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COGNITIVE DEVELOPMENT

Providing impetus for conceptual change The effect of organizing the input

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Abstract

This study was designed to test whether calling to mind an initial belief and presenting information that challenges that belief affects the extent to which preschoolers will modify it. The belief that was challenged in a controlled demonstration concerns the effect of the size of an object on its sinking speed (holding weight constant). In addition, children's belief about the effect of weight on sinking speed (holding size constant) was examined, a belief that was confirmed in a demonstration. The final belief about size for those who received nothing but empirical demonstrations was less likely to be compatible with the demonstration than the final belief of those in two other conditions. Children in the other conditions were given the opportunity in the context of interviews to form expectations about how size and weight separately relate to sinking speed, in addition to receiving the demonstrations. An interview either directly preceded the demonstration for the variable concerned (coordinated sequence) or did not (uncoordinated sequence). The tendency for the final belief about size to be compatible with the demonstration was related more strongly to age in the condition with an uncoordinated sequence than in either of the other conditions. Some children among those whose final belief about the effect of size on sinking speed was compatible with the demonstration also refined their belief about the effect of weight, suggesting that these two beliefs may cohere as a system. These findings show that a relatively short experimental procedure can be an effective means of bringing about some refinement of a young child's beliefs. © 2001 Elsevier Science Inc. All rights reserved.

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1. Introduction

Changes in people's knowledge are the focus of interest in studies (1) of cognitive development (Carey, 1985, 1991; Karmiloff-Smith & Inhelder, 1974/75; Penner & Klahr, 1996; Smith, Carey, & Wiser, 1985), (2) of the process of becoming an expert (Gobbo & Chi, 1986; Solomon, 1997), and (3) of scientific and causal reasoning (Brewer & Samarapungavan, 1991; Kister-Kaiser, McCloskey, & Proffitt, 1986; Koslowski, 1996; Levin, Siegler, & Druyan, 1990; Schauble, 1996; Wiser, 1988, 1999). In recent empirical work, the emphasis has been on domains of knowledge that are defined in a relatively narrow way (biology, e.g., Carey, 1985; Springer, 1995; astronomy, e.g., Brewer & Samarapungavan, 1991) and somewhat less on systems of thought that might apply generally (Inhelder & Piaget, 1958; Piaget, 1985). Regardless of what the exact focus of a study or a theoretical approach might be, there are two central issues in the study of change. The first is the question of what might provide an impetus for change and the second is the question of what forms change might take.

Before dealing with these two issues, it is necessary to specify the kind of knowledge under investigation. Knowledge could refer to something as broad as a whole system of beliefs in a domain (e.g., folk biology or naive physics) or to something as specific as preschoolers' knowledge of how to balance one kind of object on another (Karmiloff-Smith & Inhelder, 1974/75). A simple conceptual structure that might be found in young children is some kind of expectation about how differences between objects are linked to differences in outcome events. For example, Sodian, Zaitchik, and Carey (1991) found that first and second graders understand the link between the size of an aperture and whether an animal of a particular size will pass through it. Kohn (1993) found that preschoolers understand the link between the density of an object and whether the object will float or sink. Even infants in their first year are sensitive to regularities in physical phenomena such as the differential tendencies of objects with distinct properties to rise and fall in a tube (Schilling & Clifton, 1998). Such links between the properties of objects and the outcomes of events may be based on a systematic drawing together of everyday experiences and they need not involve any formal understanding. The term belief will be used to refer to this kind of systematization. A belief can be expressed in words but also can be inferred from a set of actions or predictions on the part of a child (or adult) that follows a pattern.

Although it may generally be accepted that young children and even infants systematize information, little attention has been given to the question of how their systematizations may change in the face of new information. This study was designed to investigate how young children's beliefs within a scientific domain may change when they are not compatible with new observations. How change comes about in preschoolers' beliefs is a topic of lively debate for the biological domain (e.g., Johnson & Solomon, 1997; Springer, 1995, 1996), but, to our knowledge, the investigation of changes in knowledge in the physical domain has, with few exceptions (e.g., Karmiloff-Smith & Inhelder, 1974/75;

Smith et al., 1985), been limited to children much older than preschoolers (e.g., Penner & Klahr, 1996; Schauble, 1990, 1996; Wiser, 1988).

1.1. Calling to mind beliefs as an impetus for change

The first question underlying the design of this study was that of what might provide an impetus for conceptual change in children of preschool age. The idea tested was that a procedure requiring a child to call to mind an existing belief before being exposed to unexpected information might foster some form of change in the belief. Similarly to the effect of semantic priming (Meyer & Schvaneveldt, 1971), calling to mind a belief ahead of a child's encounter with the information itself may help the child to ignore irrelevant information. It may open the possibility of detecting a meaningful pattern in new information. This framework can be useful as a basic infrastructure for dealing with new evidence and thus set the stage for a new interpretation of the data.

The effect of calling to mind a child's existing conceptions before supplying new information has been investigated in early studies of cognitive development (e.g., Inhelder, Sinclair, & Bovet, 1974) and has played an important role in studies concerned with education in science (Guzzetti, Snyder, Glass, & Gammas, 1993; Smith, Snir, & Grosslight, 1992). The results of studies using this kind of approach are mixed. After carrying out a metaanalytic review of instructional interventions from science education, Guzzetti et al. (1993) concluded that, overall, the procedure of calling to mind existing conceptions before giving instruction has been more successful for inducing change than other procedures. For example, in one of the studies that the review covered, it was found that 15-year-old students who were exposed to formal instruction following an interviewing session designed to evoke their starting conceptions performed better after instruction than did the students in an instruction-only condition (Hewson & Hewson, 1983). However, some recent studies in which children's preconceptions have been called to mind have not found evidence of firm conceptual progress in response to information that should challenge the preconceptions. It sometimes has been found, for example, that older children and adolescents tend, when they encounter disconfirming information, to ignore that information or reinterpret it in a belief-supporting manner (Schauble, 1990, 1996; Wiser, 1999). Similarly, Penner and Klahr (1996) found that 10-, 12-, and 14-year-olds do not make good use of unexpected outcomes, neither exploring them through further experimentation nor altering their beliefs in light of the outcomes.

