Knowing about Guessing and Guessing about Knowing: Preschoolers' Understanding of Indeterminacy

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FAY, ANNE LOUISE, and KLAHR, DAVID. *Knowing about Guessing and Guessing about Knowing: Preschoolers' Understanding of Indeterminacy.* CHILD DEVELOPMENT, 1996, 67, 689–716. In this article we investigate preschool children's understanding of indeterminacy by examining their ability to distinguish between determinate situations—in which the available evidence eliminates all uncertainty about an outcome—and indeterminate situations—in which it does not. We argue that a full understanding of indeterminacy requires the coordination of 3 processes: *search*, *evaluation*, and *mapping*. We describe 3 experiments aimed at discovering the extent to which these processes, each of which has been implicated in previous accounts of indeterminate reasoning, are developed in preschoolers and the extent to which different children organize the processes into different strategies. Experiment 1 examines 5-year-olds' performance on 1- versus 2-solution problems having different configurations of irrelevant information. Experiments 2 and 3 extend the possible sources of indeterminacy from 2 to 4 and vary the amount of consistent, inconsistent, and to-be-discovered evidence. Our results show that 4- and 5-year-old children readily give "Can tell" responses to determinate problems, as well as "Can't tell" responses when they think that the evidence warrants such a response. In addition, we report 2 new findings: (*a*) different children use different strategies to process *determinate* evidence, and these strategies, in turn, predict their performance on *indeterminate* problems; (*b*) evidence patterns in which a single positive instance is contrasted with 1 or more negative or unknown instances are particularly difficult to resolve. Many children use a decision rule—the Positive Capture rule—that produces consistent errors on this type of problem.

In this article, we investigate preschool children's understanding of indeterminacy by examining their ability to distinguish between knowing and guessing—between determinate situations in which the available evidence eliminates all uncertainty about an outcome or a cause and indeterminate situations in which it does not. Determinate situations can be either impossible or necessary, while indeterminate situations are neither. To what extent do preschoolers understand these conceptual categories, and how adept are they at mapping configurations of evidence onto them?

These questions are important because the ability to distinguish between determinacy and indeterminacy is fundamental to many problem-solving domains, including causal reasoning, decision making, and scientific discovery. In each domain, it is necessary to distinguish between situations in which evidence is sufficient for drawing conclusions and situations in which it is not. Piaget first addressed these questions in terms of the development of "possibility and necessity" (Inhelder & Piaget, 1958; Piaget, 1987). Piaget and his colleagues investigated children's ability to recognize when multi-

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ple alternative solutions were possible and when a single alternative was necessarily true. They concluded that these abilities begin to develop during the concrete operational stage but are not fully developed until the formal operational period.

Subsequent studies have provided a complex matrix of conceptualizations, empirical results, and theoretical accounts. The conceptualizations have proliferated terminological contrasts such as "possibility versus necessity," "possibility versus impossibility," "knowing versus guessing," "certainty versus uncertainty," and "sufficiency versus insufficiency." Each of these contrasts is related to the core concept of indeterminacy, but each has a slightly different emphasis.

The empirical results present a mixed picture because the differences in the types of problems used and the particular manifestation of indeterminacy under investigation have led to widely varying estimates of the age at which an understanding of indeterminacy is acquired. For example, in contrast to Piaget's conclusion that indeterminacy is fully understood only by the stage of formal operations, several investigators demonstrated that, when presented with simple and concrete contexts, children as young as 6 years old can distinguish between determinate and indeterminate problems (Byrnes & Overton, 1986; Falmagne, Mawby, & Pea, 1989; Horobin & Acredolo, 1989; Sodian, Zaitchik, & Carey, 1991; Wollman, Eylon, & Lawson, 1979). However, in tasks requiring the *generation* of such discriminating experiments, 9-year-olds perform poorly (Klahr, Fay, & Dunbar, 1993), and not until the age of 12 do children consistently distinguish between determinate and indeterminate situations in complex and propositional contexts (Acredolo & Horobin, 1987; Byrnes & Overton, 1986; Osherson, 1975; Piéraut-Le Bonniec, 1980; Scholnick & Wing, 1988; Wollman et al., 1979).

Although preschoolers have only a fragile understanding of the indeterminate nature of possibility, they are much better at identifying the determinacy inherent in *impossible* situations. For example, Braine and Rumain (1983) found that 5- and 6-year-olds were able to recognize a logical incompatibility and associate it with impossibility. Other studies have also shown that 5-year-olds can identify necessary and impossible events (Horobin & Acredolo, 1989; Somerville, Hadkinson, & Greenberg, 1979) and, to some degree, even 3.5-year-olds can discriminate between them in simple, action-based contexts (Fabricius, Sophian, & Wellman, 1987).

The theoretical accounts of children's understanding of indeterminacy have produced at least three different, but overlapping, interpretations. One account focuses on the development of children's ability to form equivalence classes, and their initial tendency to see some equally likely alternatives as more likely than others (Byrnes & Beilin, 1991; Horobin & Acredolo, 1989). Another focuses on children's bias toward determinacy (Braine & Rumain, 1983; Piéraut-Le Bonniec, 1980). The third theoretical account focuses on children's failure to fully understand the implications of the terms used to indicate relative certainty (Johnson & Maratsos, 1977; Johnson & Wellman, 1980; Miscione, Marvin, O'Brien, & Greenberg, 1978; Moore, Bryant, & Furrow, 1989; Perner, 1991; Ruffman & Olson, 1989; Wimmer, Hogrefe, & Perner, 1988).

An Information Processing Analysis of Indeterminacy Problems

In this article, we endeavor to reconceptualize previous accounts of preschoolers' understanding of indeterminacy in terms of three primary processes that are invoked in all tasks that assess indeterminacy: *search*, *evaluation*, and *mapping*. Our studies are based on the assumption that understanding indeterminacy requires the acquisition and coordination of these three processes, as well as their various subcomponents. We argue that, in order to correctly distinguish between determinate and indeterminate situations, children must *search* the task environment—attending to and encoding the relevant (and ignoring the irrelevant) information about the target and the sources of evidence, *evaluate* the encoding so as to create an internal representation of determinacy or indeterminacy, and, finally, *map* that representation onto the appropriate verbal response.

The search process iteratively attends to and encodes aspects of the task environment while creating an internal representation of the encoded features. It determines when it has sufficient information to terminate the attend-encode cycle. The evaluation process determines whether the encoded representation affords the selection of a unique outcome, or several equally satisfactory outcomes. Finally, the mapping process takes the result of the evaluation process and maps it onto one of several possible verbal responses. Our goal is to determine the extent to which these three processes are developed in preschoolers and the extent to which different children organize the processes available to them into different strategies.

