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Situated Naïve Physics: Task Constraints Decide What Children Know About Density

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Children's understanding of density is riddled with misconceptions—or so it seems. Yet even preschoolers at times appear to understand density. This article seeks to reconcile these conflicting outcomes by investigating the nature of constraints available in different experimental protocols. Protocols that report misconceptions about density used stimulus arrangements that make differences in mass and volume more salient than differences in density. In contrast, protocols that report successful performance used stimulus arrangements that might have increased the salience of density. To test this hypothesis, the present experiments manipulate the salience of object density. Children between 2 and 9 years of age and adults responded whether an object would sink or float when placed in water. Results indicated that children's performance on exactly the same objects differed as a function of the saliency of the dimension of density, relative to the dimensions of mass and volume. These results support the idea that constraints—rather than stable knowledge—drive performance, with implications for teaching children about nonobvious concepts such as density.

Keywords: physics misconceptions, perceptual learning, preschoolers

A naïve mind appears riddled with misconceptions—overly simple ideas about the world that were not explicitly taught. Misconceptions exist about biology, astronomy, chemistry, and physics, to name just a few domains, and they exist among a wide range of individuals, including infants, preschoolers, high-school students, college students, and adults.[1] Yet the nature of misconceptions is still debated. Why, for example, do children and adults mistakenly equate the density of a block with its heaviness? Are there cognitive limitations when it comes to differentiating density from heaviness? Or is ordinary exposure to the consequences of density (e.g., sinking vs. floating) too limited? Or are there other reasons altogether?

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The argument put forward in this article is that misconceptions originate in the competition between immediately available constraints (cf. Kloos & Van Orden, 2009, 2010). The term *constraint* refers to a relation between actor and task that changes the available degrees of freedom for task responses (Bernstein, 1967; Flach, Dekker, & Stappers, 2008; L. B. Smith, Thelen, Titzer, & McLin, 1999; Turvey, 1990; Turvey & Carello, 1981). Constraints are neither a reflection of the task protocol alone nor a reflection of the capacities of the actor alone. In other words, performance is neither a mere reflection of the environment nor a half-silvered mirror on the actor's mental structures. Instead, it is the coming together of the immediate task context and an actor's prior history, which reduces the available options leading to a particular performance.

Illustrative of this principle is the task in which a child searches for a toy hidden in one of two locations: A or B (Piaget, 1963). Factors that determine the location at which the child would search include the task instructions, the attractiveness of the toy, and the child's capacity to remember where the toy was seen last. Other,

[1] Sample references include Chinn & Brewer, 1993; Dunlop, 2000; Eryilmaz, 2002; Ferrari & Chi, 1998; Flavell, 1999; Gelman & Raman, 2002; Gopnik & Meltzoff, 1997; Krist, Fieberg, & Wilkening, 1993; Mazens & Lautrey, 2003; McKinnon & Geissinger, 2002; McKinnon, Geissinger, & Danaia, 2002; Mikkilä-Erdmann, 2001; Nakhleh, 1992; Nguyen & Rosengren, 2004; Ozay & Oztas, 2003; Pine, Messer, & Godfrey, 1999; Pine, Messer, & St. John, 2001; Riemeier & Gropengiesser, 2008; Springer, 1995; Van Dooren, De Bock, Hessels, Janssens, & Verschaffel, 2004; Walz & Kerr, 2007; Wellman & Gelman, 1992; Wilkening & Martin, 2004; Yip, 1998.

less obvious, factors include the spatial distance between the two hiding places A and B, the temporal delay between hiding and searching, the details of the hiding events, changes in the child's coordination of reaching, and probably many others (e.g., L. B. Smith et al., 1999). The immediate relations between all these factors constitute the constraints on the child's performance at a given time.

The constraints view has implications for the study of misconceptions far beyond a mere acknowledgment that a task context can affect a child's performance. First, this view presupposes interdependence between a child's environment and mental constructs. Like woven threads that become cloth, "knowledge is fundamentally a coproduction of the mind and world, which like a woof and warp need each other to produce and to complete an otherwise incoherent pattern" (Hung, 2002; p. 394). In other words, knowledge and task are not separate causal factors but mutually codetermining factors of a child's performance. As a consequence, it is not possible to empirically isolate specific mental structures or deficiencies that might elicit misconceptions (e.g., a competence that is yet blind to differences between density and heaviness). Neither knowledge nor the lack of it can be isolated empirically. Instead, misconceptions—like every cognitive performance—entangle the factors that underlie the expressed misconception. Successful and unsuccessful performances both entail the relevant congruent and opposing constraints present in a "knowledge" response.

Second, an emphasis on constraints makes unique predictions about how to support veridical understanding and conceptual change. It underscores the importance of aligning task constraints so as to favor veridical performance from the beginning. In contrast, a conventional way to correct a misconception is to create a task context in which mistaken performance is elicited first (e.g., Kloos & Somerville, 2001). The idea of such an approach is to change a misconception by highlighting its shortcomings through juxtaposition. However, giving priority to the mistaken performance might, in fact, be counterproductive if it increases the salience and possible coherence of constraints that support making an error. Instead, a child may be made less susceptible to irrelevant features of the task if the task context reliably tips the balance of constraints in the direction of veridical performance.

Before these ideas can be explored, the importance of immediately available constraints needs to be demonstrated empirically. With this goal in mind, we focus on children's misconceptions about object density.

Misconceptions in Density Tasks

Material density is defined by the ratio of an object's mass over volume. Therefore, any manipulation of density is also a manipulation of the relation between mass and volume, neither of which predicts density by itself. It is commonly assumed that density has to be inferred from the relation of mass to volume, making density something of a hidden feature, compared with the more obvious features of mass (e.g., heaviness) or volume (e.g., size). This is one reason that density is a concept covered in school (e.g., Ohio Department of Education, 2009), making it relevant for investigation.

Tasks that test for understanding of density often involve scenarios in which variations in density are pitted against variations in mass and volume (e.g., Kloos & Van Orden, 2005; C. Smith, Carey, & Wiser, 1985). For example, children are presented with pairs of objects for which the heaviest objects have the lowest density. In these task contexts, children perform poorly (cf. Hewson & Hewson, 1983; Penner & Klahr, 1996; Piaget, 1963; C. Smith et al., 1985). For instance in C. Smith et al. (1985), 80% of 3-year-olds, 70% of 4-year-olds, 81% of 5-year-olds, and 62% of 6- to 7-year-olds incorrectly concluded that a less dense object was made out of "heavier kind of stuff" (p. 197). And when an aluminum block was heavier than a steel block, only 33% of 8- to 9-year-olds could categorize the blocks correctly on the basis of density.