There are at least two factors that could account for the divergent findings regarding the effects on conceptual change of calling to mind existing conceptions before providing new information. In the first place, the usefulness of calling to mind a belief in terms of providing an organization of information may depend on the degree to which the new information is connected to the child's expectation (or belief) that is called to mind. In Hewson and Hewson's (1983) study, the new information was explicitly linked to the students' existing conceptions through a procedure in which an adult discussed the initial expectations and pointed out their shortcomings. At the conclusion of this procedure, children tended to have a more correct understanding than they had had at the outset. In Schauble's (1996) study, interviews about beliefs occurred at the beginnings and ends of experimental sessions but were not connected directly with the experimentation. With this procedure, the pattern found for beliefs that initially were faulty was one of changing back and forth.

The second factor is the amount of consolidation of the information presented to children. In Hewson and Hewson's (1983) study, the students participated in an extensive educational session in which there was consolidation of information gained from both empirical observation and formal instruction. Children in Penner and Klahr's (1996) study, on the other hand, were left free to choose what information to gather through experimentation and the focus was on the children's own approaches to the testing of hypotheses. Even children in the oldest age group (14-year-olds) in their study did not make good use of unexpected results that they obtained in their experiments. There was thus little evidence that children could consolidate for themselves the outcomes of separate tests and their implications. In the procedure used by Schauble (1990), interviews about the children's beliefs were coordinated to some extent with the experiments that the children carried out and there were repeated sessions in which children had the opportunity to consolidate the two. Schauble found some improvement across the sessions in children's ability to revise their beliefs appropriately, including improvements in their abilities to design well-controlled experiments, and to draw valid inferences.

1.2. Forms of change

The second question regarding conceptual change refers to the forms that change might take. Knowing that incoming information is organized in a particular way is not sufficient to specify the exact impact that the information might have. Two different levels can be distinguished at which the new information can have its impact: the level of a single belief and the level of a system of beliefs.

A change in a belief considered on its own could mean the abandoning altogether of the belief or simply the refining of it. Abandoning a belief altogether means, for example, deciding that a variable previously considered relevant to an outcome is in fact irrelevant. Achieving this kind of insight has been shown to be difficult for children and adults (e.g., Inhelder & Piaget, 1958; Kuhn, Amsel, & O'Loughlin, 1988; Schauble, 1990; Somerville, 1974; Tschirgi, 1980). For example, children younger than adolescents typically do not conclude from experiments that, contrary to their expectation, the magnitude of the weight on a pendulum is irrelevant to the period of oscillation (Inhelder & Piaget, 1958; Somerville, 1974). Refining a belief, on the other hand, seems likely to be a more common process in conceptual change than complete abandonment of a belief.

This kind of change means adjusting only part of the belief to fit the new information rather than overthrowing it completely. With regard to beliefs about the physical world, it could mean, for example, reversing the direction of an expected relation between a variable and an outcome. In this study, the refinement rather than the abandoning of a belief is investigated.

Beliefs are unlikely to exist in isolation (cf. Murphy & Medin, 1985; Strike & Posner, 1992). Instead, it is reasonable to assume they are interrelated in networks. Information that disconfirms one belief could fail to lead to a change in that belief if the new belief would be incompatible with other already existing related beliefs. For example, students in a study conducted by Wiser (1988) may not have profited from disconfirming evidence because they were starting out with an entire framework that would have had to be abandoned in order for them to acquire a correct understanding. In our study, the new information presented to children went beyond a single belief and had relevance to children's broader understanding of how two variables affect an outcome.

1.3. Overview of the study

We set out to investigate conceptual change at the level of refinement of a belief that, potentially, is linked with a second belief. Each of the two beliefs concerns how differences in a variable are related to differences in an outcome. As the outcome event, we used the sinking speed of objects in water, as did Penner and Klahr (1996) for older children. The behavior of sinking objects is contingent upon complex interactions among forces that result in different sinking accelerations (Daily & Harlemann, 1966). In this project, the effects of only two of the relevant characteristics of objects were investigated: size (strictly speaking, volume; however, in our case, variations in volume were created by changing height alone) and weight (strictly speaking, mass). Size and weight do not have independent effects on sinking speed. Instead, it is the ratio of one to the other (i.e., the density of an object) that determines sinking speed. However, in this project, one of the variables (either size or weight) was always kept constant when the effect of the other variable was explored. Additionally, the beliefs relating size and weight to sinking speed presumably are not the only beliefs about the sinking of objects that are held by young children. It is likely that children also consider such aspects as the shape and material composition of objects to have an effect on sinking speed (Kohn, 1993; Penner & Klahr, 1996). The simplifying steps of incorporating only two variables and investigating the effects of each on sinking speed in the special case when the other variable is held constant allowed us to investigate change in a precisely controlled setting.

The beliefs about how size and weight relate to sinking speed are likely to interconnect and thus form a system. The reason for this is that children may hold beliefs about how the two variables, size and weight, are related to each other, independently of their relation to an outcome. It has been shown empirically that children expect size and weight to covary (Hauer, Mounoud, & Mayer, 1981).

