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ABSTRACT

Two experiments were conducted to assess the nature and extent of children's knowledge about the density of objects. In the first experiment, 18 children 3- to 5-years-old were shown 8 objects which were placed in water 1 at a time. The children were later asked to judge whether the objects would sink or float when placed in water. Findings indicated subjects were sensitive to substance, with high accuracy in their judgments for objects made of metal; errors were not connected to size or absolute weight. However, a large number of errors occured, particularly in regard to the heaviest wooden object, which suggests that subjects' judgments were linked to the weight of an object relative to its substance. Such judgments may indicate the core of a concept of density. Experiment 2, while controlling for volume, explored whether children were likely to judge floatability by substance, absolute weight, or relative weight. Participants were 10 college students, five 6-year-olds, and five 4-year-olds. All showed that neither absolute weight nor substance was the basis for their floatability judgments. Adults and children made the most errors on the same small number of objects which were near the boundary between floatability and sinkability. Findings suggest that a rudimentary concept of density exists which depends neither on simple, heuristic rules, nor on prior, perhaps even more simple concepts, such as that of weight. (RH)

Does the Concept of Density Develop?

Judgments of Sinking and Floating

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Does a child's knowledge of basic physical properties grow and change with development? Piaget suggests children's knowledge development is analogous to scientific theory development. characterized by distinct qualitative changes (Piaget and Inhelder. 1948/1974). A recent study representing this view concerns children's knowledge of density. Following Piaget and Inhelder. Smith. Carey. and Wiser. (1985). argued that density becomes a functioning concept for the child only after differentiation from its closely linked concepts size and weight.

In a series of experiments. Smith et al asked children to judge which of a pair of objects was made of a "heavier stuff". Critical pairs contained a small. relatively lightweight object made of dense material. and a large. relatively heavy object made of less dense material. Young children's errors showed systematic intrusion of weight into the density judgments. For example. four year-olds typically judged heavier objects to be made of "heavier stuff", while in fact, these were made of a less dense material. In contrast, eight year-olds judged objects that were lighter but made of a denser material to be made of "heavier stuff", indicating that they had separated weight from density.

However, Smith et al. may have underestimated children's knowledge of density. In their study, the critical pairs directly pitted weight against density. Since accurate estimates of density require accounting for both an object's volume and its weight, children's failures could have been due to difficulty in making these estimates, (and consequent over-reliance on weight), rather than difficulties with the concept of density itself. These problems may persist into adulthood, but do not necessarily compromise a basic understanding of the property of density.

Using a somewhat different method, we explored the possibility that children might demonstrate their knowledge of density in judgments of whether objects will sink or float in water. Historically, our earliest formalized knowledge of density appears through Archimedes' discovery of water displacement as a function o density. Each substance has a specific density which determines whether it will sink or float: substances that are denser than water sink, while those that are less dense than water float. Accurate predictions of an object's floatability cannot rely on weight alone; weight for volume, or the density of a substance must be considered and compared to the density of the floating medium. The fact that even young children have extensive experience floating objects in water makes plausible that they might reveal their knowledge of density through such a procedure.

In our first experiment, eighteen children were shown a series of 8 objects placed one at a time in water, and were later asked to judge whether these same objects would sink or float. Eight subjects were 3 year olds (between 36 and 42 months of age), and ten were 4 1/2 to 5 years old (between 56 and 65 months). Children were given a pre-test to verify that they could use the words *sink* and *float* correctly.

The 8 object set was designed to completely cross 3 factors: sinkability of material (dense: metal and clay; *not dense* : plastic and wood), size/weight (small and light: large and heavy) , and object type (ball: spoon). See Figure 1. Children could make judgments based on any of these 3 regular properties. After seeing each object placed in water, each child judged for each object, one at a time, whether it would float or sink. After each judgment, the object was again placed in water, giving the child *feedback* about her/his response. The set of eight objects was judged twice, for a total of 16 responses per subject. Following their participation in the study, each child was asked why they thought objects sink or float in water.

Number of correct predictions showed that 5 year-olds performed almost perfectly and better than 3 year-olds (mean 1.2 errors for 5 year-olds: 2.4 errors for 3 year-olds: $F = 6.83$. $p < .05$. d.f. = 15). Eight 5 year-olds and three 3 year-olds performed non-randomly, judging at least 12 out of 16 trials correctly ($p < .05$. binomial test).

Further. performance improved reliably during the second set of trials (mean difference 0.8 errors for 5 yr-olds: 0.75 errors for 3 yr-olds: comparison across trials $F = 8.79$, $p < .01$. d.f. = 16). suggesting that both the 3 and 5 year-olds learned something about which objects sink and float during the first trial set.

