Ockham's razor as inductive bias in preschooler's causal explanations

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Abstract—**A growing literature suggests that generating and evaluating explanations is a key mechanism for learning and development, but little is known about how children evaluate explanations, especially in the absence of probability information or robust prior beliefs. Previous findings demonstrate that adults balance several explanatory virtues in evaluating competing explanation, including simplicity and probability. Specifically, adults treat simplicity as a probabilistic cue that trades-off with frequency information. However, no work has investigated whether children are similarly sensitive to simplicity and probability. We report an experiment investigating how preschoolers evaluate causal explanations, and in particular whether they employ a principle of parsimony like Ockham's razor as an inductive constraint. Results suggest that even preschoolers are sensitive to the simplicity of explanations, and require disproportionate probabilistic evidence before a complex explanation will be favored over a simpler alternative.**

***Index Terms*—Causal Reasoning, Development, Explanation, Probability, Simplicity**

I. Introduction

DECIDING between competing causal explanations pervades our every-day lives: "What made my computer crash, this new software, insufficient RAM, or a hardware error?" "Is Sally looking for her marble in the box by mistake or because she believes it is there?" Indeed, these frequent decisions are important inductive inferences: to the degree we can understand the world, we can better predict and control it.

Previous research demonstrates that adults are remarkably good at using probabilistic evidence to infer the kind of causal structure invoked in causal explanations [1]-[3], and a growing literature suggests that children are similarly sophisticated [4]. In particular, both adults and children are sensitive to the relative probabilities of competing causal explanations for observed data, and integrate probabilistic information with prior beliefs about domain-appropriate causes [5]-[7]. For example, [8] found that at baseline young children were more likely to explain a character's tummy ache by appealing to food rather than to stress when the evidence was ambiguous. However, after observing evidence supporting the a priori weak explanation, children were able to overturn their initial preferences and were more likely to choose stress as the cause of the tummy ache.

These findings fall within the broader literature on causal reasoning, which suggests that humans are built with powerful, domain-general learning mechanisms [1]-[9]. At the same time, this work recognizes an important role for domain-specific beliefs, which constrain learning and thereby make inferences on the basis of very limited data possible [10]-[14]. But children face a special challenge when it comes to evaluating causal explanations. They must not only generate judgments for events they may have observed only once, but must also do so on the basis of skeletal domain knowledge at best, and no domain knowledge at worst. That children (and adults) succeed in generating and evaluating explanations under such conditions suggests the existence of additional constraints – a domain-general basis for constraining causal inferences in the face of limited or ambiguous evidence. This paper explores one candidate for such a domain-general constraint on children's causal explanations: a principle of parsimony. In particular, do children treat simpler explanations as if they're more likely to be true?

A. *Simplicity and Probability in Adult Explanations*

The problem of evaluating explanations on the basis of limited knowledge is not isolated to children. Scientists are all too familiar with the regrettable fact that explanations are underdetermined by data, and that the world never obliges by furnishing candidate explanations with probabilities. In some cases domain-level constraints can help arbitrate alternative explanations, but often scientists, like children, are faced with the problem of evaluating explanations that are equally consistent with available data, and about which our domain theories are silent.

One solution to the problem of evaluating multiple explanations was provided by William of Ockham, who proposed a principle of parsimony that has come to be known as Ockham's razor. Ockham proposed that one should not multiply causes beyond necessity. In other words, all else being equal, one should choose the explanation involving the fewest causes [15]. Casual observation confirms that scientists, adults, and children alike conform to this principle, which has the virtue of being widely applicable and requiring nothing more specific than a commitment on how to individuate the given causes. Indeed, simplicity is often invoked in theoretical

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debates among scientists, and has been posited to play a role in children's theoretical development [16].

Although the claim that simpler explanations make for better explanations is hardly controversial, the stronger claim that simplicity is used as an inductive constraint in evaluating causal explanations requires more than anecdotal evidence. In particular, one would need to show that simpler explanations are preferred by virtue of being simple (and not because they independently have greater probabilistic support), and that this preference guides inductive judgments. A recent study, [17], demonstrates both of these points in adults.