Such findings have been taken to suggest that children start out with some mistaken idea about density, maybe that density is equivalent to mass (cf. Carey, 1985). Nonetheless, there are also reports of competent density performance in young children. Most notable is Kohn's (1993) study, in which children responded whether objects would sink or float. No feedback was provided, and no object was ever placed in water. Yet even preschoolers performed above chance when they had to distinguish between sinkers and floaters, without being misled by mass or volume. Similar success was reported in a steel-and-aluminum sorting task used in the C. Smith et al. (1985) study mentioned previously. The proportion of incorrect responses, for the same objects, was cut in half when objects were judged one by one rather than in pairs pitting mass against density.

One explanation for this apparent contradiction is that successful performance may stem from an implicit rather than explicit understanding of density (Kohn, 1993). Another explanation is that children are more successful on less complex tasks than on more complex tasks (C. Smith et al., 1985). Both of these explanations assume the primacy of knowledge about mass and volume over density. But this assumption is difficult to reconcile with instances in which people fail to ignore density, even with explicit instructions to do so. For instance, when presented with two equally heavy objects that differ in size, children and adults judge the bigger object as being heavier than the smaller object, a finding known as the size–weight illusion (Pick & Pick, 1967; Robinson, 1964; Stevens & Rubin, 1970). In particular, because a heaviness judgment requires the participant to lift the object, and thus to rotate it around a joint (the wrist, the elbow, or the shoulder), perceived heaviness is determined by the object's rotational inertia, which is a function of object density (Amazeen & Turvey, 1996; Kloos & Amazeen, 2002). Apparently, some task conditions make it difficult to perceive heaviness without density intrusions; yet other task conditions make it difficult to perceive density without heaviness intrusions.

Constraints on Density Performance

As we suggested earlier, rather than reflecting stable misconceptions (or stable veridical knowledge, for that matter), a stable, repeatable performance reflects a stable configuration of constraints in the relations between participant and task. That is to say, misconceptions are neither necessarily a reflection of different types of knowledge (implicit vs. explicit knowledge) nor a reflection of different cognitive demands (easy vs. difficult tasks). Instead, both successful and unsuccessful performances might reflect the tipping point of a ratio of opposing constraints (for a review, see Van Orden, Kloos, & Wallot, 2009). If so, then what constraints are prominent in performing density judgments?

Density tasks involve category judgments (e.g., "Does it sink or float?"; "Which one is made of the heavier kind of stuff?"). Nonobvious constraints in this case might be supplied, in part, by the relative salience of features that vary in the task context.[2] Indeed, in tasks that elicited successful density performance, mass, volume, and density were distributed across objects in a way that made it difficult, if not impossible, to compare objects on any dimension other than density. For example, in Kohn's (1993) study, children were never given an opportunity to compare objects side by side, and differences in mass or volume were never brought to children's attention. Conversely, in tasks that elicit unsuccessful density performance, children were either explicitly encouraged to focus on mass and volume in isolation (e.g., by asking children to point to the heavier of two objects), or objects differed in many salient properties other than density, including shape, function, and color (Piaget, 1963). Thus, the latter task contexts were such as to maximize constraints that favored a focus on properties other than density.

This difference in how tasks were implemented—rather than an implicit versus explicit density understanding (or high vs. low cognitive demand)—could account for the differences in density performance just discussed. The experiments we report here tested this hypothesis explicitly. Does a nonobvious manipulation of constraints change the apparent knowledge children exhibit in density tasks? We hypothesized that salience of object properties determines whether a child performs correctly—even for the same objects.

One intuitive way to manipulate the salience of objects' properties would be to manipulate the distribution of mass and volume factorially with the distribution of density. However, given that density is a ratio of mass and volume, any variations in density are also variations in mass or volume. It is therefore not possible to construct a within-object factorial manipulation. Instead we manipulated presentation conditions and how objects' properties were distributed across the set of objects that were presented to participants. A set of cubes was constructed such that half of the cubes had one density (they floated) and the other half of the cubes had another density (they sank). Mass and volume, on the other hand, varied incrementally, such that there were seven different levels of mass and six different levels of volume. Adjacent values of mass and volume increased in relatively small increments (i.e., approximately 60%) compared with the single increment of density (i.e., 400%). As a result of this manipulation, variations in density demarcate a category (e.g., floaters vs. sinkers), whereas neither variations in mass nor variations in volume could function as clear category markers. Therefore, across the entire set of cubes, with each cube presented one by one, density is likely to be the most salient dimension in a context in which category membership needs to be determined.

Such one-by-one presentation of cubes is contrasted by presentation of the same cubes in pairs. Figure 1 shows possible combinations of objects in schematic form. As in the symbolism of C. Smith et al. (1985), the heavier object in a pair is underlined, and the denser object has the darker outline. Pairs of objects could differ in mass and density (Combination 1), in volume and density (Combination 2), in mass and volume (Combination 3), or in all three dimensions (Combinations 4 and 5). In pairs that differ in density as well as in mass or volume, density is no longer the only

Combination	Type of Pairs	Condition Label	Correlation	Predicted Density Judgment
1.		Density-Confounded	Mass-Density: $r = +$ Volume-Density: $r = 0$ Mass-Volume: $r = 0$	Correct
2.		Pair Presentation	Mass-Density: $r = 0$ Volume-Density: $r = –$ Mass-Volume: $r = 0$	Incorrect
3.		Density-Unconfounded	Mass-Density: $r = 0$ Volume-Density: $r = 0$ Mass-Volume: $r = –$	Incorrect
4.		Pair Presentation	Mass-Density: $r = –$ Volume-Density: $r = –$ Mass-Volume: $r = –$	Incorrect
5.		Density-Confounded	Mass-Density: $r = +$ Volume-Density: $r = –$ Mass-Volume: $r = –$	Correct

Figure 1. Combination of object pairs and predicted density judgments. Pairs of cubes differ in volume (shown as different sizes), mass (the heavier of the two objects is underlined), and/or density (the denser of the two objects has a darker outline). Combination 4 was used in Experiment 1 (as part of the pair-presentation trials) and in Experiment 3 (as part of the density-unconfounded pairs).

dimension that functions as a category marker. That is to say, the salience of density as a category marker in a pair trial is reduced with respect to the salience of mass or volume as a category marker, at least so long as mass is pitted against density within a pair. Therefore, unless mass and density are correlated positively, density will be less salient in paired presentations than when cubes are presented one by one. The goal of Experiment 1 was to test whether such a difference in the salience of density affects children's performance on density tasks.

Experiment 1

As in Kohn's (1993) study, participants were asked to predict whether cubes would sink or float in water. Unlike in previous research, however, we changed the experimental protocol to manipulate the salience of object density. For pair-presentation trials, objects appeared in pairs for which density was not a salient category marker. In particular, mass was either held constant while volume and density varied (see Combination 2 in Figure 1), or mass and volume were pitted against density (see Combination 4 in Figure 1). For single-presentation trials, the same objects were presented one by one as part of a larger set of objects for which density was the most salient category marker across presentations. Children between 2 and 9 years of age and adults participated. We predicted that even young children could judge whether a cube will sink or float, as long as variation in object density is made salient.