Of course. some of the high level of performance could be due to the testing procedure : since children actually saw each object placed into water prior to test trials, they could have simply memorized which ones floated and which sank. However, memory effects cannot explain error patterns.

The children's errors were not linked to object type, size. or absolute weight. See Figure 2. However. there were some indications that substance might have been a factor: more errors were made on wood than metal objects ($t = 1.56$. $p < .07$, d.f. = 14). with particularly large number of errors on the heaviest wooden object.

One particularly intriguing possibility is that the large number of errors on this object was due to the child taking into account the object's weight for its substance. In fact, judgments based on apparent substance alone are inadequate: ebony wood is a wood, looks like a wood, but sinks. Further, absolute weight is, of course, inadequate: "heavy" large pieces of wood float, and so do battleships.

Recall that the children's errors in this experiment were not linked to absolute weight. The most frequent errors were made on the absolutely heaviest wooden object (the large wood ball) and the absolutely lightest plastic object (the small foam ball). If errors were linked to <u>absolute weight</u> they would have to be clustered on one end, or perhaps the center of, the weight spectrum. If performance was linked to <u>relative weight</u> -- the weight of an object relative to its substance -- this would seem to indicate the core of a concept of density, as density is specified in terms of the weight of a particular volume of a substance relative to the weight of water in the same volume.

Therefore, in a second experiment, we asked whether children were likely to judge floatability by <u>substance</u>, <u>absolute weight</u>, or by <u>relative weight</u> (weight for substance,perhaps), while controlling for volume. Only relative weight would be consistent with true knowledge of density : judgments by substance alone would lead to problems with ebony wood, judgments by absolute weight would lead to predictions that pennies should float. But judgments by relative weight would indicate that subjects knew that they must take into account both substance and weight for a given volume.

In this experiment, subjects were asked to predict the floatability of a set of wooden objects and one of metallic objects given the behavior of a wood or a metal standard. In each of the two object sets, size and object type were constant while weight relative to a standard varied. Two sets of objects were constructed. See Figure 3.

In the wooden set, a 2" X 2" X 1 1/8" pine block of 44 grams served as the standard. The test series was then seven wooden blocks of the same size as the standard varying in weight from 27 to 69 grams. One block was identical to the standard. Two of the blocks varied both substance and weight, with one block made of balsa (27 grams) and one of oak (69 grams). Two blocks varied substance (balsa, oak) while keeping weight constant, by hollowing or weighting the blocks. And the last two blocks kept substance constant (pine), while varying weight -- one block was hollowed (35 g.), and one filled with lead weights (57 g.).

In the metal set a 2" X 2" X 3/4" aluminum block of 203 grams was the standard. The test series was seven metallic blocks of the same size varying in weight from 121 to 328 grams. Again, one block was identical to the standard, while 2 varied both weight and substance (plexiglass, 121 grams; steel, 329 grams). Two blocks varied substances, but not weight, and two varied weights but not substance, by weighting or hollowing aluminum (245 and 162 grams, respectively). All objects in the wooden set were capable of floating, while those in the metallic set would all sink if placed in water.

Ten Columbia University students were the adult subjects in the second study. Five 6 year-olds (mean age 6:3), and five 4 year-olds (mean age 4:8), participated as subjects in their homes. Four year-olds were given a pre-test to verify that they could use the words "sink" and "float" correctly.

Each subject was given the standard, and asked to place it in a basin of water. The standard was then taken out of the water and left in front of the subject, and the basin of water was removed. The subject then saw the 7 objects in the test series, (6 novel and 1 standard), and was asked to predict for each if it would sink or float. No feedback was given after the predictions. Each subject made predictions for each object twice, for each of the two object sets, for a total of 28 predictions.

Number of correct predictions showed that adults performed better than the children, with mean error scores of 0.6 errors for adults, 4.4 errors for 6 year-olds, and 5.2 errors for 4 year-olds, out of 28 trials. ($F = 8.83$, $p < .01$, d.f. = 2). The 4 and 6 year olds did not differ reliably from each other. The subjects high level of performance could in principle, be due to simple heuristics, such as "all wood floats" and "all metal sinks" -- since, in fact, these statements were true of our test objects. However, error analyses suggest both the children's and adult's knowledge went beyond these simple rules.