In [17], adult participants learned the following about three diseases on a fictional alien planet: D_1 causes symptoms S_1 and S_2; D_2, causes symptom S_1; and D_3 causes symptom S_2. (Participants were provided with fake disease and symptom names, but we use variables here for clarity.) Participants then learned about an alien with symptoms S_1 and S_2, and were asked to identify the most satisfying explanation for these symptoms. The possibility that the alien has D_1 is the simplest, one-cause option and having D_2 *and* D_3 is a possible complex alternative. Importantly, participants received information about the baserates of these diseases, and in some conditions the probability of an alien having both D_2 and D_3 was greater than the probability that alien having D_1. By varying the relative probability of D_1 to D_2 and D_3, [17] was able to characterize how adults trade-off simplicity and probabilistic evidence.

The results demonstrated that adults are sensitive to both simplicity and probability, but required disproportionate probabilistic evidence before selecting a complex explanation over the simpler alternative. Perhaps more striking, participants who chose a simple explanation when it was unlikely to be true went on to systematically and selectively overestimated the baserate of D_1, suggesting that simplicity not only influences judgments of explanatory satisfaction, but also has probabilistic consequences. This pattern of data suggests that simpler explanations are assigned a higher prior probability, and that adults employ a constraint in explanation evaluation akin to Ockham's razor.

B. *Simplicity and Probability in Children's Explanations*

While [17] suggests that adults employ a principle like Ockham's razor, little is known about the degree to which children appeal to simplicity and probability in evaluating causal explanations, and in particular whether simplicity and probability trade-off in the sophisticated way demonstrated by adults. Even more than adults, children rely on explanations to learn about the world [4], [18], and in the absence of rich prior knowledge and experience have all the more need for domain-general constraints to guide underdetermined inferences. Explanation evaluation is thus a key mechanism in learning and development, but one about which little is known.

Past research suggests that probability information plays an important role in children's causal inferences [4]-[7]. For example, in one study [19] children were trained that 'blickets', blocks that activate a machine, were either rare or common. Then children were presented with a backwards blocking paradigm: two objects (A & B) activate the machine together, then children are shown that one object (A) activates the machine by itself. The question is whether children will also label the other object (B) as a blicket. When children are taught that blickets are rare, they make the correct backwards blocking prediction and only extend the blicket label to object A. However, when children are taught that blickets are common, they categorized the uncertain object, B, as a blicket as well. These results suggest that children are incorporating the probability of events in their implicit causal explanatory predictions.

Backwards blocking may reflect a principle like Ockham's razor: why assume both blocks are potential causes of the machine's activation if A alone is a sufficient explanation? However, this research does not directly examine how children choose between competing explanations. In particular, children's judgments may rely exclusively on probability, and it's unclear whether and how simplicity trades-off with probabilistic evidence. The experiment that follows extends the method employed in [17], which deconfounds probability and simplicity, to preschool age children using a novel procedure. The study demonstrates that like adults, children use simplicity as a basis for evaluating explanations, and do so in a way that suggests simplicity is treated as a constraint on probabilistic inference.

II. Experiment

In this experiment, we directly examine whether and how children employ simplicity in underdetermined inference by providing children with a choice between a simple explanation (involving only one cause) and a more complex explanation (involving two causes), where both explanations account for the data being explained. This task was structurally similar to that in [17] and [20], but adapted to create a more interactive procedure that would capture the interest of and be understandable to preschool children. To accomplish this, we designed a toy in which we could independently vary the simplicity and probability of candidate explanations. Rather than diseases and symptoms, children saw a device with colored chips that generated one or two effects: the activation of a light and of a fan. Varying the numbers of available chips was equivalent to varying the baserates of diseases in [17].

The considerations in the introduction suggest that children have, if anything, a greater need than adults for sophisticated domain-general strategies for evaluating explanations under uncertainty. This would suggest that children should mirror adults in using simplicity as a constraint on inductive judgments. One possibility is that children will actually rely on simplicity more than adults do, and prefer simpler explanations regardless of their relative probabilities. This outcome would also be predicted if the basis for adults' reliance on simplicity comes from cognitive constraints, such as limited working memory. But if Ockam's razor is to help rather than hinder learning, one might predict that children will mirror adults in integrating a preference for simplicity with probabilistic evidence. Under this reasoning, children should show a preference for simpler explanations, but should also demonstrate more nuanced responses, favoring the more complex explanation as the probability evidence becomes overwhelming.

A final possibility is that presenting young children with this kind of intuitively conflicting information will be overwhelming, and children will be unable to successfully integrate a preference for simplicity with probabilistic evidence. If this is the case, children may respond on the basis of a single dimension (choosing either probability or simplicity at chance), or select among the response options at random.