[2] Note that salience—like any constraint more generally—is never a function of task context alone, nor is it a function of a person's history alone. Even large changes in a task context will be ignored if the actor's propensities to perform are not aligned with the changes in the task context. For example, adults instructed to focus on the ball handling in a basketball game will fail to notice a man in a gorilla suit pounding his chest on the basketball court (Simons & Chabris, 1999). On the other hand, even a tiny change in a task context can affect performance if the learner has become attuned to the relevant dimensions, as documented in numerous instances of perceptual learning (Gibson, 1963; Hall, 1991).

In contrast, we expected that even older children would make mistakes when the salience of density is relatively low.

Method

Participants. Twenty-one adults (14 women, 7 men) and 58 children between 2 and 9 years of age (25 girls, 33 boys) participated in this experiment. Adults were recruited through the subject pool of introductory psychology classes and received partial course credit for participation. Children in this and all subsequent experiments were recruited from urban and suburban middle-class day care centers and elementary schools. Five additional children were tested but omitted from the analyses because they lost interest and failed to complete the task.

Materials. Ten wooden cubes were constructed according to the specifications of mass, volume, and density shown in Figure 2 (adapted from Kohn, 1993): All objects were one of two densities (2.0 g/cm^3 or 0.5 g/cm^3), one of seven masses (between 30 g and 503 g), and one of six volumes (between 39 cm^3 and 405 cm^3). Neither mass nor volume alone was absolutely predictive of the cube's sinking behavior: Cubes with a mass of 77 g, 123 g, or 197 g and cubes with a volume of 64 cm^3, 104 cm^3, 166 cm^3, or 262 cm^3 could either sink or float. This full set of cubes, presented one at a time, was used for the single-presentation trials.

A subset of six cubes (from the total of 10) were combined into pairs for the pair-presentation trials, portrayed with connecting lines in Figure 2. Within a pair, one cube would sink if placed in water (density = 2 g/cm^3) and the other would float (density = 0.5 g/cm^3). In addition, cubes within a pair could differ either in volume (solid lines) or in mass and volume (dashed lines). Given that mass either did not correlate with density or correlated negatively, we predicted lower accuracy on these trials than on single-presentation trials (see Combinations 2 and 4, respectively, in Figure 1).

Cubes were hollowed out and filled with lead and wood putty until the desired mass was obtained. Care was taken to distribute mass equally throughout each cube. Once the cube was filled and closed, individual sides were painted in bright colors (each side a different color), such that cubes could not be distinguished from each other on the basis of color alone. A string of number digits, added surreptitiously to a side of the cube, made it possible for the experimenter to distinguish between the cubes.

Procedure. Participants were tested in a quiet room (either at their school or in the lab) by hypothesis-blind experimenters. The cover story involved a character named Wump, who found special rocks on a faraway planet and wanted to know whether the rocks would sink or float in earth water. For single-presentation trials, participants were presented with one cube at a time, each of the 10 cubes occurring twice in random order. Participants were asked to pick up the cube and report whether it would sink or float. For pair-presentation trials, participants were presented with a pair of cubes at a time, each of the six pairs occurring twice in random order, with counterbalanced left–right arrangement. For each pair, participants were asked to pick up the two cubes and report whether one cube would sink and the other float, both cubes would sink, or both cubes would float. Participants could hold the cubes for as long as they wanted, and they were prompted to simply guess if they hesitated to respond. Randomization of trials and data collection for this and all subsequence experiments was supported by SuperLab Pro 2.0 software.

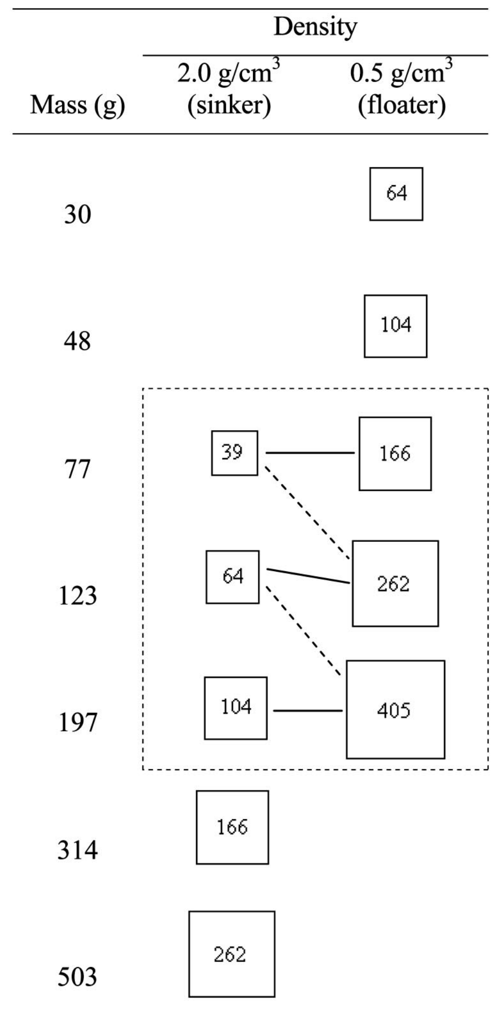

Figure 2. Masses, volumes, and densities of objects used in Experiments 1–3. Values displayed on cubes reflect their volume (in cm^3). The lines connecting cubes show how cubes were combined into pairs for the pair-presentation trials of Experiment 1, with density correlating either with volume alone (solid line; see Combination 3 in Figure 1) or with both mass and volume (dashed line; see Combination 4 in Figure 1). Cubes inside the dashed box were used in both conditions.

Throughout the experiment, there were no practice trials, no cube was ever placed in water, and children did not receive feedback on their performance. Therefore, learning across an experimental session was unlikely. Participants were first presented with pair-presentation trials and then with single-presentation trials, because we predicted better performance in the latter kind of trials. Had the single-presentation trials been presented first, children might have been sensitized to density variations in the entire set, inflating performance on pair-presentation trials. Therefore, the ordering of the tasks used in Experiment 1 runs counter to our predictions, because children could potentially become attuned to mass and volume during pair-presentation trials and subsequently underperform during single-presentation trials.

Results and Discussion

The first preliminary analysis pertained to children's performance on pair-presentation trials, when children had to decide whether one of the cubes in a pair would sink, both would sink, or both would float. On a majority of these trials (73%), participants determined that one cube would sink and the other would float. The answer option *both sink* was chosen on 18% of trials, whereas the answer option *both float* was chosen on 9% of trials.