Both adults and children made the most errors on the same few objects. As seen in Figure 4, it was the heaviest wooden objects and the lightest metallic objects that gave all subjects the most difficulty. This result is particularly interesting because the two weight distributions do not overlap. Therefore, subjects are not making a judgment based on absolute weight, or on a simple substance-based rule..

Seven of the ten adult subjects showed perfect performance. This indicates that adults accept a range of densities within which objects will float or sink. That is, not everything that floats must be as light as a feather. Although they made more overall errors, the children showed quite similar responses to the adults. In particular, cases which near the boundary between floatability and sinkability seem to create problems for adults and children. For example, when an object made of wood is excessively heavy for its volume (compared to the standard), more errors occur -- that is, the subject judges the object to sink even though it really floats. Similarly, when a metal object is excessively light for its volume, the subject judges the object to float even though it really sinks.

Many children spontaneously offered rules of the sort, "all metal things sink", but they only obeyed these rules with the most "prototypic" objects : the lightest, wooden objects, and the heaviest metallic objects were always judged correctly, while the heavy wooden and light metallic objects elicited the most errors.

This relativizing of weight can be seen in an analysis of errors across object type -- most errors occured on "abnormal" objects : those which weigh much more than the wood standard for the same volume (very heavy wood), or much less than the metal standard for the same volume (very light metal). Performance is perfect for all age groups on "super-normal" objects : very light wooden objects, or heavy, metal ones. ($F = 33.5$, $p < .01$, d.f.= 2,18, no errors on "super-normal" objects, few errors on "normal ones, many errors on "abnormal" objects).

In sum, children did not perform randomly in judgments of whether objects made of different materials sink or float. In the first experiment, they indicated a sensitivity to substance, with high accuracy in their judgments for objects made of metal, and errors not tied to size or absolute weight. However, a large number of errors occured on especially heavy wooden objects, suggesting a possible relativizing of weight for substance underlying these judgments.

In the second experiment, all subjects showed that neither absolute weight nor "absolute substance" was the basis for floatability judgments. Rather, they seemed to be taking into account an object's weight within a normal range for objects made of that substance. The errors on this task suggest that subjects should be quite accurate in rather counter-intuitive, odd, real-world cases: they should correctly judge that ebony wood sinks, even though it's a wood, and that tin foil floats, even though it's metal. This seems to be evidence for at least the rudiments of an independent concept of density that does not depend on simple heuristics, such as, "all wood floats", or prior, perhaps simpler concepts, such as weight.

Experiment 1 : Stimulus Set

	Floating Materials (Wood, Plastic)	Sinking Materials (Metal; Clay)
Small, Relatively Light Objects (1" in diam., x < 4" long 16g>x>0.9 g)	Plastic Spoon (1 gram) Foam Ball (1 gram)	Metal Spoon (3 grams) Metal Ball (15 grams)
Large, Relatively Heavy Objects (3-4" in diam. x > 5" long 215g>x>12g)	Wooden Spoon (13 grams) Wooden Ball (66 grams)	China Spoon (39 grams) Clay Ball (214 grams)