A. *Methods and Design*

Participants & Design

Children were tested at a local museum in the Boston area in one of four conditions: a 1:1 probability condition (in which the probability of the complex, two-cause explanation was equal to that of the simple, one-cause explanation); a 2:1 condition (in which the probability of the complex explanation was twice that of the simple explanation), a 4:1 condition, and a 6:1 condition. Eighteen children (R=48m-70m; M = 58.7m) participated in the 1:1 condition; eighteen children (R = 47m-69m; M = 57.4m) participated in the 2:1 condition; twenty-one children (R = 49m-70m; M = 58.0m) participated in the 4:1 condition; and twenty-five children (R = 49m-72m; M = 59.9) participated in the 6:1 condition. Approximately equal numbers of boys and girls participated (47% female), with a distribution of races reflecting the population of Cambridge/Boston metro area.

Materials

A yellow box (12inX12inX18in) was created. On the left front top corner a toy was inserted such that the top portion of the toy was visible, but the bottom portion where the on-off switch was located hung inside the box, only visible from the back of the box. The toy was brightly colored, with a blue bar connecting a circular red bulb (which spun around and lit up when activated) to a propeller-like green fan (which also spun around and lit up when activated). Switches on the bottom of the toy made it possible to light up just the bottom red globe, just the top green fan, or both the bottom globe and green fan simultaneously. Additionally, red, green, and blue domino-sized wooden chips were used. There was an opaque 'activator' bin in the back right of the top of the box. Additionally, a transparent bucket and an opaque, rigid bag were used in the experiment.

Procedure

Children were introduced to the toy box, the red, green, and blue chips, and the activator bucket (see Fig. 1). Children were shown that when a red chip was placed in the activator bucket, the bottom globe lit-up and spun around. Children were then shown that when the green chip was placed in the activator bucket, the top fan lit-up and spun around. Finally children were shown that the blue chip made both the bottom and top parts of the toy spin-around and light up. In all cases, the toy was actually activated surreptitiously by the experimenter. Pilot testing confirmed that the illusion of the chips causing the activation were so strong that even adults believed the chips were somehow causing the toy to work and were not aware that the experimenter was actually controlling the toy.

After children were introduced to different colored chips, children were asked to remind the experimenter what happened when the red chip went in the bucket, what happened when the green chip went in the bucket, and what happened when the blue chip went in the bucket. Children were also asked to predict what would happen if both a red and green chip went in the bucket simultaneously. This memory check served as a basis for eliminating children that were unable to attend to the information and also made sure that children were aware that both the blue chip or the red and green chip combined could cause the toy to activate both top and bottom events in the same way.

Next the experimenter took out the clear container and asked the children to help count out chips into the container. In all conditions only 1 blue chip was added to the container. To manipulate the probability of the more complex explanation (red & green), we varied the number of red and green chips such that there were 3 of each (red & green) in the 1:1 condition, 6 of each in the 2:1 Condition, 12 of each in the 4:1 Condition, and 18 of each in the 6:1 Condition The experimenter then asked the child: "Can you help remind me? How many red chips are in the container? And, how many blue chips? And how about green chips?" The children's responses were coded and included as the second memory check.

After mixing the chips in the container in front of the child, the experimenter got out the opaque rigid bag and said to the child: "See, now I'm going to put all my chips into this bag." After pouring the chips into the bag, the experimenter sat the bag on top of the container on top of the toy and then 'accidentally' knocked the bag on its side, so that the opening fell in and towards the 'activator bucket' and away from the child. The bag fell such that the child could not see or hear what chips actually fell into the activator. As soon as the bag fell, the top and bottom portions of the toy activated. During the 'accidental' fall, the experimenter exclaimed "Oops! I knocked my bag over! I think one or two chips may have fallen into my toy! What do you think fell into the toy?" Children's explanations were recorded. [2]

[2] The probability ratios for each condition were computed by assuming that accidentally tipping the bag was equally likely to result in one or two chips and that the probability of a second chip being of a given color was affected only by the fact that the first chip decreased the pool of available chips of that color by one (i.e. the chips were otherwise conditionally independent). For the purposes of computing the probability ratios, we also counted explanations containing the simplest explanation (i.e. a blue chip and a red chip) as instances of the simple explanation, as this results in a more conservative estimate for the role of simplicity. Note, however, that we used a more stringent criterion in coding children's explanations.