Precursors of our three-process model can be found in the different emphases in the three theoretical accounts mentioned earlier. For example, Braine and Rumain's (1983) focus on decidability biases bears directly on children's search strategies, because such a bias would lead children to search among alternatives for *any* discriminating information, regardless of its relevance. This strategy would result in correct responses on determinate problems where the alternatives differ on the relevant dimension. Furthermore, the justifications for such responses would appear logical. However, on indeterminate problems, where the alternatives do not differ on the relevant dimension, the strategy would lead children either to prematurely terminate search once a possible alternative was found or to underconstrain search and focus on irrelevant dimensions such as functionality, location, or personal preference. Vurpillot (1968) reports evidence of young children's incorrect responses on a discrimination task stemming from premature termination of search, and both Piéraut-Le Bonniec's (1980) and Somerville et al.'s (1979) results suggest that, when irrelevant features are available, 5-year-olds tend to use them to resolve indeterminacy.

Byrnes and Beilin's (1991) emphasis on children's ability to form equivalence classes addresses the evaluation phase of the model. They argue that children's failure to form true equivalence classes during this phase leads them to choose the alternative that they see as the most likely, rather than acknowledging the indeterminacy of the situation.

Finally, the theoretical accounts that address children's inadequately refined lexicon of determinacy and indeterminacy are relevant to the mapping phase of our model. For example, Moore et al. (1989) showed that around the age of 4 children begin to correctly contrast terms such as "guess", "think," and "know"—selecting "know" as indicating more certainty than "guess." However, Horobin and Acredolo's (1989) finding that children assigned absolute certainty to one alternative but also assigned nonzero probabilities to other alternatives suggests that these children do not understand that terms of absolute certainty are qualitatively different from terms of relative certainty. Before the age of 4 or 5 children do not recognize that "know" requires an informational base whereas "think" and "guess" do not (Johnson & Maratsos, 1977; Johnson & Wellman, 1980; Miscione et al., 1978; Perner, 1991; Ruffman & Olson, 1989; Wimmer et al., 1988). Even when this basic distinction is understood, children still have a poorly developed understanding of how the quality and quantity of the information constrains what is known. At first, children appear to operate with an all-or-none rule, whereby *any* informational access enables knowing and *no* informational access requires guessing, regardless of the sufficiency or insufficiency of the information (O'Neill, Astington, & Flavell, 1992; Taylor, 1988).

In summary, the goal of the studies reported in this article is to further examine the three processing components—search, evaluation, and mapping—and to identify their role in children's ability to distinguish determinate from indeterminate situations. We follow Piéraut-Le Bonniec's (1991) suggestion that one useful method "for studying how children learn to reason in terms of necessity rather than probability" is to "analyze in fine detail children's *strategies* in solving various problems" (p. 226, emphasis added). In particular, we seek to explain preschoolers' responses to different patterns of determinate and indeterminate evidence in terms of the adequacy of their search, evaluation, and mapping processes.

Our point of departure is an experiment by Piéraut-Le Bonniec (1980) in which 5-year-olds were presented with problems having either one or two possible solutions. Children were presented with two types of objects. One type was made only from sticks and the other type was made from sticks and curves. In addition, children were presented with two boxes, one containing both sticks and curves and the other containing only sticks. As each object was presented, children were asked which box was used to make it. On the determinate problems (objects made from sticks and curves), 90% of the children identified the correct box. However, on the indeterminate problems (objects made only from sticks), 96% incorrectly picked a specific box as being the one that had been used. When these children were asked if the box they did not choose could have been used to make the object, 20% said that it could, but they still maintained that they knew which box actually had been used. Thus, even when these children correctly identified multiple possible solutions, they failed to evaluate the situation as indeterminate.

In the three studies described in this article, we progressively modified this task in order to investigate preschool children's ability to recognize and understand the implications of single- and multiple-solution problems using a simple, concrete task. In Experiment 1, we examined 5-year-old children's performance and strategy use on one- versus two-solution problems when different configurations of irrelevant information were available. In Experiments 2 and 3, we extended the decision context from two to four possible sources of indeterminacy. We used problems that varied in the amount of consistent, inconsistent, and to-be-discovered evidence in order to investigate the effects of different levels of indeterminacy.

Experiment 1

Experiment 1 was designed to extend Piéraut-Le Bonniec's (1980) findings on 5-year-olds' understanding of determinate and indeterminate events in a concrete and simple task. We focused on four aspects of children's performance: (*a*) success on determinate versus indeterminate problems, (*b*) encoding of multiple alternatives versus evaluation of indeterminacy, (*c*) the effect of irrelevant information on performance, and (*d*) the relation between children's performance and the reasoning they use to justify their responses.

We made three major modifications to Piéraut-Le Bonniec's procedure:

1. In the original task children were asked, "Which box was used to make this object?" This question implies that a unique box could be selected and may have strengthened children's bias toward a determinate response. We introduced each problem by stating the two possible ways of evaluating the problem: "Sometimes you can tell which box was used and sometimes you cannot tell which box was used," and changed the question to "Is this a time that you can tell which box I used to make this or is this a time that you cannot tell which box I used?" Our goal was to reduce the tendency of the mapping process to select determinate responses by making explicit the types of problems that could occur and the types of responses that were acceptable.

2. To investigate the role of the search process on children's recognition of indeterminacy, we added another condition to the task. In Piéraut-Le Bonniec's task, children were presented with two boxes: one containing two types of elements (sticks and curves) and the other containing one type of element (curves). On indeterminate problems (objects made from curves) children often selected the single element box and used a functional argument to justify their response. That is, they would argue, in effect, as follows: "It only has curves in it, and the thing you made is only made of curves, so you would use that box for making curve things, and use the other box for making things out of curves and non-curves." In our new condition, two types of elements were in each box; elements that matched the target object (e.g., curves) and elements that did not match the target object (e.g., sticks in one box and squares in the other box). In this condition, neither box could be identified as more likely on the basis of a functional argument.

3. The third modification enabled us to separate failures in search from failures in evaluation and mapping. In the original study, the test question was followed with a probe. If children gave determinate responses to determinate problems, then the probe question asked them whether the other box could have been used. If children gave determinate responses to indeterminate problems, then the probe question asked them whether the other box or both boxes could have been used. However, because there was no further questioning *following* the probe, its effect could not be analyzed. In our procedure, we followed the probe with a repeat of the test question. If children correctly answer the probe, then a subsequent failure to accept the problem as indeterminate cannot be attributed to a search failure. Furthermore, a pattern of responses indicating that success on the probe was necessary but not sufficient for success on the postprobe test question would suggest that the evaluation and mapping processes are acquired after the ability to encode multiple solutions.