Figure 1

Results : Experiment 1

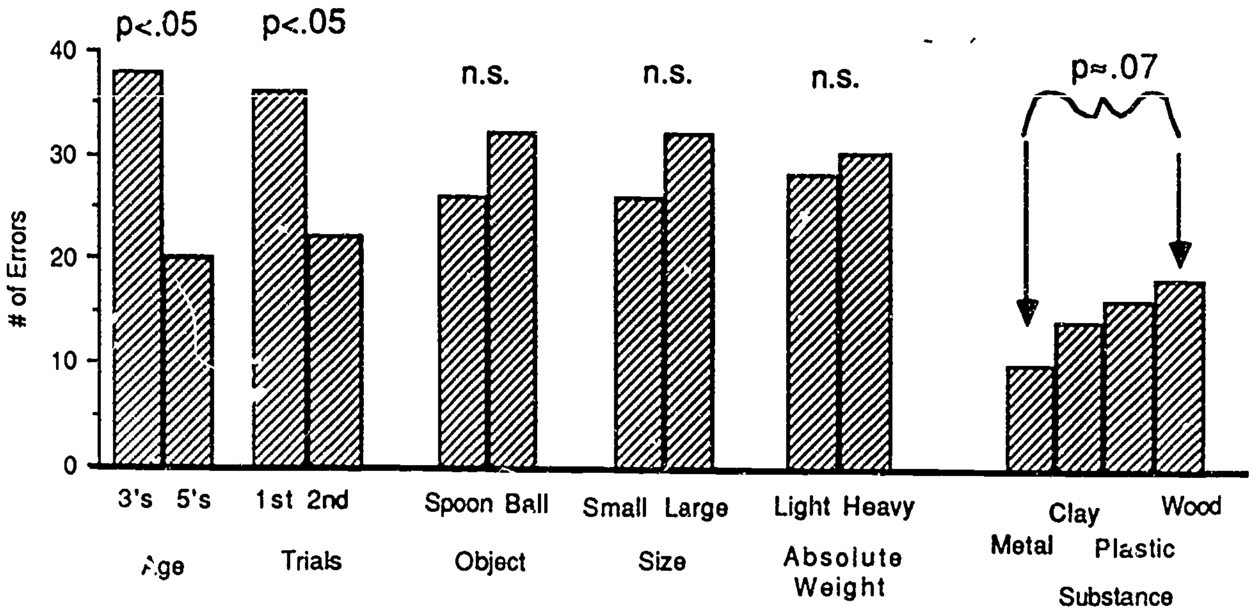

Figure 2

Experiment 2 : Stimulus Set

	Wooden Objects (all float)			Metallic Objects (all sink)		
Substances differ Weights differ	44 grm standard pine	27 balsa	69 oak	203 standard aluminum	121 plexiglass	329 steel
Substances differ Weights equal	47 weighted balsa	46 hollowed oak		196 weighted plexiglass	203 hollowed steel	
Substances equal (apparently) Weights differ	35 hollowed pine	57 weighted pine		162 hollowed aluminum	245 weighted aluminum	

Figure 3

Results : Experiment 2

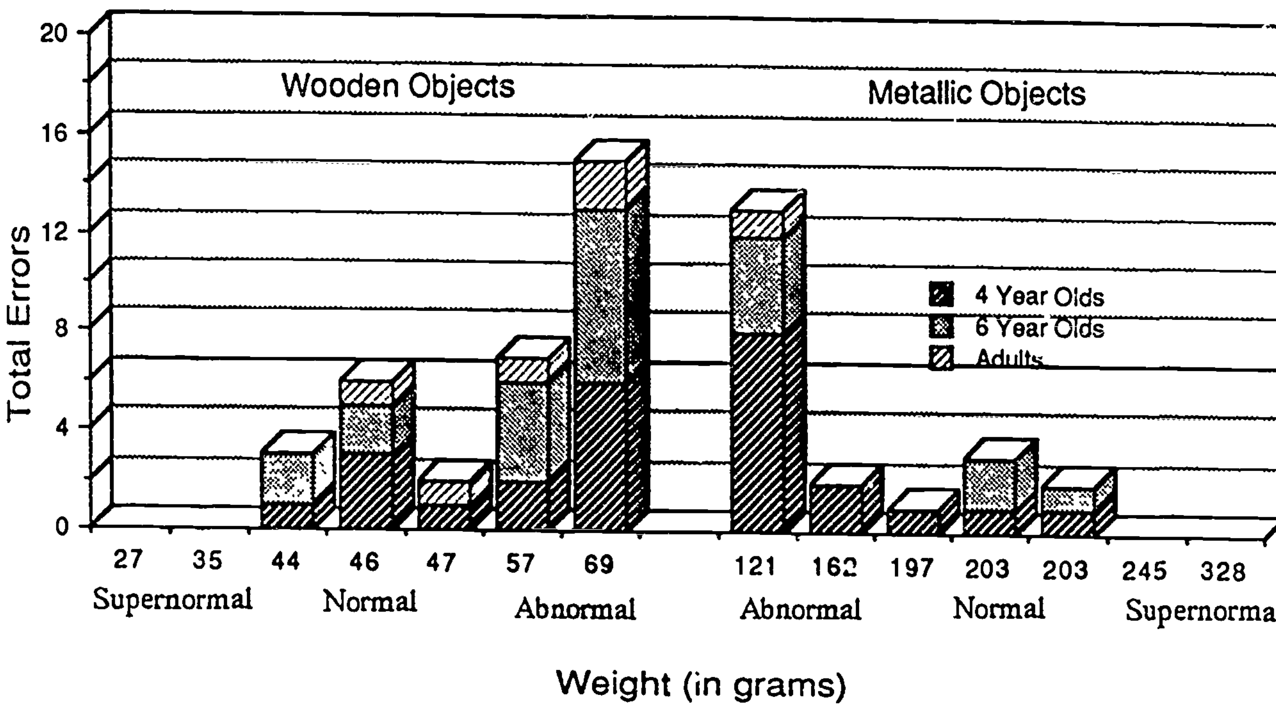

Figure 4

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