B. Results

Children's responses on the memory check were coded. If a child failed any portion of the check, they were not included in analyses. Analyses revealed no difference in age between conditions (Kruskal-Wallis, k = 4; h(3) = 1.33, *n.s.*).

Before considering children's relative preference for simple and complex explanations, we note that children overwhelmingly provided explanations that were adequate in the sense that they accounted for both observed effects. Of the 64 explanations generated by children who passed the memory check, only 4 failed to account for both effects (eg. just a red chip). In each condition, children generated an adequate explanation more often than predicted by chance if children were selecting randomly among the 8 possible distinct combinations of 3 color chips (binomial tests, $p < .01$)

We next examined the roles of simplicity and probability in explanation evaluation. As detailed in Table 1, responses fell unambiguously and uniquely into one of three categories: simple (blue chip only), complex (red & green chips only), or other (red only, green only, both blue and red, both blue and green, or one of each color). Collapsing across all four conditions, children were no more likely to choose the simple explanation over the complex explanation ($\chi^2(1) = 1.17$, *n.s.*) .

Critically, the distribution of explanations differed significantly as a function of condition ($\chi^2(6) = 20.25$, $p < .01$). As the complex explanation became more likely, children became increasingly likely to select it over the simpler alternative (see Figure 2). Before interpreting this trend in relation to simplicity and probability, it's worth rejecting an alternative explanation for this finding, namely that as the total number of chips involved in the task increased, children simply became more inclined to cite explanations involving multiple chips. Were this the case, the total number of explanations citing more than one chip should differ across conditions. This was not the case ($\chi^2(3) = 5.69$, *n.s*).

The fact that a greater number of children selected the complex explanation as it became more likely suggests that children are sensitive to probability in evaluating competing causal explanations. Yet when these explanations were equally likely (in the 1:1 condition), significantly more children selected the simple explanation (($\chi^2(1) = 7.58$, $p < .01$), suggesting that all else being equal, children prefer simple explanations. Moreover, these explanatory virtues competed, with children continuing to select the simpler explanation even when it was less likely to be true. Even in the 6:1 condition, over 30% of children chose the simple explanation.

In sum, children demonstrated sensitivity to both the simplicity and probability of explanations, with a clear preference for simple explanations, even when the complex explanation was twice as likely as the simple one. However, children integrated simplicity and probability, and began to favor the complex explanation as it became much more likely than the simple alternative.

Could these data be explained without appeal to simplicity? We must acknowledge the possibility that children's assumptions may not match those used to calculate the probability ratios in each condition (see footnote 1). Although these ratios were calculated in a way more likely to underestimate the influence of simplicity, it could be that children think the probability of a single chip falling from the accidentally tipped bag is much more likely than the probability of two chips falling, with the result that "simple" responses in the 2:1, 4:1, and 6:1 conditions need not indicate that simplicity is trading-off with probability. The most compelling reason to reject this alternative is that the ratio of simple responses monotonically decreased as a function of probability, a trend that could only be accounted for on this alternative explanation if assumptions about the probability of two chips falling likewise changed, a hypothesis we rejected above. As additional evidence that the 50% assumption is reasonable, note that across all four conditions, the frequency of 1-chip and 2-chip explanations, 33 and 30 respectively, did not differ from each other ($\chi^2(1) = .28$, n.s.) or from the presumed value of 50% (binomial tests, n.s.).

Finally, one might be concerned by the striking number of 'other' responses in the 1:1 condition. However, children in this condition were burdened with the lowest cognitive load in order to pass the memory check, only being required to remember 1 and 3 for total number of chips. In fact, because the chips were visible through the clear container, even if the child had forgotten the number of chips, she would be able to successfully pass the memory check by quickly counting the chips in the container. Indeed, more children failed the memory checks in the later conditions which required tracking a larger number of chips. It's possible that because it was easier to pass the memory check in the 1:1 condition, more children who may not have been paying close attention during the experiment were able to pass through in the 1:1 condition, where those same children would have failed out in later conditions; thus, increasing the likelihood of children who would generate extraneous, 'other' explanations.

III. Discussion

A. Simplicity bias in children's explanations

Our findings demonstrate that children are not only sensitive to simplicity and probability in evaluating competing causal explanations, but that as a group they can integrate these bases for evaluation. The data provide two reasons to believe that children treat simplicity as a probabilistic cue that constrains inductive inferences. First, as a group children continued to value simplicity even when the complex explanation was more probable. This suggests that simplicity is not merely a basis for evaluating explanations in the absence of probabilistic evidence; rather, simplicity is treated as commensurate with baserate information. Second, children were asked which chips they thought fell into the toy. Unlike [17], which asked adults to rate the quality of explanations, this prompt is explicitly about the true state of affairs. That children used simplicity as a basis for inferring a property of the world suggests that simplicity is not regarded as a desired but undiagnostic property, but rather as a legitimate basis for inference.