Such an expectation is likely to constrain the two beliefs about how size and weight are related to a given outcome, setting up a system of nonindependent beliefs. In such a system, children should expect information about size to be interchangeable with information about weight. Indeed, Halford, Brown, and Thompson (1986) found that 7–9- and 11–13-year-olds who were encouraged to discuss why blocks placed in water would float or sink gave weight explanations even on problems in which the blocks varied only in volume. Furthermore, children should expect size and weight to correspond in their effects on outcomes of events. Indeed, in a pilot study that we conducted, the participating preschoolers ($n = 19$) expected that both increasing weight (while holding size constant) and increasing size (while holding weight constant) would result in greater sinking speeds of the objects. In this study, we presented to children information that challenged that particular size–sinking speed link and confirmed that particular weight–sinking speed link. Through this procedure, children were confronted with disconfirming information, firstly on the level of a single belief (size being negatively rather than positively related to sinking speed) and secondly on the level of a system of beliefs (size and weight having opposite rather than parallel effects on sinking speed).

As a means of investigating how calling to mind an existing belief may provide an impetus for change, several features were incorporated into the procedure. Firstly, children were not asked for verbal statements of their initial beliefs nor were those beliefs discussed explicitly. Instead, children were asked to predict, in interviews, how a difference in the magnitude of a single variable (either size or weight) would be related to a difference in the magnitude of the outcome (sinking speed). Secondly, the new information about how differences in size or weight relate to differences in sinking speed was not specifically pointed out or formally taught. Instead, children were instructed to watch sets of demonstrations and “see what happens,” this procedure mirroring children’s experience gained outside an experimental context. However, to ensure their taking in of the new information, children had to confirm the outcome of each demonstration. Thirdly, in order to manipulate the degree of match between existing belief and new information, the two components, the calling to mind of the belief in an interview and the empirical demonstration, were coordinated differently in each experimental condition. In the *Coordinated Interview and Demonstration* condition (CID), the belief called to mind immediately before the demonstration referred to the same variable as the demonstration. In contrast, in the *Uncoordinated Interview and Demonstration* condition (UID), the belief called to mind and the immediately ensuing demonstration did not refer to the same variable. Rather, one referred to size and one to weight. In the *Demonstration Only* condition (DO), serving as a control, no variable was addressed and children just received the demonstrations (one for size and one for weight).

Finding a greater degree of refinement of belief in the CID and UID conditions than in the DO condition would support the claim about the impact on conceptual change of providing a structure that serves to organize new information and link it with existing beliefs. Finding a greater degree of refinement of belief in the CID than the UID condition would support the claim that, to be taken in and used effectively by a child, a demonstration must immediately follow the calling to mind of the belief on which that demonstration has a bearing.

2. Method

2.1. Participants

The participants were 48 preschoolers, 30 boys and 18 girls, with an age range from 3 years 10 months to 6 years 3 months. The median age was 5.0 years (i.e., 60 months), the mean ages for the three conditions (CID, UID, DO) in months being 59.1 (S.D. = 8.2), 61.0 (S.D. = 7.7), and 60.0 (S.D. = 7.9), respectively. In each condition, there were 10 boys and 6 girls. Three additional children (a 4-year-old girl and 4- and 5-year-old boys) did not meet the consistency criterion in one of the interviews (see Procedure). They were not included in the experiment.

In the two interview conditions (CID and UID), we were able to assess children's initial beliefs about how size and weight are related to sinking speed.[1] On the basis of pilot results, we expected that children would consider both relations to be direct (akin to a positive correlation). However, five children (two from the CID and three from the UID condition) did not respond as expected in the interviews. When given a pair of objects and asked to pick the object that would sink faster, they (1) consistently picked the smaller one, (2) consistently picked the one with fewer weights, or (3) both (see Appendix A). Nevertheless, these five children were included in the experiment to avoid any selection bias that might make the CID and UID groups not comparable to the DO group.

2.2. Materials

For the interviews, colored pictures of objects, referred to as toy submarines, were used. They were glued onto cardboard and laminated. A red hatch (3 × 5 cm oval) was taped onto each submarine and could be lifted up. It completely covered a variable number of black spots (diameter = 1 cm) referred to as "weights" (see Fig. 1). The submarines in the pictures differed either in their overall area (ranging from ca. 30 to 90 cm^2) or in the number of weights under the hatch (ranging from one to five weights).

For the demonstrations, a tall glass tank (60 × 30 × 100 cm) filled with water was used. A "finishing line" was marked horizontally at the bottom of the tank

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[1] Children in the DO condition were not asked for predictions, so there was no possibility of determining the initial beliefs of that group of children.

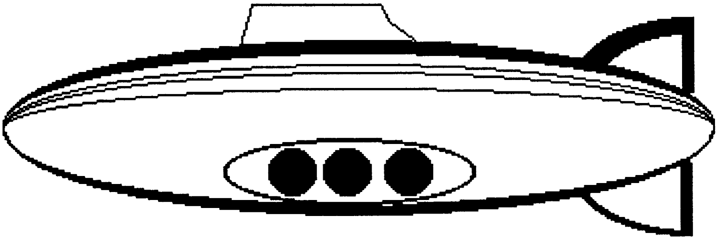

Fig. 1. An interview picture with the hatch uncovered and containing three weights.

so that the faster submarine could be identified as the first to hit the line. The submarines were modified baby-food jars of one of three heights (ca. 4, 6, and 8 cm). A glass wall divided the tank into two racing lanes. To create units of weight, 3 cm high sticks, each covered with a black pencil pillow,[2] were used. Each toy submarine was capable of holding two, three, or four units of weight. For the faster submarines, the material of the sticks was steel, whereas for the slower ones, it was wood. This manipulation of the material composition of the sticks made it possible to obtain a sizeable difference in sinking speed within each racing pair. The units of weight were stuck by means of Velcro onto a round piece of lead glued to the lid of the jar. The lead was needed to prevent the jars from floating in the water.

In conjunction with the toy submarines, two sets of pictures (one for size and one for weight) were used in the demonstrations. The pictures in the set that captured differences in size were laminated cutouts that resembled the actual jars. Weight was captured by laminated cutout circles (diameter = 3 cm) with round spots (diameter = 1 cm) resembling the arrangement of the actual units of weight (see Fig. 2 for an example of a picture of each set). For the final test, these sets were expanded to five levels comprising three levels that matched the levels used in the demonstration and two additional intermediate levels.