Were children affected by the particular combination of cubes (Combination 2 vs. Combination 4; see Figure 2)? To answer this question, we collapsed the proportion of correct responses across the three pairs of Combination 2 and across the two pairs of Combination 4. A repeated-measures analysis of covariance, with age as a covariate, revealed no main effect or interaction of combinations (all Fs < 0.5, ps $> .51$). We therefore collapsed each child's performance across the pair-presentation trials. Figure 3A displays individual children's proportion of correct responses on pair-presentation trials as a function of age. There was no significant improvement across age, $r(56) = .16$, $p > .23$, with only 48% of children (28 out of 58) performing significantly above chance (choosing the correct option on six or more of the 10 trials; two-tailed binomial probability $p < .05$, assuming a chance probability of .25).

The second preliminary analysis pertained to children's performance on single-presentation trials, when children had to decide whether a cube would sink or float. Figure 3B shows individual children's proportion of correct responses (across trials) as a function of age. There was an overall improvement across age, $r(56) = .50$, $p < .001$. As can be seen in the figure, the youngest participants (2- to 3-year-olds) performed at chance (choosing the correct option in fewer than 15 out of 20 trials; binomial probability $p > .12$, assuming a chance probability of .5). However, performance improved with age: Five 4- to 5-year-olds (out of 15; 33%) performed consistently above chance, and by 6 years of age, the majority of children (at least 80% per age group) performed above chance. No systematic pattern of performance was apparent when contrasting cubes within the subset (e.g., the heaviest vs. lightest cubes).

To compare performance on pair-presentation trials with performance on single-presentation trials, we rescored performance on pair-presentation pairs to gauge performance on each individual cube. This allowed us to equate chance probability across the two types of trials at 50% (children could be either correct or incorrect for each particular cube). Furthermore, we restricted our analysis to those cubes that appeared in both the pair- and the single-presentation trials (shown in the dashed box of Figure 2). Figure 4 shows the mean proportion of correct performance as a function of trial type and the following age groups: 2- to 3-year-olds ($n = 12$), 4- to 5-year-olds ($n = 15$), 6- to 7-year-olds ($n = 18$), 8- to 9-year-olds ($n = 13$), and adults ($n = 21$).

A 2 × 5 mixed-design analysis of variance (ANOVA) was conducted, with trial type as the within-subject factor and age group as the between-subjects factor. The analysis revealed a

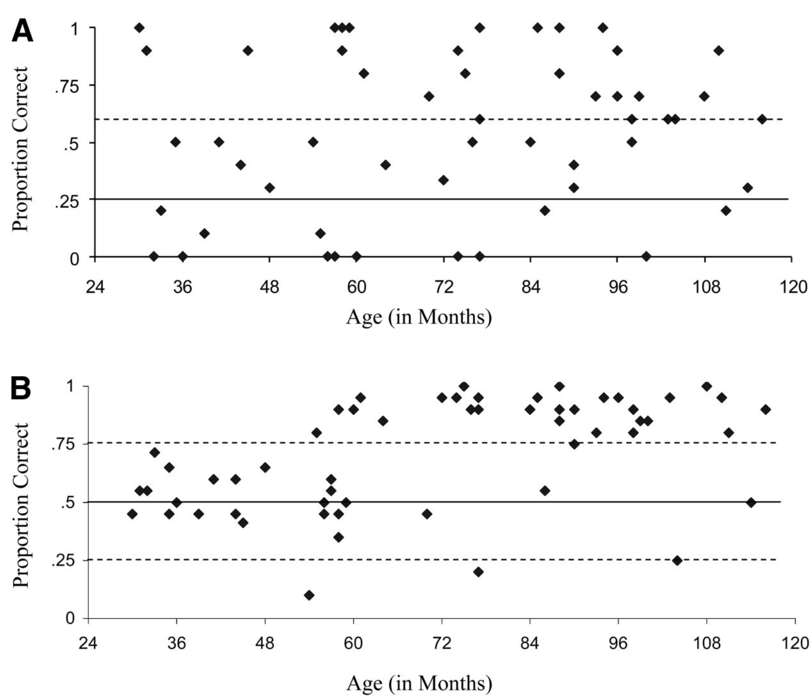

Figure 3. Individual children's proportion of correct performance on pair-presentation trials (A) and single-presentation trials (B). Solid lines represent chance performance ($p = .25$ for the four-choice pair-presentation trials; $p = .50$ for the two-choice single-presentation trials). Dashed lines demarcate performance that is different from chance using the binomial probability test (above chance for A: performing correctly on at least six out of 10 trials; above chance for B: performing correctly on at least 15 out of 20 trials; below chance for B: performing correctly on less than five out of 20 trials).

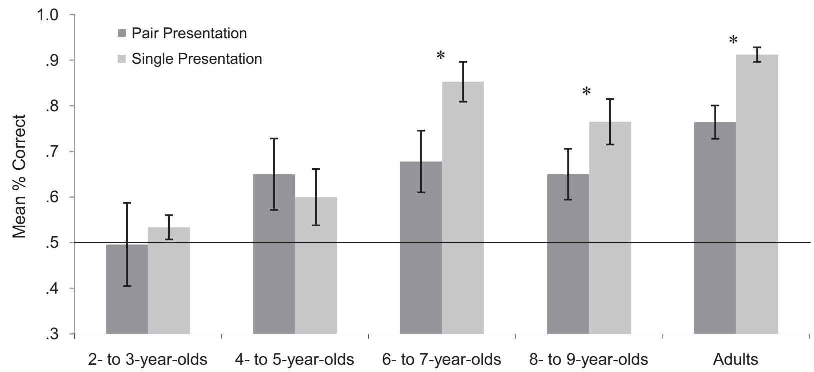

Figure 4. Mean proportion of correct judgments in Experiment 1 for cubes that were presented as part of a pair (pair-presentation trials) or alone (single-presentation trials), separated by age group. Chance performance is .5. Error bars represent standard errors, and asterisks represent reliable differences between trial types (pair presentation vs. single presentation).

reliable linear trend of age, $F(4, 74) = 7.15$, $p < .01$, with participants performing better with increasing age. More importantly, the effect of trial type was statistically reliable, $F(1, 74) = 8.1$, $p < .01$. Children performed better on single-presentation trials ($M = .75$, $SD = .23$) than on pair-presentation trials ($M = .66$, $SD = .27$). Planned paired-sample *t* tests revealed an effect of trial type for the three older age groups (6- to 7-year-olds, 8- to 9-year-olds, and adults), paired-sample ts > 2.1, ps $< .05$, but not for the younger children between 2 and 5 years of age (ps $> .6$). In particular, children 6 years and older performed better on the single-presentation trials than on the pair-presentation trials, whereas children 5 years and younger failed to produce a reliable difference.