B. Why privilege simpler explanations?

Why might children privilege simpler explanations? One possibility is that simpler explanations are less demanding. They involve fewer cognitive resources, and are thus easier to generate and reason about. While an explanation of this kind is possible, it seems unlikely on the basis of the data. Children had no problem generating complex explanations in the 6:1 condition, and a comparison of these data to [17] suggests that children are not more simplicity-prone than adults, as one might expect were cognitive limitations the basis for the preference.

Might a strong bias for simpler explanations be adaptively useful? There are a few reasons to think such a bias could be beneficial, even if it results in 'errors' when over-extended. First, simpler explanations are in many cases more likely than alternatives. When the base rates of all potential causes are equal (and less than 50%), the joint probability of causes happening together will be smaller than the probability of only one cause. In fact, the causes appearing in a complex explanation could be considerably more common and still be less likely in conjunction than the single cause in a simple explanation. Given this regularity, children may have learned that simplicity is a reliable heuristic for probability. And because probability information is often unavailable, such a heuristic could be widely applicable and often correct (or at least unfalsified). Second, a preference for simpler explanations has been defended on methodological grounds. Simpler explanations tend to rule out a greater number of possible observations, which means that they are easier to falsify. Third, arguments from statistics and computer science suggest that complex explanations run the risk of fitting "noise" or idiosyncratic properties of the possible observations one has sampled. To the extent simpler explanations avoid these dangers, they will generalize more effectively to future situations.

C. Future Work

It is striking to find this kind of sensitivity to simplicity in children as young as four-years-old. Future work could develop paradigms that are appropriate for younger, preverbal toddlers and infants and examine the degree to which even younger children use simplicity in evaluating competing explanations.

Additionally, here we define simplicity by the number of causal variables posited, and compare cases where the simpler explanations involve only one cause, and the complex explanations involve multiple causes. Future work could compare cases when the simpler explanation also involves multiple (but fewer) causes. There have also been suggestions of other definitions involving simplicity, such as Kolmogorov complexity and minimum description length. Do children and adults also favor explanations that fall under these definitions of simplicity?

Finally, work may also be extended to more natural explanation settings where children can bring their depth of knowledge to bear. For example, how do social information and simplicity in explanation interact: do children find complex explanations provided by a trusted source more or less compelling than a simpler explanation provided by a less reliable source?

IV. Conclusions

In the course of learning and development, children are constantly faced with situations that require judgments on the basis of sparse data. Domain-general learning mechanism provide a powerful way to leverage experience in the service of inference, but even sophisticated causal and associative strategies have trouble accounting for children's ability to rapidly draw inferences on the basis of only a few data points. This has lead many theorists to posit domain-specific constraints on learning and inference. Our findings suggest an additional resource available to children and adults: domain-general constraints that inform judgment by playing a role in the evaluation of explanations. Specifically, we've provided evidence for a principle of parsimony like Ockam's razor, and for the claim that children employ simplicity as a constraint on inductive inference. Our data are neutral as to how this constraint is implemented. One possibility is that simplicity constrains inference in the same way as domain knowledge, but at a higher level of abstraction – what Goodman called an 'overhypothesis' [21]. Another possibility is that simplicity is implicitly privileged by underlying mechanisms, without being explicitly represented as a basis for judgment. Either way, our data demonstrate children's sophistication when it comes to evaluating explanations, and suggest that explanation is a rich and underexplored window onto development.

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Condition	1:01	2:01	4:01	6:01
	# Chips Used			
Responses	1 Blue 3 Red 3 Green	1 Blue 6 Red 6 Green	1 Blue 12 Red 12 Green	1 Blue 18 Red 18 Green
# Simple	8	10	6	5
# Probable	1	3	9	10
# Other	7	3	1	1
# Failed Memory	2	2	5	9
% Simple/ Probable+Simple	89	77	40	33

Table 1:Types of explanations generated by preschoolers.