2.3. Procedure

Children were tested individually in a quiet room at their preschool. The session lasted approximately 30 min and was conducted by two experimenters (E1 and E2) who were familiar to the child. It consisted of demonstration procedures for both size and weight, combined in different ways with the interviews for children in the CID and UID conditions. Children in the DO condition had the same demonstrations without interviews. The order of the demonstrations was counterbalanced by giving half of the children in each

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[2] Pencil pillows are small tubes made out of soft rubber (designed to help young children to hold a pencil in a comfortable way). They were used in this study to make it appear that the units of weight consisted of uniform material.

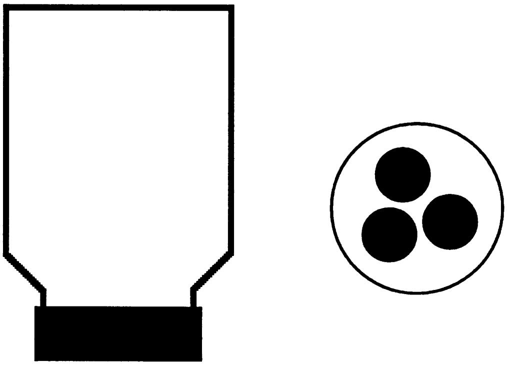

Fig. 2. An example of a jar picture and of a circle (the one with three spots) used in the final test.

condition the demonstration for size first and for weight second and using the reverse ordering for the other children. The sessions were recorded on audiotape.

2.3.1. Familiarization

First, the tank and the idea of a submarine race were introduced. If necessary, it was explained that a submarine is a special kind of ship that can go under water. With the help of E1, each child built two submarines, making use of a pair of middle-sized jars holding three weights each. E2 dropped this pair in the water demonstrating that the outcome of the race was a tie (time to reach the finishing line: ca. 1.60 s). Next, children heard the following instruction:

> These two submarines tied in their race, but we want to have a race with a winner and a loser submarine. In the end, E2 will design a submarine and we need to design one that goes faster than her submarine. But in order to do that, we need to find out the rules that tell us what makes a submarine go faster. For this reason, we will watch some races. Can you help me find out the rules telling us what makes a submarine sink faster?

2.3.2. Interview

The five interview pictures (see Fig. 1) were lined up in a random order. As a first step, children were required to name the relevant variable (either size or the number of dots under the hatch). If necessary, the experimenter provided help by putting the two extreme ones next to each other. Secondly, children were required to order the pictures according to this variable. Maximally two prompts designed to help were given: The experimenter picked out the picture at one extreme and, if necessary, the next one, asking the child each time to find the picture, which would go next. All children succeeded in ordering the pictures correctly.

Then, children were asked: "If we could sink all five submarines, do you think they would all sink at the same speed or do you think they would sink at different speeds? Why do you think so? Which one will go fastest?" Children were then presented with a pair of two nonadjacent pictures selected from the five and asked, "If we sink these two submarines, which one will go fastest?" Two other pairs followed and, in each case, children were asked the same question. To be included in the study, children were required to be consistent in answering three consecutive questions (i.e., consistency criterion). Consistent responding served to indicate that children based their judgments in the task on their belief about the variable in question. Children who did not meet this requirement after five questions were excluded from the study (see Participants).

2.3.3. Demonstration

As a way of introducing the submarine race, children were told: "Let us see how the submarines sink in our tank. Let us see if we can find out the rules telling us what makes these submarines sink fast." Six races in each demonstration session were presented in a random order. The winner submarine was always either the smaller or the heavier of a pair (which did not differ on the other variable). After each race, children were asked to point to the winner of the race (i.e., the object that had reached the finishing line first) and also to choose from a pair of pictures representing the two submarines in the race the picture of the "winner." This procedure made it possible to find out whether children had grasped the outcome of the race and also whether they appreciated the correspondence between pictures of the kind to be used later in the test phase and actual jars. A race was repeated, once, on the rare occasions when a child was not able to indicate correctly the winner of the race, by both pointing to the correct jar and choosing the correct corresponding picture. No child who had failed after the first demonstration failed a second time.

2.3.4. Final test

After having participated in both demonstration sessions, a child was enlisted to act as a submarine designer. The test comprised 11 trials and was carried out with pictures (see Materials). For nine of the trials, there was a standard submarine and the child's task was to choose from an array of parts and design a submarine (i.e., the critical submarine) capable of either winning (in $n=6$ trials) or losing (in $n=3$ trials) in a race against the rival submarine (i.e., the standard). Children were given three options for one or both variables to complete the critical submarine. The options consisted of (1) the level of the standard submarine, (2) a higher level, and (3) a lower level, chosen from sets of five (one set for size, another for weight). The levels for the standard submarine and the correct critical choice varied systematically across the nine trials so that no particular pairing of a standard and a correct critical choice occurred more than once. On six of these nine trials (three for weight, three for size), a child made a choice for just one variable, with the value of the other variable already specified as that of the standard. For two of these six trials (one for size, one for weight), the child had to design a loser submarine. On the other three of the nine trials that had a standard submarine, a child first made a choice for one variable (e.g., size, determined randomly on each trial for each child) and then made a choice for the other variable. For the remaining two trials, there was no standard submarine and the arrays of options given to the child consisted of all five levels for each variable. The child was asked on one of these trials to choose, first for one variable (determined randomly) and then for the other, in such a way as to make the fastest possible submarine. On the other of these trials, the child was asked to choose to make the slowest possible submarine. The 11 trials were presented to the child in one of four different orders (two random orders and their reverses). The procedure of asking children, throughout these trials, to make a choice for one variable at a time allowed us to determine beliefs about the effect of size on sinking speed separately from beliefs about the effect of weight.