Method

Subjects

Seventeen kindergarten children (eight girls and nine boys) from a university laboratory preschool participated as subjects. Children ranged from 5.2 to 6.1 years (M = 5.6

years) and came primarily from upper-middle-class families.

Materials

The stimulus materials consisted of two lidded boxes (4 × 6 × 2 inches) and three shapes of plastic construction toys (curved pieces, square pieces, and stick pieces). For ease of reference for the child and the coder, one box had a picture of a car on it and was referred to as the "car box" and the other had a picture of a star and was referred to as the "star box." Target objects were constructed by joining three of the construction pieces in different combinations: (*a*) stick pieces only, (*b*) curved pieces only, (*c*) square pieces only, (*d*) stick and curved pieces, and (*e*) stick and square pieces. Other materials included a cardboard screen, a tape recorder, and a microphone.

Construction of Problems

There were two types of problems—Determinate and Indeterminate—and for each problem type, there were two problem conditions: One-vs.-Two-Feature problems and Two-vs.-Two-Feature problems. Figure 1 contains an example of each of the four problem arrays. In the One-vs.-Two-Feature problems, one box contained only one type of construction piece (e.g., curved pieces) and the other box contained the same type of piece plus one other type of piece (e.g., curved and straight pieces; see Fig. 1*C*, 1*D*). In the Two-vs.-Two-Feature problems, each box contained two types of construction pieces, one set of pieces that were identical and one set of pieces that were unique to each box (e.g., curved and straight pieces vs. curved and square pieces; see Fig. 1*A*, 1*B*).

For determinate problems, the objects were made from the construction pieces that were available in only one of the boxes. For the indeterminate problems, the objects were made from the construction pieces that were available in both boxes.

Procedure

Children were tested individually in a laboratory adjacent to their classroom. They were seated at a small table across from the experimenter and were told that they were going to play a game. The experimenter showed them the two opened boxes with the building pieces in them, and said: "I am going to make something using the pieces in one of these boxes, but I'm not going to let you see which box I use." The experimenter then placed the screen in front of the boxes. "I'm going to close this box and put it over here [one closed box is placed to the side of

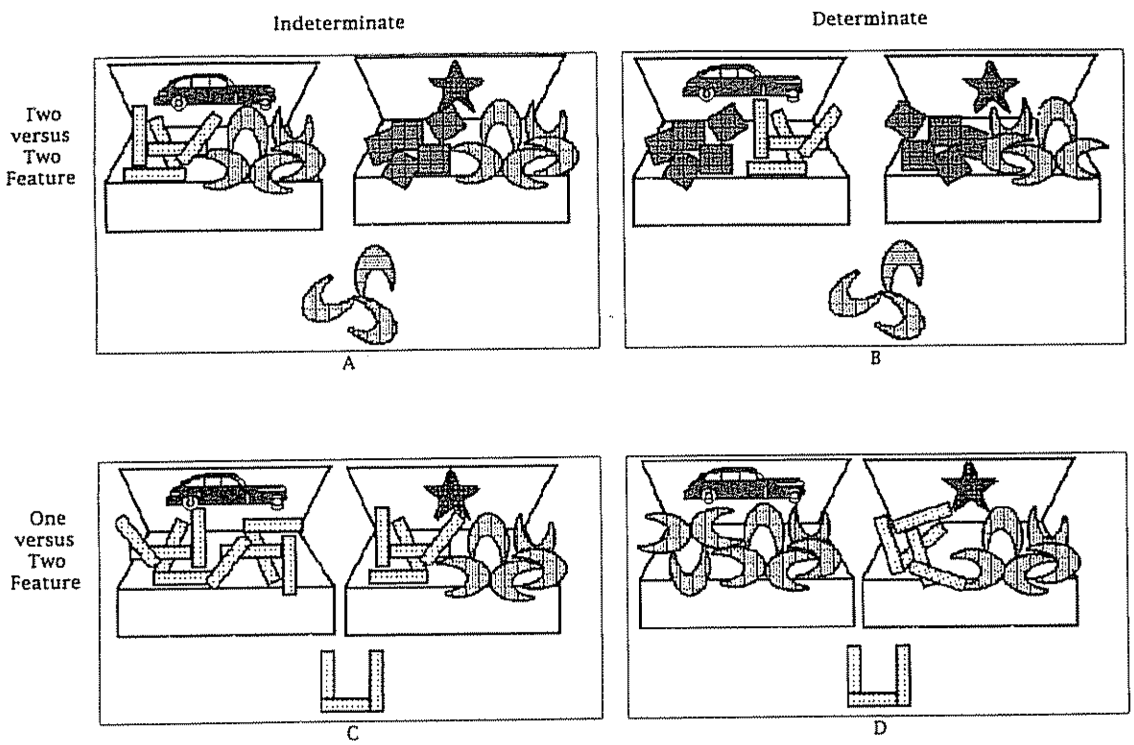

FIG. 1.—Problem set, Experiment 1: *A*, Indeterminate Two-vs.-Two Feature; *B*, Determinate Two-vs.-Two Feature; *C*, Indeterminate One-vs.-Two Feature; *D*, Determinate One-vs.-Two Feature. Target objects are shown below the boxes.

the screen, within view of the child] and now I'm going to make something using this other box." Then, the experimenter surreptitiously took a pre-made object from a hidden shelf below the table. "Now I'm going to bring this box back with the other one and I will show you what I made." The experimenter placed both boxes behind the screen and then removed the screen and showed children the object and the two opened boxes. Finally, she asked children the following questions (with the order of *can* and *cannot* randomized):

1. Initial Test: "Is this a time that you *can/cannot* tell which box I used to make this or is this a time that you *cannot/can* tell which box I used to make this?"

2. Justification: (Response = "can tell," chooses a box) "How can you tell that I used the pieces in this box?" (Response = "cannot tell") "Why *can't* you tell which box I used?"

3. Probe: "Could I have used the other box to make this?"

4. Final Test: "Is this a time that you *cannot/can* tell which box I used or is this a time that you *can/cannot* tell which box I used to make this?"

The experimenter used probes only when children gave a determinate response (i.e., on all correctly answered determinate problems and on all incorrectly answered indeterminate problems).[1] We used a 2 (condition: One-vs.-Two Feature vs. Two-vs.-Two Features) × 2 (problem type: determinate vs. indeterminate) within-subject design. All children received eight problems: two determinate and two indeterminate problems in each of the two conditions. Order of presentation for condition was counterbalanced, with half the children receiving the Two-vs.-Two-Feature condition first and half receiving the One-vs.-Two-Feature condition first. Within each condition, problem types were presented in an alternating sequence. The type of problem (determinate or indeterminate) presented first in each condition was counterbalanced for each child and across children.