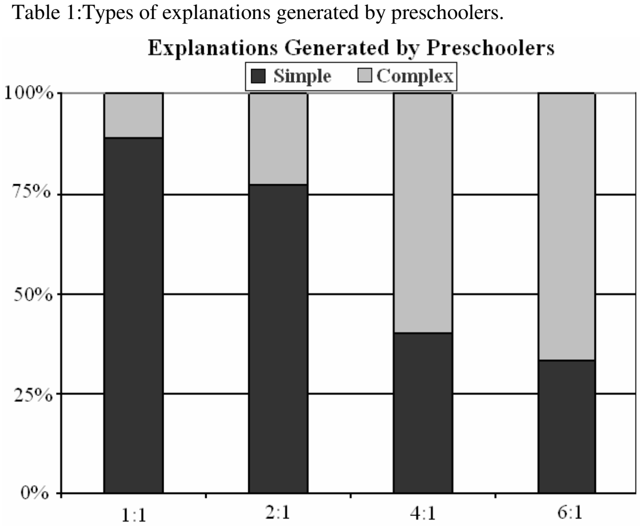

Fig. 2: Proportion of children generating simple explanations over complex explanations for each probability condition.

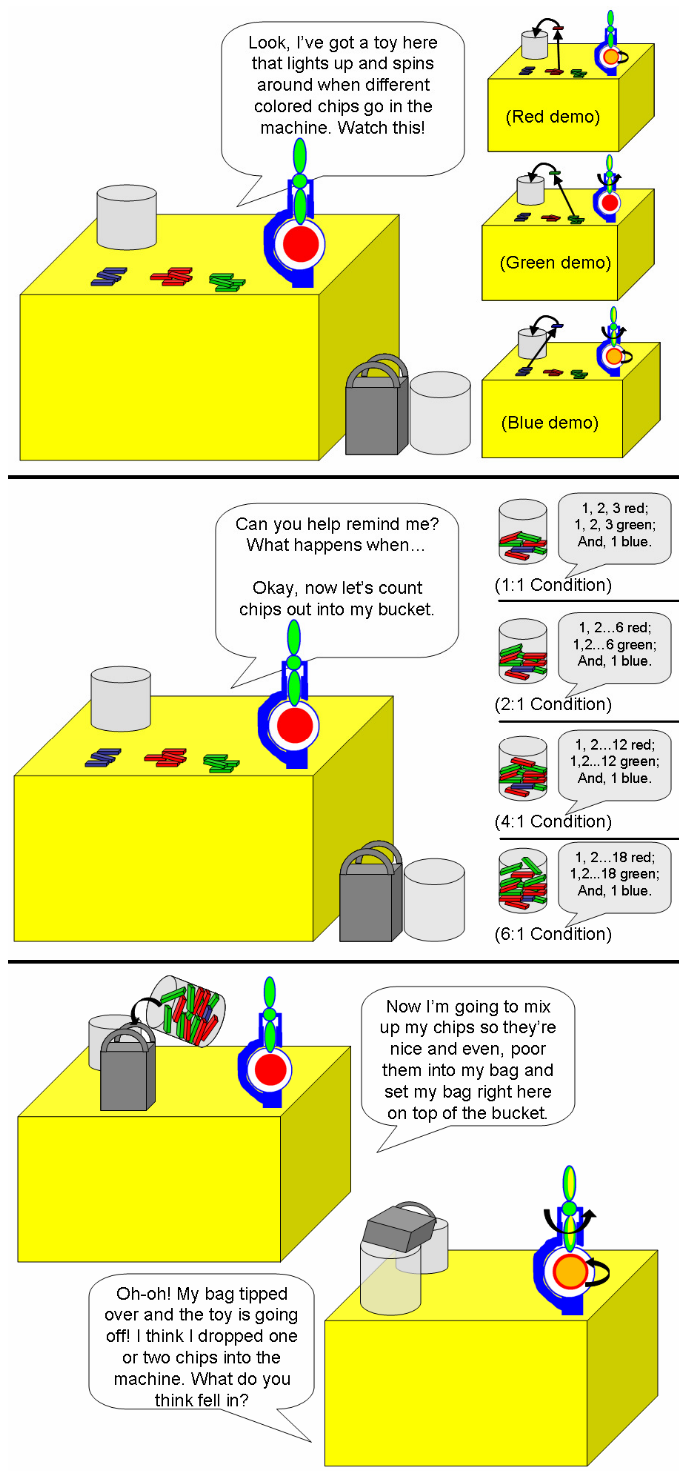

Fig. 1: Materials and procedure used in Experiment 1.