Consistent with our prediction, adults and children 6 years and older were affected by the trial-type manipulation. Participants who performed above chance were more likely to do so for single-presentation trials than for pair-presentation trials. This was true even though the same cubes were considered in both types of trials. Experiment 2 takes a second look at younger children's ability to pick up on difference in density, whereas Experiment 3 investigates whether extraneous factors of the pair-presentation, other than the targeted difference in salience, could explain children's low performance.

Experiment 2

An unexpected finding of Experiment 1 pertained to the relatively weak performance of preschool children on single-presentation trials. Previous research (e.g., Kohn, 1993) found above-chance performance for this age group, yet in our experimental setup, children younger than 6 years of age performed at chance. It is possible that children's performance on single-presentation trials suffered from fatigue or boredom, or some other confounded factor, given that these trials always occurred last. In Experiment 2, we tested this hypothesis, presenting children between 2 and 5 years of age with single-presentation trials only (as was done in Kohn, 1993).

Method

Participants. Children between 2 and 5 years of age (9 girls, 11 boys) participated, none of whom participated in Experiment 1. The younger age group included ten 2- and 3-year-olds ($M_{\text{age}} = 3.4$ years), and the older age group included ten 4- and 5-year-olds ($M_{\text{age}} = 5.01$ years).

Materials and procedure. Materials and procedures were identical to those used during the single-presentation trials of Experiment 1. The only difference was the number of trials. This time there were three blocks of trials (10 trials per block), and each cube was presented once per block (resulting in a total of 30 trials).

Results and Discussion

How well could children sort cubes into sinkers versus floaters when it was the first task they were asked to complete? Performance of the 2- to 3-year-olds did not exceed chance level, whether considering their performance during a single block of 10 trials ($M_{\text{Block 1}} = .53$, $M_{\text{Block 2}} = .53$, $M_{\text{Block 3}} = .50$; SDs $< .16$) or across the total of 30 trials ($M = .52$, $SD = .07$), single-sample ts < 0.9. Only one of the ten 2- to 3-year-olds performed above chance in one block of trials (choosing the correct answer in eight out of 10 trials, binomial probability $p < .05$). All other 2- to 3-year-olds performed at chance, whether considering only the first block of trials or across all 30 trials.

Many 4- and 5-year-olds, on the other hand, were successful in this task. Six of the ten 4- to 5-year-olds performed above chance during the first block, and five children performed above chance across all three blocks (choosing the correct answer in at least 21 of the 30 trials; binomial probability $p < .05$). Figure 5 shows 4- to 5-year-olds' performance in each block of trials, separated by whether we considered all 10 cubes presented or just the subset of cubes that were the focus of analysis in Experiment 1. Performance was above chance in both cases, whether we considered Block 1 only, $M_{\text{all cubes}} = .72$, $M_{\text{subset of cubes}} = .77$, SDs $= .24$; single-sample ts$(9) > 2.85$, ps $< .02$, or considered all 30 trials, $M_{\text{all cubes}} = .70$, $M_{\text{subset of cubes}} = .69$, SDs $< .22$; single-sample ts$(9) > 2.92$, ps $< .02$. Importantly, performance in Block 1 was better than performance of 4- to 5-year-old children on single-presentation trials of Experiment 1, independent-sample $t(23) = 1.79$, $p < .05$.

Taken together, the results show that 4- to 5-year-old children, as a group, perform successfully when presented with only single-presentation trials, replicating Kohn's (1993) finding. Apparently,

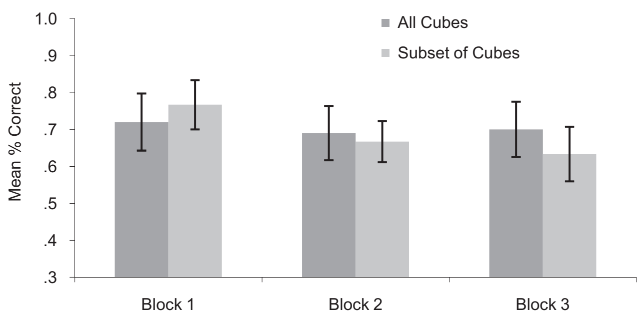

Figure 5. Mean proportion of correct judgments of 4- to 5-year-olds in Experiment 2 for single cubes (single-presentation condition), separated by session. Means displayed were computed both across all cubes and across the subset of cubes that were entered into the analysis in Experiment 1. Chance performance is .5. Error bars represent standard errors.

4- to 5-year-olds' performance in Experiment 1 suffered from presenting the single-presentation trials last, after the pair-presentation trials. Of course, whatever factor was confounded with order in Experiment 1 is yet another nonobvious and seemingly trivial factor that determines whether children perform successfully. It is this ever-present context sensitivity of performance that is the heart of our hypothesis.

Experiment 3

In Experiment 1, the salience manipulation was confounded—by necessity—by differences in whether objects were presented singly (single-presentation trials) or in pairs (pair-presentation trials). Making a judgment about two cubes (pair-presentation trials) versus making a judgment about one cube might pose different cognitive demands on children. This difference in demand could account for the difference in performance reported in Experiment 1. Experiment 3 was designed to test for this possibility: Are sink or float judgments for a pair of cubes inherently difficult?

To answer this question, we presented children with pairs of cubes only (see Figure 6). For one type of pair, mass correlated positively with density, yielding *density-confounded* pairs. The heavier object in a pair was the denser one, either with volume held constant (double-dashed lines; see Combination 1 in Figure 1) or with an added manipulation of volume (double solid lines; see Combination 5 in Figure 1). We expected competent performance concerning these pairs because children could perform correctly merely by paying attention to the difference in mass (while ignor-