Results

Scoring

For the initial test and the final test questions ("Is this a time that you can tell or you cannot tell which box I used to make this?") the correct response for determinate problems was "can tell" or the selection of the correct box. For indeterminate problems, the correct response was "can't tell" and no box selection. For the probe ("Could I have used the other box?"), correct responses were "no" and "yes" for determinate and indeterminate problems, respectively. For each of these measures, children received a score of one for a correct response and a zero for an incorrect response.

Performance on Initial Test, Probe, and Final Test

On the initial test question all the responses were correct for determinate problems, but only 35% of the responses were correct on the indeterminate problems—50% and 20.5% on the Two-vs.-Two-Feature and One-vs.-Two-Feature conditions, respectively. Figure 2 shows the mean number of indeterminate problems correct for the initial test question, probe question, and final test question by problem condition. Because there were no errors on the determinate problems ($M = 4.0$, SD = 0), children's performance on the indeterminate problems was analyzed using one-sample t tests with $M = 4$ as the hypothesized mean. Children were more successful on the determinate problems than on the indeterminate problems, $t(16) = -7.52$, $p < .0001$, and this difference was significant for both the indeterminate One-vs.-Two-Feature and Two-vs.-Two-Feature problems, $ts(16) = -10.6$ and -4.4, respectively, $ps < .0005$. Comparing performance on the indeterminate problems by condition revealed that children were more successful on the Two-vs.-Two-Feature problems than on the One-vs.-Two-Feature problems, $t(16) = 3.41$, $p < .005$.

Following the probe question, children continued to get all determinate problems correct, and the percent of indeterminate problems correct increased to 57%—62% and 53% on the Two-vs.Two-Feature and One-vs.-Two-Feature problems, respectively. Although children's performance on the indeterminate problems improved after the probe, it was still significantly lower than performance on the determinate problems, $t(16) = -3.65$, $p < .005$, and this difference was significant for both the One-vs.-Two-Feature and Two-vs.-Two-Feature problems children, $ts(16) = -3.77$

[1] The experimenter did not use probes when children gave an indeterminate response because children already justified their "can't tell" responses by stating that both boxes could have been used to make the object.

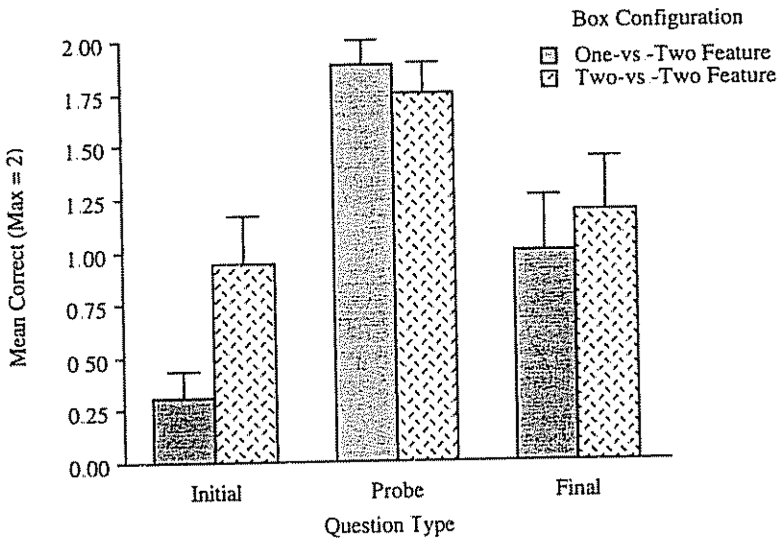

FIG. 2.—Mean scores for Two-vs.-Two Feature and One-vs.-Two Feature problems by question (Experiment 1). Error bars represent the standard errors of the means.

and −3.25, respectively, $ps < .005$. The difference in performance on the One-vs.-Two-Feature versus Two-vs.-Two-Feature indeterminate problems was not significant, $t(16) = 1.38$, $p = .5$.

Effect of Condition on the Indeterminate Problems

Children's poorer performance on the initial test question for indeterminate One-vs.-Two-Feature problems could result from their using a strategy of selecting the box that seems most likely to have been used based on the functionality of the box contents (e.g., "You must have used the box with only sticks in it because it's the box for making stick things"). To test this hypothesis, we coded each child's incorrect responses on the One-vs.-Two problems according to whether they chose the One-Feature or Two-Feature box. We then categorized children as Functional Responders if they selected the One-Feature box on *all* their incorrect responses. Out of 16 children who made errors, 12 were categorized as Functional (binomial test, $p < .05$).[2]

Effect of Probe

The probe question and final test question were designed to examine whether children's incorrect responses on the indeterminate problems stemmed from failures in the search or evaluation process. If children's incorrect "can tell" responses were a result of their failure to attend to and encode the contents of both boxes, then correctly responding "yes" to the probe should be followed by correctly responding "can't tell" to the final test question. However, if children's incorrect responses were a result of the evaluation process failing to correctly interpret the encoding of the boxes, then correctly responding to the probe would be necessary but not sufficient for correctly answering the final test.

Recall that children were asked the probe and final test question only if they gave an incorrect "can tell" response to the initial test question. Thus any correct responses to the probe or final test question are inherently "gain" scores because they indicate that children got some problems correct on the probe or final test question that they got wrong on the initial test question. We conducted one-sample t tests comparing the number of correct responses on both the probe question and the final test question to the expected mean of zero. Children performed better on the probe question

[2] Because the problems were presented in alternating order, choosing the one feature box on the indeterminate problems and choosing the correct boxes on the determinate problems also fits an alternating box strategy, where the child never selects the same box twice in a row. To assess whether children were using an alternating strategy or a functional strategy, the same analysis was conducted on the Two-vs.-Two-Feature problems, where a strategy based on the functionality of the box is eliminated. If children were using alternation, rather than a strategy based on the functionality of the box contents, then we would also expect to see the alternating-box pattern on the two cue problems. However, only three out of 10 children who made errors on the Two-vs.-Two-Feature problems fit the alternating-box pattern (binomial test, $p > .1$).

(mean gain score = 2.4) and the final test question (mean gain score = .94) than on the initial test question, $ts(15) = 8.73$ and 3.03, $ps < .0001$ and .01, respectively, and children performed better on the probe question than on the final test question, $t(15) = 3.62$, $p < .01$. All 16 children showed a gain in score from the initial test to the probe question (sign test, $p < .0001$), and eight of the 16 showed a gain from the initial test question to the final test question (sign test, $p < .01$).