3. Results

The two main questions of interest in this study are what might provide an impetus for change in children's beliefs and what forms such changes in beliefs might take. The results will be reported in two sections addressing those questions. In the first main section, the effects of condition on beliefs about the effects of size and weight, considered separately, are examined. In the second main section, beliefs about size and weight are considered together, as a system, and the tendency for one belief to change as a function of changes in the other is assessed.

3.1. Refining beliefs as a function of condition

3.1.1. Scoring

Children's responses in the final test were scored according to their compatibility with the relevant demonstration. On trials when the child was asked to design faster submarines, the compatible answer was to choose the smallest or the heaviest option (and the largest or the lightest on trials when the child was asked to design a slower submarine). An answer compatible with the relevant demonstration was scored $+1$, and an answer incompatible with that demonstration was scored -1. A choice of the medium level of size or weight (i.e., matching the standard) was scored 0. Choices of the intermediate levels (for the two trials with no standard submarine) were scored $+0.5$ or -0.5, depending on compatibility.

To examine the comparability of scores obtained in the various test trials, we conducted two 3×3 ANOVAs (Types of trial: standard and choice for one variable, standard and choice for two variables, and no standard and choice for two variables; Condition: CID, UID, and DO), one for size and one for weight. There was no significant main effect of type of trial for size (*M*'s $= -0.22$, -0.24, and -0.27, respectively) or for weight (*M*'s $= 0.37$, 0.38, and 0.46, respectively) and there was no significant interaction of trial type with condition.

Because performance across trials of different types was comparable, for each variable, in the main analyses two overall scores were used for each child, one capturing performance on size (i.e., *size score*) and the other performance on weight (i.e., *weight score*). These scores were averages across the eight relevant trials, for each variable, ranging between $+1$ and -1.

As a basis for interpreting children's final beliefs in the three conditions, it was assumed that prior to seeing a demonstration children would have had a size score of -1 (incompatible with the demonstration) and a weight score of $+1$ (compatible with the demonstration). To the extent that the demonstration about size was effective, children's scores on that variable after the demonstration should exceed -1. Weight scores below $+1$ would indicate a change of belief for that variable not justified by the demonstration.[3]

3.1.2. Preliminary analyses

In two preliminary 3×2 ANOVAs (Condition: CID, UID, and DO; Order: size demonstration first and weight demonstration first), one for size and one for weight, demonstration order was not found to have a significant effect on either the size score or the weight score, and no significant interaction of condition and order was found (for either the size score or the weight score). For all the following analyses, the scores were collapsed across order.

3.1.3. Effects of condition

In two one-way ANOVAs (one for size and one for weight), we tested two orthogonal contrasts. The first contrast compared performance in the CID and UID conditions combined with performance in the DO condition. The second contrast compared performance in the CID and UID conditions. Neither contrast was significant for the weight score. In the analysis for size, children's performance was significantly better in the conditions that had interviews as well as demonstrations (CID and UID conditions combined) than in the condition with demonstrations alone (DO condition; $F_{(\mathrm{CID+UID})/2\ \mathrm{vs.}\ \mathrm{DO}}(1,45)=5.26$, $\mathrm{Mse}=0.48$, $P<.03$). The difference between performance in the CID and UID conditions approached significance ($F_{\mathrm{CID\ vs.\ UID}}(1,45)=3.57$, $P<.07$), higher

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[3] Note that 5 of the 32 children did not perform in the interviews according to the predicted initial beliefs (see Participants). Thus, the scores for the final test do not perfectly reflect change. However, using final test scores is preferable to using change scores for several reasons. The first is that change scores cannot be calculated for children in the control (DO) condition, who were not given initial interviews about the effects of size and weight on sinking speed. Comparisons involving the control condition thus could not be made using change scores. The second is that the interviews given to children in the CID and UID conditions did not assess children's beliefs in the same way as was done in the final test. Different materials were used and the child's task was to predict the winner of a submarine pair rather than to design a submarine that would be faster/slower than a standard. Furthermore, the interviews for the CID and UID conditions were used to screen out children who did not respond consistently (see Interview), restricting the range of performance in a way that did not apply to the final test.

Table 1

Mean size scores and mean weight scores for each condition with standard deviations in parentheses

	Performance	
Condition	Size score	Weight score
CID	0.15* (0.70)	0.28 (0.62)
UID	– 0.31* (0.78)	0.46 (0.63)
DO	– 0.56* (0.57)	0.46 (0.59)

$n = 16$ per cell. Scores range from -1 (incompatible with the demonstrations) to $+1$ (compatible with the demonstrations).

* $P < .05$.

scores being obtained when the interviews and demonstrations were coordinated (CID condition) than when they were not (UID condition). This suggest that children who were given demonstrations and interviews were more likely to modify their belief about the effect of size on sinking speed than children who received the demonstrations only, whereas their belief about the effect of weight did not change as a function of condition. The mean scores for each condition and each variable are given in Table 1.

3.1.4. Effects of age

Although it was not a central aim of the study to examine the effect of age or a possible interaction involving age, the difference across conditions in the relation between age and performance with respect to size is interesting. Fig. 3 displays the relation between age and size score in the form of regression lines, one for each condition. The slope for the UID condition is significantly greater than the slopes in both the CID and DO conditions ($t_{\text{CID vs. UID}}(28) = 4.91$, $t_{\text{UID vs. DO}}(28) = 6.62$, $P_s < .01$[4]) suggesting that, depending on condition, age and performance were related differently to one another. The tendency to profit from the demonstration showed a significantly greater relation to age when the demonstration was not coordinated with the appropriate interview (UID condition) than when it was coordinated (CID condition) or there was no interview (DO condition). This suggests that whereas the young children tended not to profit from the demonstration unless it was coordinated with the appropriate interview, with increasing age, children tended to profit not only when the demonstrations and interviews were coordinated but also when they were uncoordinated.