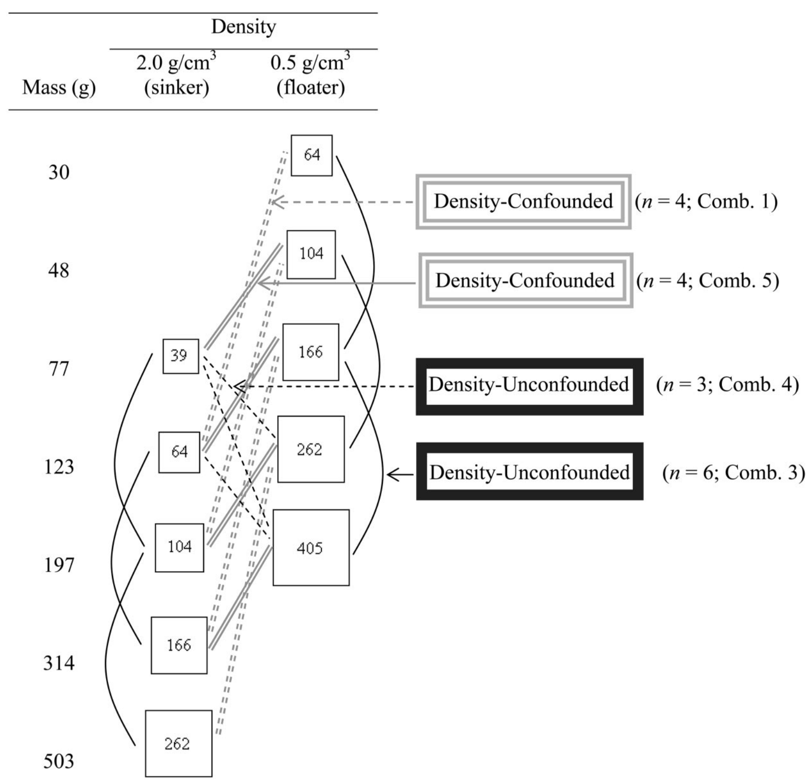

Figure 6. Pairs of cubes used in Experiment 3. In density-confounded pairs (gray lines), mass and density correlate positively, either with changes in volume (solid double lines; see Combination 5 in Figure 1) or with volume fixed (dashed double lines; see Combination 1 in Figure 1). In density-unconfounded pairs (black lines), mass and density correlated either negatively (dashed lines; see Combination 4 in Figure 1) or not at all (solid curves; see Combination 3 in Figure 1). Children were exposed to one of the two density-confounded combinations and one of the two density-unconfounded combinations. Comb. = combination.

ing differences in density). Or they could perform correctly because the correlation between mass and density might heighten attention to both features (cf. Fisher & Tokura, 1996; Morgan, Meier, & Newport, 1987).

Conversely, for the other type of pair, mass and volume were pitted against density, yielding *density-unconfounded* pairs. Mass and volume were either negatively correlated with density (i.e., the lighter and smaller object in a pair was always the denser one; dashed lines; see Combination 4 in Figure 1) or were uncorrelated with density (density was the same despite changes in mass and volume; solid curves; see Combination 3 in Figure 1). For both combinations, we expected children to have difficulty correctly identifying sinkers and floaters. Although the present experiment does not test children's ability to attend to density, it does allow us to determine whether trials that present paired objects are inherently difficult and thus could explain the low performance in Experiment 1.

Method

Participants. Participants were twenty-five 4- and 5-year-old children who did not participate in the previous experiments (17 girls, 8 boys; $M_{\text{age}} = 5.08$ years). This age group might be best suited to test a possible effect of cognitive demand: Children at this age are sensitive to differences in density (see Experiment 2), yet their performance is more likely to suffer under the possibly higher cognitive demand of a pair-presentation context, compared with the performance of older children and adults.

Materials. Figure 6 shows how the cubes were combined in Experiment 3 to create density-unconfounded pairs and density-confounded pairs. Pairs of cubes corresponded to four of the combinations shown in Figure 1 (Combinations 1, 3, 4, and 5). For two of these combinations (Combinations 1 and 5; depicted in gray double lines), mass was positively correlated with density, yielding eight density-confounded pairs. These two combinations differ in whether volume was varied (solid double lines; see Combination 5 in Figure 1) or not (dashed double lines; see Combination 1 in Figure 1). For the other two combinations (Combinations 3 and 4; depicted in black single lines), mass was pitted against density, yielding nine density-unconfounded pairs. These two combinations differed in whether mass and density correlated negatively (dashed lines; see Combination 4 in Figure 1) or not at all (solid curves; see Combination 3 in Figure 1).

Procedure. The procedure was identical to the pair-presentation procedure of Experiment 1 except for the different combinations of pairs that were presented. Some children were presented with Combinations 1 and 4 (see Figure 1), and other children were presented with Combinations 3 and 5. This division ensured that every child performed on density-confounded trials (Combination 3 or 4) as well as on density-unconfounded trials (Combination 1 or 5), without creating an excessively long experimental protocol.

Results and Discussion

Preliminary item analyses revealed no difference between the first and second presentation of each unique pair (each unique pair was presented twice), $t\text{s} < 1.6$, $p\text{s} > .10$, and—after collapsing across pairs presented twice within each combination—no difference was found between different pairs within Combinations 1, 3, and 5 (see Figure 1; repeated-measure one-way ANOVA, $F\text{s} < 1.3$, $p\text{s} > .34$). For the density-unconfounded pairs from Combination 4, it is noteworthy that children were much more likely to perform incorrectly when the cube pair had maximal mass difference ($M_{\text{120-g mass difference}} = .28$) than when the mass difference was smaller ($M_{\text{46-g mass difference}} = .58$; $M_{\text{74-g mass difference}} = .58$), planned-contrast repeated-measure one-way ANOVA, $F(8) = 2.1$, $p < .05$. This suggests that children are highly affected by the perceived difference in mass when cubes are combined in pairs. We nevertheless combined performance on pairs within Combination 4 for subsequent analyses.

Children's most common response was that one cube of the pair would sink and the other would float, when that was the correct response (see Combinations 1, 4, and 5 in Figure 1). However, children had no difficulty per se with the response options *both float* and *both sink*. For Combination 3, when both cubes floated or both cubes sank, children chose these two response options in almost half of the trials. Figure 7 shows the mean proportion of response choices (*both sink* or *both float* vs. *one sinks, one floats*), separated by combination. There was a significant difference in the proportion of *one sinks, one floats* response options between Combination 3 (pairs for which both cubes sink or both cubes float) and Combinations 1, 4, and 5 (pairs for which one cube sinks and the other floats), planned-contrast between-groups one-way ANOVA (assuming each combination as a between-subjects factor), $F(1, 46) = 3.44$, $p < .03$.

To address the main question of the experiment, Figure 8 shows children's proportion of correct responses for density-confounded pairs and density-unconfounded pairs, either overall across trials or for cubes that were shared across types of trials for a child. For comparison purposes, we also displayed 4- to 5-year-olds' performances on the pair-presentation trials of Experiment 1 and on the single-presentation trials of Experiment 2.[3]

Two mixed-design ANOVAs were conducted—one for the trial data and one for the shared-cubes data—with pair type as the within-subject factor (density-confounded, density-unconfounded) and group as the between-subjects factor (Group 1: children presented with Combinations 3 and 5; Group 2: children presented with Combinations 1 and 4). There was a main effect of pair type, $F\text{s}(1, 24) > 10.5$, $p\text{s} < .01$, with children performing worse on density-unconfounded trials than on density-confounded trials, whether we considered their performance on trials ($M_{\text{unconfounded}} = .46$, $M_{\text{confounded}} = .72$) or on shared cubes ($M_{\text{unconfounded}} = .60$, $M_{\text{confounded}} = .80$). Neither the main effect of group nor the interaction reached significance, $F\text{s}(1, 24) < 1.7$, $p\text{s} > .20$.