If children's failure on the initial test question was due solely to an encoding failure, then correctly answering the probe should be associated with correctly answering the final test question. If, however, encoding multiple alternatives is a separate and earlier acquired ability than evaluating a situation as indeterminate, then we would expect more children to be correct on the probe question than on the final test question, and no children to be correct on the initial test or final test questions and incorrect on the probe question. Of the 16 children who were given at least one probe and final test question, eight performed better on the probe question than on the final test question and no child performed better on the final question than on the probe question (paired-sign test, $p < .005$).[3] Thus, although all 16 children at least once encoded the unchosen box as one that could have been used to construct the target object, only half of them then evaluated the situation as indeterminate.

Relation between Search Strategies and Performance

The first component of our three-process model is search: the process in which children gather information about the pattern of evidence. We inferred different search strategies by analyzing the referents in children's replies to the justification question ("How can you tell that I used the pieces in this box?"). We conjectured that, even though children responded correctly to all determinate problems, there might be individual differences in the search strategies they used to generate those correct responses. Furthermore, such strategy differences on the determinate problems might be predictive of performance on indeterminate problems.

In the following analyses we inferred search strategies based on children's justifications for their responses across determinate and indeterminate problems. We then examined the relation between children's search strategies and their performance on determinate and indeterminate problems.

Search strategies.—In order to explore the relation between search strategies and performance, we classified children according to their *search strategies* (based on their justifications) and their *responses* (to the test question). This analysis yielded three types of search strategies and a residual category:

1. Children using a *Confirmative* strategy search the boxes until a match is found, and when one is found, they say "can tell" and select that box. We inferred the use of this strategy from justifications that focused on the match between the object and the contents of one box and made no reference to the other box (e.g., "It's the car box because the car box has red curves in it").

2. Children using an *Eliminative* strategy attend to and encode each box as matching or not matching the object. They say "can tell" if there is only one matching box and "can't tell" if there is more than one matching box. We inferred the use of this strategy from justifications that focused on the impossibility of one box (e.g., "The star box doesn't have red curves so it must be the car box") or the unique match of one box (e.g., "It is the car box because it is the *only* box with red curves"), or the failure to eliminate either box because of multiple matches (e.g., "I can't tell because they both have red curves").

3. Children using a *Pseudo-Eliminative* strategy attend to both boxes and encode any

[3] One might argue that children performed better on the probe question because they interpreted it as an indication that their initial box selection was incorrect. Two pieces of evidence argue against this explanation. First, if this was the case, we would also expect to see children respond "yes" to the probe on the determinate problems, but no child ever responded this way. Second, if children interpreted the probe as an indication that their initial selection was incorrect, then we would expect them to follow up affirmative responses to the probe with a change in box selection. Not one of the six children who responded "yes" to the probe question and then selected one box on the final test question changed their box selection from the initial to the final test question.

features that are unique to one box. If the boxes can be distinguished, they say "can tell." The use of this strategy was inferred from justifications focusing on the uniqueness of one box based on irrelevant characteristics (e.g., "It's the car box because the curves are spread out more than the star box") or false characteristics (e.g., "It is the car box because it is bigger than the star box").

4. The *Noninformative* category included failing to give any justification or giving responses such as "because" or "I don't know."

Children were categorized separately for determinate and indeterminate problems. For each type of problem, children were categorized as having an Eliminative search strategy if at least two of their four justifications were eliminative, regardless of the categories of their remaining justifications. They were classified as either Confirmative, Pseudo-Eliminative, or Noninformative if the majority of their justifications were from that category.

Response classifications.—Children were categorized as Indeterminate-Correct (I-C) responders if they were correct on at least three indeterminate problems by the time of the final test question and Indeterminate Incorrect (I-I) responders otherwise.

Relation between responses on indeterminate problems and search strategies on determinant problems.—Of the nine children who were classified as I-C responders, eight were classified as Eliminative searchers and one was classified as a Confirmative searcher on the determinate problems. In contrast, of the eight I-I responders, only three were classified as Eliminative, and the remaining five were classified as Confirmative. None of the children gave either Pseudo-Eliminative or Noninformative justifications on the determinate problems. A Fisher exact test revealed a significant relation between using an Eliminative versus Confirmative search strategy on determinate problems and being correct (I-C) or incorrect (I-I) on the indeterminate problems, $p = .04$.

On determinate problems, both the Confirmative and the Eliminative strategies produce correct responses because these problems have a single matching box, thus meeting the criteria to select the correct box in both cases. In principle, the Pseudo-Eliminative strategy could produce either a correct or incorrect response, depending on which feature is used and whether it corresponds to the correct box. However, as noted earlier, children made no errors on determinate problems.

Although all these search strategies lead to correct responses on determinate problems, they result in different outcomes on the indeterminate problems, where both boxes match the object. A Confirmative strategy will result in incorrect determinate responses because the first matching box results in premature termination of the attend-encode cycle of search. A Pseudo-Eliminative strategy will also result in incorrect determinate responses because irrelevant features are attended to and encoded as a basis for discriminating between the boxes. Only an Eliminative strategy will produce a correct response, because it attends to both boxes and encodes the features relevant to the target object. The Eliminative strategy implies that the child searches both boxes, encodes only the relevant dimensions, and evaluates the evidence correctly. Thus children who use an Eliminative strategy should perform better on the indeterminate problems than children who use a Confirmative or a Pseudo-Eliminative strategy.

In summary, children who used a Confirmative search strategy on the determinate problems were more likely to be incorrect on the indeterminate problems than children who used an Eliminative strategy.

Search strategies on indeterminate problems.—Children's justifications on the indeterminate problems were also examined in relation to their responses on the indeterminate problems. All of the nine children who were classified as I-C responders used Eliminative search on the indeterminate problems. That is, they justified their "can't tell" response by focusing on the failure to eliminate a box and find a single match (e.g., "I can't tell because they both have green sticks"). Of the children who were classified as I-I responders, three were classified as Pseudo-Eliminative, one as Eliminative, one as Noninformative, and three were combinations of Pseudo-Eliminative and Noninformative.

Recall that children were classified as I-I responders if they tended to give incorrect "can tell" responses to indeterminate problems. Because all children correctly responded "can tell" to determinate problems, I-I children might be completely insensitive to the difference between the two types of problems. If so, then we would expect them to use the same kind of justification on both types of problems. Seven of the eight I-I children used a different type of justification on the indeterminate problems, binomial test, $p = .035$. These seven children justified their incorrect indeterminate responses by using Pseudo-Eliminative or Noninformative justifications. The use of these two justifications on the indeterminate but not the determinate problems suggests that these children do discriminate, at some level, between the two types of problems. When relevant features are available to discriminate among the alternatives these children use them, but when they are unavailable, they use irrelevant features to discriminate and choose among alternatives.