3.2. Refining the weight belief as a function of refining the size belief

An interesting finding pertains to children's final belief about weight. The demonstrations about the effect of weight confirmed children's initial belief

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[4] The formula for the t test comparing slopes of regression lines was taken from Cohen and Cohen (1983).

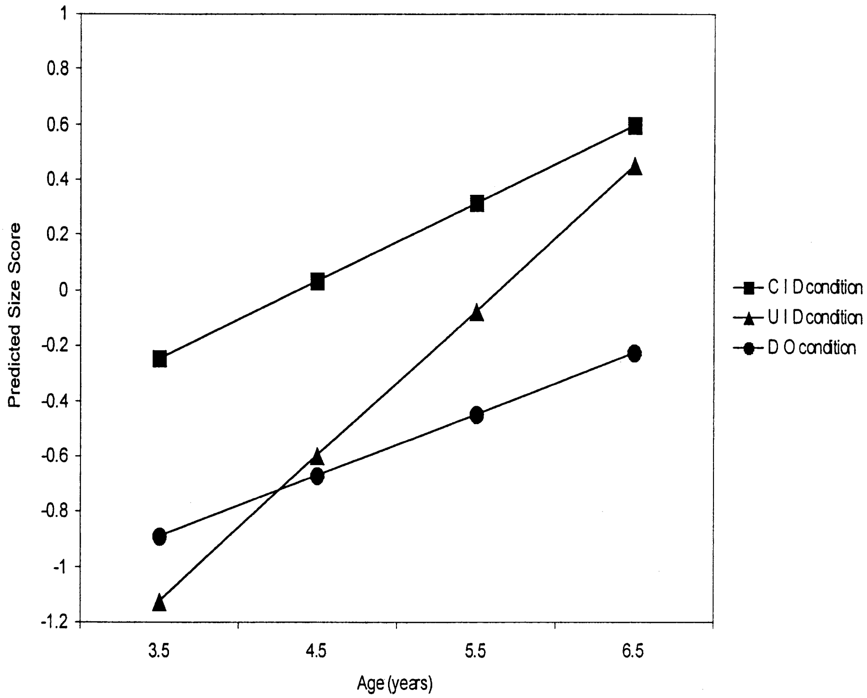

Fig. 3. Regression line predicting children's size scores from their age for each condition ($n=16$ per condition).

regarding how a change in the weight of an object should affect its sinking speed when the size of the object does not change. However, in the final test, some children's belief about weight was incompatible with the demonstration and there was some indication that a child's final understanding of how weight links to sinking speed was related to his or her final belief about how size relates to sinking speed. For example, one 6-year-old commented after being given the demonstration about the effect of size: "The smaller one must be heavier then." Another 6-year-old asked during the final test while she was looking for the units of weight to complete her submarine: "Do we have a zero? Because that would make it really fast!" The responses given by both of these children in the interviews indicated that they had started out with a conception regarding the effect of weight that was compatible with the demonstration.

To examine children's choices for weight and size in relation to each other, the weight and size scores were collapsed across all three conditions. A regression analysis showed the correlation between the two scores to be significant and negative ($r_{\text{size and weight}} = -.63$, $df=46$, $P<.001$). This finding suggests that some of the children who gave compatible answers for size may have been disadvantaged when it came to thinking about the effect of weight. A similar

Table 2
Frequency distribution for joint performance on size and weight for each condition

	Responders for size								
	Consistent (Cs)								
	Compatible (Cs+)			Incompatible (Cs −)			Inconsistent (Is)		
Condition	CID	UID	DO	CID	UID	DO	CID	UID	DO
Responders for weight									
Consistent (Cw)									
Compatible (Cw+)	**2**	**1**	0	**4**	**8**	10	2	2	0
Incompatible (Cw −)	**2**	**1**	1	**0**	**0**	0	0	2	0
Inconsistent (Iw)	2	1	0	0	1	2	4	0	3

Inconsistent responders, either for weight (Iw) or for size (Is), gave a consistent response in less than six out of eight trials. Consistent responses, either for weight (Cw) or for size (Cs), were either compatible (+) or incompatible (−) with the demonstrations. Values in bold collapsed across condition show a significant association (Fisher's Exact Probability Test, $P < .05$, two-tailed).

correlation was found for just those children in the CID and UID conditions ($r_{\text{size and weight}} = -.61$, $df = 30$, $P < .001$).

To explore this finding further, children's response patterns for size and weight in the final test were considered. Any child was considered a *consistent responder* (C) who was consistent in at least six of the eight trials for a given variable (size or weight; binomial $P = .04$, two-tailed, assuming a chance probability of making a particular choice on each trial of .33). Any other pattern characterized the *inconsistent responder* (I). The majority of children showed a consistent pattern of response (72.9% for both size and weight) and there was no difference according to condition (CID condition: 62.5% consistency for both size and weight; UID condition: 75% and 87% for size and weight, respectively). Further, the performance of the consistent responders was classified as either compatible (+) or incompatible (−) with the demonstrations. Table 2 displays the joint performance on size and weight for consistent and inconsistent responders in the form of frequency distributions.

To evaluate the extent to which children's final beliefs about the effect of weight are a function of their final beliefs about the effect of size, we considered only children who responded consistently in the final test and whose initial beliefs about the effects of size and weight had been assessed. Thus, all children from the DO condition and those from the other conditions who were classified as inconsistent responders for one or both variables were excluded. This approach has the advantage of drawing attention to children for whom we can be confident there was a change in their belief about weight. It can be seen in Appendix A that all children whose responses in the final test were consistent and were incompatible with the demonstration for weight (Cw −) had started out with a belief about the effect of weight that was compatible with the demonstration.