The high performance of preschoolers on the density-confounded trials rules out the possibility that the difference between trial types reported in Experiment 1 was due to differences in cognitive demand (e.g., due to pair judgments being inherently

[3] This comparison was appropriate, given the order effect we found between Experiment 1 and Experiment 2 for 4- to 5-year-olds' performances in the density-salient condition (see the Results and Discussion section of Experiment 2).

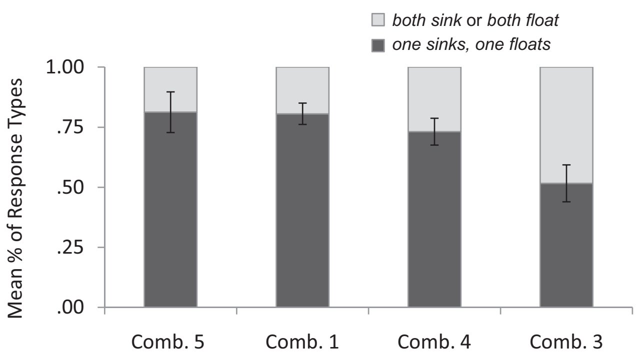

Figure 7. Mean relative frequency of choosing answer options *one sinks, one floats* versus *both float* or *both sink*, separated by combination. Error bars represent standard errors. Comb. = combination.

more difficult than judgments about single objects). Children easily distinguished between sinkers and floaters in a pair condition when density and mass correlated positively. This finding supports the idea that children's low performance in the pair-presentation trials of Experiment 1 is due to our salience manipulation.

General Discussion

We examined whether children's understanding of density is constrained by the distribution of mass, volume, and density in the immediate context of the task. Our hypothesis was that children would correctly predict whether an object sinks or floats when variations in density are sufficiently salient. Results of Experiments 1 and 2 support our predictions. By 5 years of age, participants performed above chance when objects were part of the set for which density was distributed saliently. Performance decreased when salience of density was reduced relative to the salience of mass and volume. Results of Experiment 3 suggest that this difference was not merely due to differences in cognitive demand when judging paired items versus single items.

Our findings make superfluous a discussion about what task might reflect a child's "real" competence. If available constraints matter to successful performance, then successful performance in a single-presentation condition is not an overestimation of a child's competence. And unsuccessful performance in a pair-presentation condition is not an underestimation of a child's competence. Furthermore, and consistent with the well-known *effect = structure* fallacy (e.g., Lakoff, 1990), the current findings question the need to postulate the existence of a mental structure to explain an effect. Successful performance does not imply the existence of one kind of structure (e.g., implicit knowledge). And inaccurate performance does not imply the existence of (or the lack of) a different kind of structure (e.g., explicit knowledge). Instead, differences in performance in the current task can be explained by differences in the salience of density versus mass or volume. When density was made salient, even preschool children performed well. And when density was made less salient, performance decreased even among adults. It remains to be seen whether differences in the salience of relevant dimensions could explain other context-dependent differences in performance (cf. Diamond, 1998; Ferretti & Butterfield, 1986; Gigerenzer & Richter, 1990; Kaiser, Proffitt, & Anderson, 1985; Keen, 2003; Krist, Fieberg, & Wilkening, 1993; Levin, Siegler, & Druyan, 1990; McCloskey, 1983).

Note that similarity in performance does not always imply similarity in constraints. Take for example the equivalent performance on single-presentation trials (Experiment 1) versus density-confounded trials (Experiment 3; both *M*s = .72). Despite similar performance, the constraints available in single-item presentations are likely to differ from the constraints available in the paired-item presentations. At the minimum, density was uncorrelated with mass in the single-item presentation, and neither mass nor volume serves as a dichotomous category marker across these trials. Conversely, in successful pair trials, density correlated positively with mass, making available an additional distinction to affect performance. The mere difference in whether there is more than one viable stimulus dimension may change the relation between the

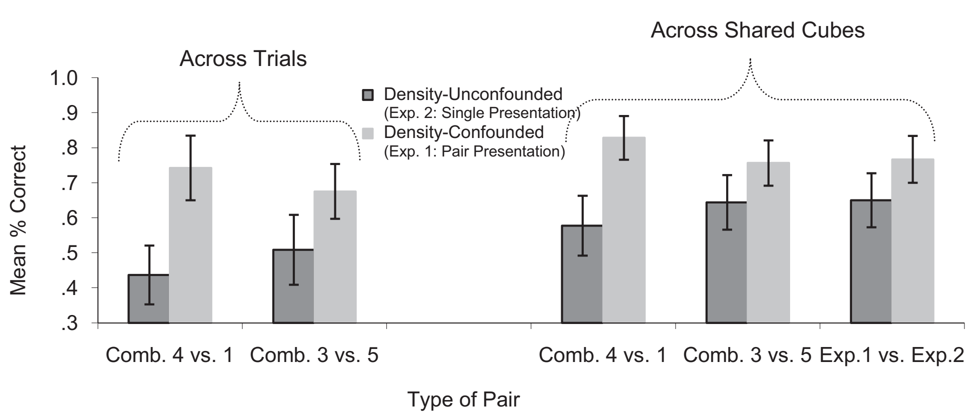

Figure 8. Mean proportion of correct judgments of 4- to 5-year-olds in Experiment 3, separated by whether cubes were part of a density-unconfounded pair or a density-confounded pair (repeated-measure design). Data represent performance across pairs of a certain type or for cubes shared across the pairs in a particular combination. Corresponding means from Experiment 1 (pair-presentation trials) and Experiment 2 (single-presentation trials) are displayed for comparison purposes. Error bars represent standard errors. Comb. = combination; Exp. = experiment.

child and the task protocol, yielding a different basis for performance.

Although the current manipulation pertained to changes in the task context, it is important to stress that constraints pertain more broadly to relations between participant, instructions, procedures, and stimuli that reduce or increase the degrees of freedom for particular response actions. Thus, constraints are not found in the body, brain, or task, each working in isolation. They are discoverable only in relations between the participant and task (e.g., Havas, Glenberg, & Rinck, 2007). In the current experiments, changes in the composition of stimuli changed the landscape of constraints for a child's judgments of sinking and floating. If the task were changed such that the instructions were to "throw the cubes at a target," the new task ecology would exclude previous response options while expanding the degrees of freedom for arm trajectories in throwing. And if the cubes were too heavy for the child to lift, the task ecology would change yet again.