Discussion

Results from this experiment support the view that, around the age of 5, children begin to acquire the component processes necessary to distinguish between determinacy and indeterminacy. All of the children correctly identified the determinate problems, and half of them also correctly identified the indeterminate problems at the time of the final test question. Although this success rate on the indeterminate problems is far greater than that found by Piéraut-Le Bonniec (1980), where only 4% of the 5-year-olds succeeded on the indeterminate problems, it is consistent with the results reported by Somerville et al. (1979), who also used the "can tell"/"can't tell" response option and varied the type of irrelevant feature. Our probe-retest procedure revealed that children who incorrectly responded "can tell" on indeterminate problems could correctly encode and represent multiple alternatives. However, many of them continued to give determinate responses when the test question was repeated. Moreover, although many of these children gave "can tell" responses to both determinate and indeterminate problems, the *types* of justifications they used on the two problems were qualitatively different.

We can interpret these results in terms of our three-process model. In order to correctly respond to an indeterminate situation, the search process must accurately register the similarities and differences between the alternatives and the target object and recognize that multiple alternatives match the problem criteria. Two factors are likely to influence this process: memory demands and search demands. In our task, memory demands were minimal: there were only two boxes, the contents were always visible, and the boxes could be viewed simultaneously. However, the search process may have been affected by the saliency of the indeterminacy. Children's failure on indeterminacy problems may result from an underconstrained search process that extends to both relevant and irrelevant features. On the determinate problems, children never used irrelevant features to justify their responses, even though they were available. On the indeterminate problems, children who gave "can tell" responses overwhelmingly used irrelevant features to justify their responses. The difference in justifications between the determinate and indeterminate problems suggests that children first search the relevant feature for discriminating evidence, but if unavailable, some will search other features for potentially discriminating evidence. When the irrelevant feature not only discriminates among alternatives but also provides a "reasonable" basis for choosing a specific alternative, performance declines further, as shown by the difference between the One-vs.-Two-Feature versus Two-vs.-Two-Feature conditions.

Changes in search constraints may account for the performance of those children who changed their responses on indeterminate problems from "can tell" to "can't tell" after correctly answering the probe question. Focusing these children's attention on the unchosen alternative helped them to identify the match between that alternative and the object and then to evaluate the problem as indeterminate.

Individual differences can be attributed to differences in search and evaluation processes. Children who were correct on indeterminate problems attended to both boxes, encoded the contents of the boxes in terms of the relevant feature, and evaluated the problem based on the presence or absence of a single matching box. That is, they justified the necessity of one box by eliminating the possibility of the other or they justified the possibility of both boxes by the failure to eliminate either box on the basis of the relevant feature only. Children who were incorrect on indeterminate problems tended to attend to and encode the relevant feature on the determinate problems, focusing on the match between the object and the box, but on indeterminate problems they extended their search and encoded irrelevant differences between the boxes as evidence for selecting one box over the other. Differences in attending and encoding processes may result from differences in children's interpretation of the task. If children are interpreting the task as asking if they "can guess" the correct response, rather than if "they know for sure" the correct response, then they may select a strategy that searches for any clues that they can use to increase the likelihood of guessing the correct alternative. On the other hand, if children are interpreting the task correctly, they would constrain their search to the relevant clues.

The results of Experiment 1 suggest that it is fruitful to view indeterminacy judgments in terms of three underlying processes: search, evaluation, and mapping. In our second experiment we further investigated these processes by attempting to manipulate the effects of different patterns of evidence on each process.

Experiment 2

In Experiment 2, we made several modifications to the procedure and materials used in Experiment 1. The most important changes were (*a*) increasing the number of boxes in each problem from two to four and (*b*) starting each problem with all four boxes closed and then opening them sequentially. The two additional changes were (*c*) adding a brief familiarization phase prior to the experimental problems and (*d*) placing only one kind of material in each box. These changes were introduced so that we could address several questions raised by Experiment 1:

1. Because all the boxes were closed at the outset and then opened—and left open—in a fixed sequence, children had to reason about both visible evidence (i.e., the contents of the already opened boxes) and potential evidence (i.e., the contents of yet-to-be opened boxes). This enabled us to explore which of the component processes that support indeterminacy judgments are sensitive to the pattern of matching, mismatching, and unopened boxes. More specifically, it enabled us to identify how the search and evaluation processes responded to visible versus potential information.

2. Four-box problems enabled us to examine two proposals about how children make indeterminacy judgments: (*a*) *Probability-based evaluation;* children may respond to indeterminacy problems by, in effect, estimating the likelihood that they can correctly guess which box had been used to construct the target item and responding according to that estimate. Four-box problems were designed to assess this possibility (a detailed description of the probability-based evaluation is presented in the Method section). (*b*) *Saliency based evaluation;* we included indeterminate problems that varied with respect to the final saliency of the indeterminacy (i.e., once all the boxes were opened). In some cases two of the four boxes matched the target object; in others all four matched. Although the binary logic of indeterminacy treats the two cases as equivalent (i.e., they are both indeterminate), it is possible that, for some children, the evaluation process interprets the latter case as "more indeterminate" than the former (cf. Byrnes & Beilin, 1991; Horobin & Acredolo, 1989). If so, then we should see a higher rate of indeterminate responses to problems with four matching boxes than those with two matching boxes.

3. The combination of four boxes and sequential opening enabled us to distinguish between children's ability to create representations for visible indeterminacy (when all the evidence is available and the outcome is indeterminate) and potential indeterminacy (when it is not yet clear whether the current problem will turn out to be determinate or indeterminate because all the evidence is not yet in). In the latter condition, the child is faced with the indeterminacy of indeterminacy. As Acredolo and O'Connor (1991, p. 207) put it, "uncertainty is itself uncertain." Children's response patterns to visible and potential indeterminacy could indicate whether they encode and evaluate the two situations in different ways.

4. In contrast to Experiment 1, where some target objects were constructed from two kinds of elements, in Experiment 2, the target objects were made from a single type of element (e.g., a necklace made from only red wooden beads), and each box had a single type of element in it (e.g., one box might have only red wooden beads, another only blue wooden beads, another green, and so on). This reduced the likelihood that the search process would get sidetracked by irrelevant features, as it did for some children in Experiment 1.