For the 18 eligible children, the frequencies were collapsed across condition (CID and UID) and a significant association between weight and size performance was found (Fisher's Exact Probability Test, $P = .04$, two-tailed). Thus, this analysis of consistent response patterns for children in the CID and UID conditions gives more precise information than the overall negative correlation between size and weight scores. It shows that there were some children among those whose final belief about the effect of size on sinking speed was compatible with the demonstration ($n = 9$; see Table 2), who refined their belief about the effect of weight. The impetus to refine their belief about weight could not have come from the demonstration about the effect of weight. Instead, children were found to refine their belief about weight if their final belief about size was compatible with the relevant demonstration.

4. Discussion

In our study, we investigated 4–6-year-old children's refining of a belief that is likely to be interconnected with a second belief. We considered the participants in our study to be starting out with two beliefs, namely, that the heavier of two objects would sink faster when size was held constant and that the larger of two objects would sink faster when weight was held constant. These two beliefs are assumed to be linked to each other through the overarching expectation that size and weight are correlated. Rather than leaving children free to explore a domain largely in their own way, as investigators have done in previous research (e.g., Karmiloff-Smith & Inhelder, 1974/75; Penner & Klahr, 1996; Schauble, 1996), we tailored demonstrations precisely to children's beliefs. The two demonstration sets shown to children revealed that (1) the heavier and (2) the smaller of two objects would sink faster (given that the other variable was held constant). Hence, the demonstrations relating to size, but not those relating to weight, were out of fit with the children's predictions. The results of our study provide evidence that changes in children's belief about size were a function of condition and changes in their belief about weight were a function of changes in their belief about size. Thus, the relatively short experimental procedure that we devised was, at least in some circumstances, an effective means of bringing about some change in a young child's beliefs.

4.1. Impetus for refining the size belief

Had empirical demonstrations running counter to what children would predict been enough to provide an impetus for change in a belief, children in all three conditions should have shown similar changes in their beliefs. However, the results of our study indicate that simply encountering new information is not sufficient to bring about refinement of a belief. Children who had nothing but the demonstrations (DO condition) showed significantly less change in their belief about size than children for whom an interview requiring them to predict the sinking speed of objects that differed (in either size or weight) was added to the demonstration of how the outcome relates to size (CID or UID condition, respectively). This aspect of our findings supports the claim that it is necessary to combine the calling to mind of a belief with empirical demonstrations that convey new information in order for that new information to take effect. The significantly greater relation of size score to age in the UID than the CID condition suggests, further, that a tight coordination of interviews with demonstrations may be essential if younger children, in particular, are to profit from new information and refine their view of how size relates to sinking speed.

It is unlikely that the interviews helped the children who had them simply to observe the outcomes of the demonstrations more accurately than the children who did not have interviews. All children correctly determined the outcome of each of the demonstrations. Hence, all children must have acknowledged at some level the information in those demonstrations. What additional support was added by presenting children with a sequence that had interviews as well as demonstrations? Support may have come, firstly, as encouragement to think in comparative rather than absolute terms and, secondly, through the organization of information in such a way as to make a contradiction apparent.

4.1.1. Encouragement to think in comparative terms

The demonstrations were conducted with objects that were introduced as being big, medium, and small and as holding two, three, or four weights. Under these circumstances and without having had a preceding interview, children's tendency may have been to code the information in absolute rather than comparative terms and link it with sinking speed (cf., Adams, 1978; Breslow, 1981; Sinclair, 1967; Somerville, 1974). In the test, however, children could not succeed by applying information that had been understood in absolute terms. This is the case because the pictures used in the test represented five levels for each variable. Two of the five were levels for which no correspondence had been established with the actual properties (size and weight) of the objects whose sinking speeds had been observed in the demonstrations.

Being required in the interviews to order schematic pictures and make predictions about specific pairs could have encouraged the child to concentrate on comparative information about the objects and sinking speeds rather than on their absolute values. This kind of interviewing procedure may have allowed children to learn something general about how the differences in sinking speed covaried with the differences between two objects that were compared in a race. For example, it may have allowed them to infer that the information conveyed in the demonstrations does not apply only to the objects used to demonstrate effects but also to general differences in size and weight. Children may have structured the information in such a way that it could bear on the effect of a variable rather than being construed as pertaining just to the exact objects that had been seen.

4.1.2. Making contradiction apparent to children

If the advantage of combining interviews with demonstrations were to reside solely its potential to encourage children to think in comparative terms, sequences following either the CID or UID structure would be equally effective in bringing about a change in belief. However, there is evidence in the comparison of the slopes of regression lines (size score on age) for the two experimental conditions to support the idea that, at least for younger children, the two types of sequence were not equally effective. Younger children showed a tendency to change the belief about the effect of size only when each interview was specifically tailored to the demonstration that followed it in the sequence (CID condition). A plausible explanation for this pattern of results is that older children may have come to the experiment with an understanding of the sinking speed domain in which beliefs about size and weight are more strongly interconnected than they are for younger children. If this were true, an interview about weight, for example, might call to mind for older more than for younger children, not only the belief about weight but also the connected belief linking size and sinking speed. An alternative explanation is that older children may be better able than younger children to hold in mind and reorganize the nonoptimal interview–demonstration sequence. As a result, they may succeed in linking the outcomes seen in the demonstrations with their existing beliefs (called to mind in interviews), even when the interview about size is not followed immediately by the demonstration about size. In either of these ways, the contradiction may become apparent.