Along the same line, if a person's knowledge (or more generally, a person's prior history) were to be changed, then a new task ecology would emerge. Recall, for example, that infants' performance in the A-not-B task, mentioned earlier, is a function (in part) of their motor history (i.e., the number of reaches to one of the hiding locations prior to the crucial change in hiding location) and their strength of memory traces for the hidden objects (i.e., their knowledge about where the object was hidden). Similarly, children's performance in the current experiments is a function (in part) of a child's prior history with objects. For example, a child's experience of heaviness as a downward force might heighten the salience of this dimension when it comes to judging falling or sinking behaviors (for a discussion, see Kloos & Van Orden, 2005).[4] In other words, just as a change in task context changes task ecology, a difference in the child's prior history changes the task ecology. What kind of history would promote constraints to embody a veridical concept of density?

Learning About Density

How can constraints be employed to instill a sophisticated understanding of a physics concept such as density? Common teaching practices designed to replace misconceptions focus on eliciting a child's false beliefs before the child is exposed to science instruction (e.g., McDermott & Redish, 1999; Pfundt & Duit, 1991). The idea behind such practices is that false beliefs will trump formal instruction if their shortcomings are not pointed out explicitly (e.g., Kloos & Somerville, 2001). In the context of density instruction, such a procedure of initially engaging false beliefs might involve a protocol in which children are asked to relate differences in mass and volume to outcomes that are affected by density.

Results from our study suggest that such a procedure, rather than calling to mind existing beliefs, might in fact create and perpetuate them. For example, testing environments that make mass salient can lead children to rely incorrectly on mass to predict outcomes such as buoyancy (cf. Hall, 1991). Of course, once beliefs are created, they are hard to correct, not unlike a persistent priming effect (cf. Gershkoff-Stowe, Connell, & Smith, 2006) or illusory correlation effect (cf. Hamilton & Rose, 1980; Johnston & Jacobs, 2003; Lord, Ross, & Lepper, 1979). It is therefore plausible that an initial focus on mass and volume actually impedes acquiring a formal understanding of density.

A better alternative might be to avoid false beliefs altogether, namely by structuring the learning environment in such a way as to make the to-be-taught concept more salient (cf. McNeil, Uttal, Jarvin, & Sternberg, 2009; Son, Smith, & Goldstone, 2008; Uttal, Scudder, & DeLoache, 1997). For example, one could adopt a pedagogy in which density, rather than mass and volume, was most salient. The "dots-per-box" teaching model is a point in case (Maclin, Grosslight, & Davis, 1997; C. Smith, Maclin, Houghton, & Hennessey, 2000; C. Smith & Unger, 1997; Snir, Smith, & Grosslight, 1993). Students were presented with schematic representations of what an object would look like on the inside, assuming mass is expressed as the number of dots and volume is expressed as the number of same-sized boxes (hence, dots-per-box model). Density, therefore, is captured schematically through the visible distance between mass units within the available volume. Middle-school children were found to benefit from this visualization to understand density.

Of course, given that knowledge is always grounded in task constraints, successful performance need not necessarily lead to an abstract concept of density that will generalize to new contexts. Making density salient, such as through a dots-per-box model, allows children to perceive density directly, on the basis of attentional processes that tune in to the most salient dimension. However, such direct perception might not instill an understanding of the mathematical relation between mass, volume, and density. Such a lack of an abstract understanding of density might leave the learner prone to mistakes when a misleading task context makes inappropriate dimensions salient.

In order to bootstrap a more formal understanding of the concept of density, one may need to combine a supportive task context with the protracted weaning of students from the scaffold available in the supportive task context. This might be accomplished by providing children with diverse instances (O'Reilly & Munakata, 2000; Reeves & Weisberg, 1994) or by explicitly contrasting a supportive task context with one that leads to mistakes in performance (cf. Gentner, Loewenstein, & Thompson, 2003; Loewenstein & Gentner, 2001; see Dixon & Bangert, 2004, for a comparison of the two approaches). Both approaches might allow a student to come to embody stable and reliable biases, not unlike a young child gaining stronger memory for hidden objects in an A-not-B task. These embodied changes, though not empirically apparent, are likely to decrease the probability of making density errors in a misleading task context—the same way a stronger memory for a hidden object decreases the likelihood of searching for it at the wrong location. The effects of task contexts can never be eliminated, however. For example, there are circumstances in which even adults commit the A-not-B error. Likewise, a suffi-

[4] In the current set of experiments, children did not show a bias toward focusing on mass alone. When mass was pitted against density (density-unconfounded pairs), mean performance was at chance, with a majority of children failing to base their judgment on mass alone (and thus failing to perform below what would be predicted by chance alone). However, in different contexts, children were indeed found to focus exclusively on mass (e.g., C. Smith et al., 1985).

ciently misleading task context can lead otherwise competent adults to misjudge the density of a material.

Conclusion

Our results have demonstrated that minimal changes in available constraints can influence children's and adults' knowledge of density in predictable ways. These findings resolve a previous conflict between reports about children's naïve understanding of density. The resolution stems from the idea that task performance, successful or not, directly reflects the situated relations between the participant's history and the details of the experimental protocol. Consistent performance across age reflects consistently available constraints rather than intrinsically stable beliefs or competence. The demonstrated consequences of constraints underscore the importance of a scaffolded structure in the learning environment. Our results support learning and testing approaches that include environmental support for competent performance and only later weaning performance of its supportive structure.

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New APA Editors Appointed, 2012–2017

The Publications and Communications Board of the American Psychological Association announces the appointment of 9 new editors for 6-year terms beginning in 2012. As of January 1, 2011, manuscripts should be directed as follows:

- *Emotion* (http://www.apa.org/pubs/journals/emo), **David DeSteno, PhD,** Department of Psychology, Northeastern University, Boston, MA 02115
- *Experimental and Clinical Psychopharmacology* (http://www.apa.org/pubs/journals/pha), **Suzette M. Evans, PhD**, Columbia University and the New York State Psychiatric Institute, New York, NY 10032
- *Journal of Abnormal Psychology* (http://www.apa.org/pubs/journals/abn), **Sherryl H. Goodman, PhD**, Department of Psychology, Emory University, Atlanta, GA 30322
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Electronic manuscript submission: As of January 1, 2011, manuscripts should be submitted electronically to the new editors via the journal's Manuscript Submission Portal (see the website listed above with each journal title).

Manuscript submission patterns make the precise date of completion of the 2011 volumes uncertain. Current editors, Elizabeth A. Phelps, PhD, Nancy K. Mello, PhD, David Watson, PhD, Gordon M. Burghardt, PhD, Brent S. Mallinckrodt, PhD, Charles M. Judd, PhD, Fernanda Ferreira, PhD, Glyn W. Humphreys, PhD, and Timothy R. Elliott, PhD will receive and consider new manuscripts through December 31, 2010. Should 2011 volumes be completed before that date, manuscripts will be redirected to the new editors for consideration in 2012 volumes.