5. We used a brief familiarization phase (with a series of two-box problems) prior to presenting the four-box series. Its purposes were (*a*) to familiarize the child with the general procedure of starting with closed boxes and then opening them one at a time, (*b*) to emphasize the fact that there were situations in which a "don't know" response

was appropriate, thereby reducing the likelihood of errors in the mapping process, and (*c*) to demonstrate the manner in which a pattern of information about determinacy and indeterminacy could unfold as boxes were opened.

METHOD

Subjects

Twenty-six kindergarten children (14 girls and 12 boys) from a university laboratory school participated in the experiment. Children ranged from 4.8 to 6.0 years (M = 5.3 years) and came from predominantly upper-middle-class families.

Materials

The stimulus materials consisted of 26 boxes fitted with lids that could be opened and closed and six different element sets: plastic chain links, plastic construction pieces, buttons, wooden beads, pipe cleaners, and pasta shells and tubes. Each element set contained several items of four different shapes, colors, or sizes. Nine target objects were constructed by combining two to five pieces from each element set. Other materials consisted of a white cardboard screen, five pieces of poster board (8 × 30 inches), an assortment of cartoon stickers, a video camera, and a tape recorder. The boxes were arranged into three sets of two boxes (practice problems) and five sets of four boxes (experimental problems). For each problem, the boxes were arranged side by side with their bottoms secured to a piece of poster board with Velcro.

Each box contained one type of material, and the target object was made either from the material available in only one box (determinate problems) or from material available in more than one box (indeterminate problems). Each problem used only one element set (e.g., all four boxes contained plastic links) and in each box there were several identical elements from that set (e.g., 10 blue links in box 1, 10 red links in box 2, etc.).

Practice problems.—The three practice (two-box) problems included two indeterminate problems, where both boxes contained elements that matched the target object, and one determinate problem, where only one box contained elements that matched the target object. On determinate problems the position of the matching box was randomized across children.

Experimental problems.—There were five types of experimental problems: three indeterminate and two determinate. Their formal structure is shown in Table 1.[4] Two of the indeterminate problems had two boxes containing material from which the target object could have been constructed: either in boxes 1 and 3 (Indeterminate 1, 3), or boxes 2 and 4 (Indeterminate 2, 4). The other indeterminate problem had four boxes containing material from which the target object could have been constructed (Indeterminate All). Determinate problems had only one box containing material from which the target object could have been constructed: either box 2 (Determinate 2) or box 4 (Determinate 4).

The temporal micro-structure of each trial for each type of problem is shown in Table 2. When each problem was first presented, all four boxes were closed (indicated by "?" in the "Box Contents" columns). Then they were opened sequentially, revealing box contexts that either matched (+) or did not match (−) the target object. Table 2 also displays the following important properties of the state of each problem as the boxes were opened:

1. The "Problem Determinacy" column describes the momentary state of knowledge about whether the problem will turn out to be determinate or indeterminate once all the boxes are open. The unknown cases here correspond to the "indeterminacy of indeterminacy" noted earlier, when there are closed boxes and so it is not known whether the problem will ultimately be determinate or indeterminate.

2. The "Box Determinacy" columns show how information about the possibility and impossibility of box(es) used in constructing the target object becomes better specified as the box openings proceed. For example, after the third box is opened in the Indeterminate 1, 3 problem, it is clear that the problem is indeterminate and that box 2 is ruled out. However, it is not clear whether the indeterminacy includes box 4 (still closed) in addition to boxes 1 and 3 (both open). The next row shows that, after box 4 is opened, it too is ruled out, but the indeterminacy between boxes 1 and 3 remains.

[4] Table 1 depicts the problems in terms of the color of the target object and the color of the elements in the source boxes, although for some problems, a different attribute, such as shape, played the same role as does color in Table 3.

TABLE 1

PROBLEM TYPES FOR EXPERIMENT 2

Problem Type	Box Contents			
	Box 1	Box 2	Box 3	Box 4
Determinate 4	Blue	Yellow	Green	Red
Indeterminate 1, 3	Red	Blue	Red	Green
Indeterminate All	Red	Red	Red	Red
Determinate 2	Blue	Red	Green	Yellow
Indeterminate 2, 4	Yellow	Red	Blue	Red

NOTE.—The example shown is for a red target object. Color is the relevant attribute of the target object and the box contents in this depiction, but several different attributes were used in the experiment, including size and shape. For any given problem, only one attribute was critical. At the outset of each problem, all boxes were closed. Then they were opened from left to right (i.e., from box 1 to box 4).

3. As successive boxes are opened, the type of evidence that supports a response of "can tell" or "can't tell" changes. Table 2 shows the four different types of evidence: (*a*) Hidden, when all the boxes are closed; (*b*) Negative & Hidden, when none of the open boxes match the target; (*c*) Positive & Hidden, when only one box that matches the target object is open and at least one other box is closed (the remaining two boxes can be either closed or mismatch the target object); and (*d*) Positive & Visible, when two or more open boxes match the target or all boxes are open and only one matches the target.[5]

4. Children may respond "can tell" when what they mean is "can guess correctly." Such responses would vary according to children's estimates of how successful such guessing might be. In order to assess the extent of such probability-based evaluation, we computed a baseline against which to compare children's responses. The "probability of determinacy" values in the rightmost column of Table 2 are based on the assumption that, from the child's perspective, there is a 50-50 chance that an unopened box will turn out to match or not match the target item. At the beginning of each problem, all possible patterns of matching and nonmatching boxes are equally likely, but the sequential opening of boxes reveals their contents, thereby narrowing the set of remaining possible outcomes and changing the likelihood that the problem will turn out to be determinate. At the outset, there are 15 possible outcomes (i.e., + + + +, + + + −, + + − +, + − + +, . . . etc.),[6] but only four of them (corresponding to a match in one and only one of the boxes: + − − −, − + − −, − − + −, or − − − +) will produce determinate problems. Thus, when all the boxes are closed, the probability that a problem will turn out to be determinate is 4/15 (.27). As the boxes are opened, this probability changes as shown in the table. For example, for the Indeterminate 2, 4 problem, opening the first box immediately rules it out as a possible source of the target object. Of the seven possible remaining patterns of matches and mismatches, only three will produce a determinate outcome, so the probability of the current situation turning into a determinate problem is 3/7 (.43). Opening the second box reveals objects that match the target object. This reduces the probability that the problem will turn out to be determinate from .43 to .25, because only one of the four remaining possible patterns of "hits" and "misses" could render this problem determinate. Opening box 3 rules it out and increases the probability that the problem will turn out to be determinate to .5. This probability goes to zero when the final box is opened, and it is clear that this is an indeterminate problem. Overall, these probabilities provide a baseline against

[5] As shown in Table 2, in all but one instance, Negative & Hidden evidence patterns correspond to unknown determinacy patterns. The exception occurs after the third box is opened in the Determinate 4 problem, where, even though there is Hidden evidence (− − − ?), the problem must be determinate because at least one box must match the target object. Given that boxes 1–3 do not match, box 4 must match.