One way to test which of these advantages holds for older children would be to compare younger and older children's performance in the original UID condition with that in a modified UID condition. The critical step in the modified UID condition would be to replace the belief about weight and sinking speed with a belief that is less likely to be interconnected with the belief about size and sinking speed (e.g., a belief that concerns the effect of shape on sinking speed). It is reasonable to assume that younger children would tend not to refine their belief about size in such a modified UID condition, just as they did not in the original one. A finding that older children refine their belief about size less in the modified than in the original UID condition would support the hypothesis that older children's beliefs about size and weight form a more strongly interconnected system in this domain than do younger children's. On the other hand, a finding that older children are equally successful in refining their belief about size in the modified and original UID conditions would speak for the hypothesis that as they get older children progress in their general ability to organize input.

4.2. Forms of change

To make good use of the information conveyed in the demonstrations, children had to learn that decreases in size, in the special case of objects not differing in weight, and increases in weight, in the special case of objects not differing in size, both lead to an increase in sinking speed. Thus, with regard to these special conditions, a child had to maintain his or her initial belief about the effect of weight but at the same time reach the conclusion that the effect of size is the reverse of the previously held belief. This insight was likely to run counter to (1) children's belief about how size affects sinking speed and (2) their assumption that size and weight have parallel effects on phenomena such as sinking speed.

As far as the size–sinking speed belief is concerned, our results suggest that that young children are able to adjust their belief in response to disconfirming evidence, at least under the supportive circumstances of the CID condition. Considering the system of beliefs in which size and weight are expected to correlate, we found indirect evidence that children had a tendency to preserve the coherence in this system. In the CID condition, even though the demonstrations were coordinated with their respective interviews, not all of the children refined their belief about the effect of size on sinking speed. Furthermore, several of those children who learned that bigger objects sink more slowly than smaller objects were then found to believe incorrectly that heavier objects are bound to sink more slowly than lighter objects. Both strategies allow a child to keep in mind the overarching belief about size and weight corresponding in their effects.

4.2.1. Changing a system of beliefs

Ideally, children in our study should have come to the conclusion that size and weight can have opposite effects on an outcome even though the two variables may be correlated. To understand this compensatory relation between size and weight, as far as their effects on sinking speed are concerned, children would have to abandon any system of beliefs in which the correlation between size and weight plays a generative role linking those variables to sinking speed as an outcome. They would have to understand that information about size is not interchangeable with information about weight but, in fact, must be coordinated with it to yield an accurate predictor of sinking speed. Children would need to grasp that the relating of weight to size is linked in systematic ways to distinct outcome phenomena. This insight would put them in a favorable position to develop a notion of density, given that density is defined as the ratio of weight to size.

4.2.2. Developing a notion of density

To develop a notion of density, children would have to understand that neither size nor weight, considered on its own, is predictive of phenomena that depend on density. They would have to grasp that two objects that differ in size and weight can have the same ratio of weight to size. We will consider possible ways in which our interview-plus-demonstration procedures might be adapted to help children become attuned to density. One necessary modification would be to use pairs of objects (submarines) that differ on both size and weight, instead of differing on just one or the other. Another modification would be to focus on races with a tied outcome for these objects, thereby challenging children's belief that outcomes differ according to simple differences in size or weight. In the interview, children would be asked to choose one of two objects, differing on both size and weight, with the aim of producing a tied outcome in a race against a third object (the standard). The third object would match one object of the choice pair in density but would match neither in size or weight. The interview would consist of several trials of this kind, involving a variety of choice pairs and standard objects. Demonstrations accompanying the interview would show children pairs of objects differing in both size and weight, sinking at the same speed.

Spinillo and Bryant (1991) tested young children's proportional judgments using a somewhat similar procedure. In one of their studies, 4–7-year-olds were shown two boxes that varied in the numbers of blue and white bricks they contained. The children's task was to judge which of the two boxes matched in blue-to-white proportion a smaller rectangular picture divided into a blue and a white section. The children were more successful on this task when the proportions of blue-to-white bricks in the boxes to be compared fell on either side of the "half" boundary (i.e., when the blue bricks filled less that half of one and more than half of the other box) than when they both fell on the same side of that boundary. Spinillo and Bryant's subsequent studies showed (1) that choosing between "half" and another proportion, greater than or less than half, was easier for children than choosing between two proportions lying on the same side of the "half" boundary and (2) that their results generalized to conditions in which the boxes of bricks to be chosen between were different from each other in absolute size.

Drawing on these results, the ratio of weight to size could be captured visually for children in a submarine task using transparent containers that hold blocks as weights. Children could be asked to choose between and to observe the sinking behavior of two submarines that differ in density in such a way that one is above "half" and the other below "half." After that, it would make sense to go on to interviews and demonstrations in which both densities are either above or below half. Procedures modified in these ways could be used to extend the information gained from our study about young children's beliefs, leading to an account of how a developing belief system might come to incorporate new ideas such as density.

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Appendix A. Frequency distribution for the performance in the interviews and the final test

	Patterns of responses in the interviews							
Patterns of responses	s − w +		s+ w +		s − w −		s+ w −	
in the final test	CID	UID	CID	UID	CID	UID	CID	UID
Cs+ Cw +	1	1	–	–	1	–	–	–
Cs+ Cw −	2	–	–	1	–	–	–	–
Cs − Cw +	3	8	–	–	–	–	1	–
Cs − Cw −	–	–	–	–	–	–	–	–
Cs+ Iw	2	1	–	–	–	–	–	–
Cs − Iw	–	1	–	–	–	–	–	–
Is Cw +	2	1	–	–	–	–	–	1
Is Cw −	–	1	–	1	–	–	–	–
Is Iw	4	–	–	–	–	–	–	–

In the interviews, children's performance was classified as being one out of four patterns of responses. They were determined based on whether children's belief's about size (s) and weight (w) were compatible (+) or incompatible (−) with the relevant demonstrations. The performance in the final test was classified as one out of nine patterns of responses. Children's performance for the variable size (s) or weight (w) could be either compatible (+) or incompatible with the demonstrations (−) and consistent (C) or inconsistent (I) across eight trials. For example, Cs + stands for consistent responses for size, compatible with the demonstration.

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