physics being used in our experiment as there is in other studies that have used this evidence to argue for a naïve physics theory. If we take the CC class of problem first, we have the following quotes that are typical of the approach taken to these problems by our participants.
For Problem 1: *"As soon as the seagull lets go there is no forward momentum, so therefore it will drop straight down."*
And for Problem 5: *"The box dropped straight out of the plane so would not have been affected by the movement of the plane."*
Both these problems are Carried Congruent scenarios. The typical response selection was No. 2, "straight down", and the explanation offered is the classic "an object has no impetus of its own if carried" justification given on the basis of a naïve physics. But if we now consider the explanations given for the Carried Incongruent problems we have for Problem 6: *"From my experience of ball games, they don't just drop downwards."*
Which clearly indicates a reliance on experience that we take to be mediated by associative memory. It might be argued that the memory simply overrides the predictions of the theory in this instance, and of course this is a possible explanation of the forward path typically chosen for this problem. But when we come to Problem 4, one of the Free Incongruent scenarios, then the justification offered for choosing the straight down response (No. 2) is in Problem 4: *"That's how skaters do it."*
So we would have to argue that once again recall based on experience is overriding the predictions of the theory (which would predict that the path is curved forwards). At this point the reader will notice that in every case the answer chosen is one consistent with generic experience of the world, and this impression is confirmed by our final class of problem, Free Congruent, where the typical response is curved forwards as a naïve physics would predict, and the generic explanation for offering this response is in Problem 7:
"Due to moving at speed."
Which fits nicely with the idea that a freely moving object has impetus. Thus we have two conditions where we have the results and the rationale expected on a naïve physics view, and two conditions where we have the opposite. But in all cases, the responses and rationale seem grounded in experience, and an explanation based on extrapolation from experience is tenable. Surely in these circumstances it is more parsimonious to attribute the answers given to memory-based extrapolation from experience, rather than invoke some abstracted theory that has to be overridden much of the time?

But we do not think that just any memory-based extrapolation from experience will serve to explain our results. Instead, we believe that the memory involved is associative in nature, so that it has captured the basic statistical regularities embedded in experience and retrieves them on the basis of a surface similarity to the problem. As such, we believe that an error-correcting system (e.g. McClelland and Rumelhart, 1985, Rumelhart, Hinton and Williams, 1986, and see McLaren and Dickinson, 1990 for a discussion) is required, as this will be able to extract the necessary structure. A version of such a system that can then function as a model of associative memory would be ideal (e.g. see the model in McLaren, 2011, based on McLaren, 1993, and the most recent version of this in McLaren, Forrest and McLaren, 2012). Finally, the ability to capture structure over time will also be needed, and for this the SRN (Elman, 1990) and it's more sophisticated variant the Augmented SRN (Cleeremans and McClelland, 1991, see also Yeates, Jones, Wills, McLaren and McLaren, in press, and the APECS variant in Jones and McLaren, 2001) fits the bill.

This more primitive, associative system is only part of the story, however, we also postulate another rule-based system that takes the output of associative memory and then constructs a story about the answer given around it. In doing this we are advocating a dual-process theory of cognition along the lines of that given in McLaren, Green and Mackintosh (1994), and illustrated in Spiegel and McLaren (2003, 2006) and Jones and McLaren (2009). It is this combination of extrapolation based on experience, followed by induction of some heuristic to explain why a particular answer has been given, that we believe has led to the notion of a naïve physics. It results in reliably incorrect answers to physics problems, and a narrative that accompanies these answers. The point of our research, however, is to show that if we frame what is essentially the same problem in a different way, so that we access a different type of experience, then the answer changes and so does the accompanying narrative. Clearly, if a deeper physical analysis of the problems were involved in accessing experience, the answer to all the problems studied here would be the same, a parabolic path forwards. Hence we have to postulate retrieval on the basis of surface similarity for this aspect of our theory to work. We would then argue that actually the inductive inference that suggests a naïve physics is more a matter of an attempt to "make sense" of our participants intuitive response to these scenarios.

Conclusion

We have arrived at a position where the statements made by participants attempting to solve simple physics problems and taken to support the existence of a naïve physics are seen as post-hoc rationalization for the answer given rather than causally implicated in that answer. We believe that it is extrapolation based on experience, via retrieval from associative memory (that is itself the product of associative learning), which is responsible for the reliably incorrect answers given to the problems studied here. We would go further, and say that our position also applies to the more abstract problems often studied in naïve physics experiments, though clearly here the experiential memories involved must be of a more generic nature. Take as an example the problem shown in Figure 1. How are we to explain that result? What memory could be accessed for that problem? There are not many retrieval cues, just a curved tube and a ball bearing. But this is enough to retrieve memories of water emerging from a garden hose (as these are often curved) – and the path the water takes is typically curved as well. The analogy between hose and problem is, of course, incorrect – but the superficial similarity exists and this is what drives associative processing. The result is an extrapolation to an incorrect, curved path, because it feels right. And then we tell a story about why we gave that answer. The great advantage of this explanation is that it generalizes to the results reported in this paper. And so we conclude that as a theory of why we seem to have the wrong idea about how objects move, it is to be preferred to the naïve physics point of view.

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