[6] There are 15, rather than 16, possible patterns, because, as just noted, the pattern with four nonmatching boxes (− − − −) is not permitted.

TABLE 2

SEQUENCE OF INFORMATION EXPOSURE AND DETERMINACY STATES FOR DIFFERENT PROBLEM TYPES (Experiment 2)

Problem Type	Box Contents 1	2	3	4	Problem Determinacy	Box Determinacy: Possible	Impossible	Type of Supporting Evidence	Probability of Determinacy
Determinate 4:									
	?	?	?	?	Unknown	1,2,3,4		Hidden	.27
	–	?	?	?	Unknown	2,3,4	1	Negative & Hidden	.43
	–	–	?	?	Unknown	3,4	1,2	Negative & Hidden	.67
	–	–	–	?	Determinate	4	1,2,3	Negative & Hidden	1.00
	–	–	–	+	Determinate	4	1,2,3	Positive & Visible	1.00
Indeterminate 1, 3:									
	?	?	?	?	Unknown	1,2,3,4		Hidden	.27
	+	?	?	?	Unknown	1,2,3,4		Positive & Hidden	.13
	+	–	?	?	Unknown	1,3,4	2	Positive & Hidden	.25
	+	–	+	?	Indeterminate	1,3,4	2	Positive & Visible	0
	+	–	+	–	Indeterminate	1,3	2,4	Positive & Visible	0
Indeterminate All:									
	?	?	?	?	Unknown	1,2,3,4		Hidden	.27
	+	?	?	?	Unknown	1,2,3,4		Positive & Hidden	.13
	+	+	?	?	Indeterminate	1,2,3,4		Positive & Visible	0
	+	+	+	?	Indeterminate	1,2,3,4		Positive & Visible	0
	+	+	+	+	Indeterminate	1,2,3,4		Positive & Visible	0
Determinate 2:									
	?	?	?	?	Unknown	1,2,3,4		Hidden	.27
	–	?	?	?	Unknown	2,3,4	1	Negative & Hidden	.43
	–	+	?	?	Unknown	2,3,4	1	Positive & Hidden	.25
	–	+	–	?	Unknown	2,4	1,3	Positive & Hidden	.50
	–	+	–	–	Determinate	2	1,3,4	Positive & Visible	1.00
Indeterminate 2, 4:									
	?	?	?	?	Unknown	1,2,3,4		Hidden	.27
	–	?	?	?	Unknown	2,3,4	1	Negative & Hidden	.43
	–	+	?	?	Unknown	2,3,4	1	Positive & Hidden	.25
	–	+	–	?	Unknown	2,4	1,3	Positive & Hidden	.50
	–	+	–	+	Indeterminate	2,4	1,3	Positive & Visible	0

NOTE.—The entries in the four "Box Contents" columns correspond to the information provided by that box (+, visible match; –, visible mismatch; ?, box closed) as the boxes are opened from left to right (i.e., from box 1 to box 4).

which to assess various probability-based strategies that children might use.

Problem order.—All children received the five problem types depicted in Table 1. The problems were presented in two different orders. Order A is shown in Table 1 and in Order B the positions of the Determinate 4 and the Indeterminate 1, 3 problems were exchanged. The two orders were used to partially satisfy two conflicting constraints that we imposed on the problems: (*a*) starting with either a determinate or an indeterminate problem and (*b*) alternating determinate and indeterminate problems within an order. There was no theoretical basis on which to construct a more complex ordering manipulation.

Procedure

General.—Children were tested individually in a room in the preschool. Children sat at a small table facing the video camera, and the experimenter sat at the end of the table with her side to the camera. In order to make children comfortable with the experimental situation, the experimenter pointed out the video camera and asked children to say their name, birthday, and a message of their choice. After the introduction, three separate phases were presented: familiarization, practice, and experimental. In both the practice phase (two boxes) and the experimental phase (four boxes), we presented all boxes closed and then opened them, sequentially, one at a time, and left them open. As we opened each box, we asked children to decide if they could "tell for sure" which box was used to make the object.

Familiarization phase.—During familiarization, children saw the types of elements used for the task and the general procedure using two boxes. We asked children the meaning of the terms "guess," "can't tell," "know for sure," and "can tell" and corrected any wrong answers.

Practice phase.—Children were presented with three two-box problems, one determinate and two indeterminate. Half of the children received an indeterminate problem first and half received a determinate problem first. For each problem, we showed children the two closed boxes and told them the elements in only one box would be used to make the object. We blocked children's view of the boxes with the screen while we picked the appropriate object. We then removed the screen and asked children the following questions:

1. (All boxes closed.) Test question: "Can you tell for sure which box I used to make this?"

2*a*. If answered "yes" to 1: "Do you know for sure that I used this box or are you guessing?" If children still said they were sure, they were corrected and told why it was a time they had to guess, and when to use the "can tell" and "can't tell" responses.

2*b*. If answered "no" or "can't tell": "Why can't you tell which box I used?"

3. (Open the first box.) Test question: "Is this a time that you can tell for sure which box I used to make this or is this a time that you cannot tell?"

4. "How can you tell for sure (or why can't you tell) which box I used?"

5. (Point to other box). Probe question: "Could I have used this box?"

6. (Open second box.) Test question: "Is this a time that you can tell for sure which box I used to make this or is this a time that you cannot tell?"

After every response, we told children the correct answer and an explanation. Children who were incorrect on the indeterminate problems were also reminded not to guess and to select a box only if they were really sure it was the box that was used.

Experimental phase.—We used the same general procedure for the experimental problems as we did for the training problems, but with the following changes: (*a*) four boxes were used instead of two; (*b*) there was no corrective feedback; (*c*) question 5 (probe) was modified to: (Point to other boxes) "Could I have used *any* of these other boxes to make this?" (*d*) questions 3–5 were asked after each additional box was opened; and (*e*) after the fourth box was opened question 6 was asked. Thus, each child responded to the test and probe questions for each of the 25 evidence patterns shown in Table 2.

Results

Responses to the Test Question

There was a wide variation in the proportion of correct responses to each of the 16 unique[7] patterns of positive, negative, and

[7] Five of the patterns recur on different problems. (*a*) ???? occurs at the start of all five problems; (*b*) +??? occurs on both Indeterminate 1, 3 and Indeterminate All after box 1 is

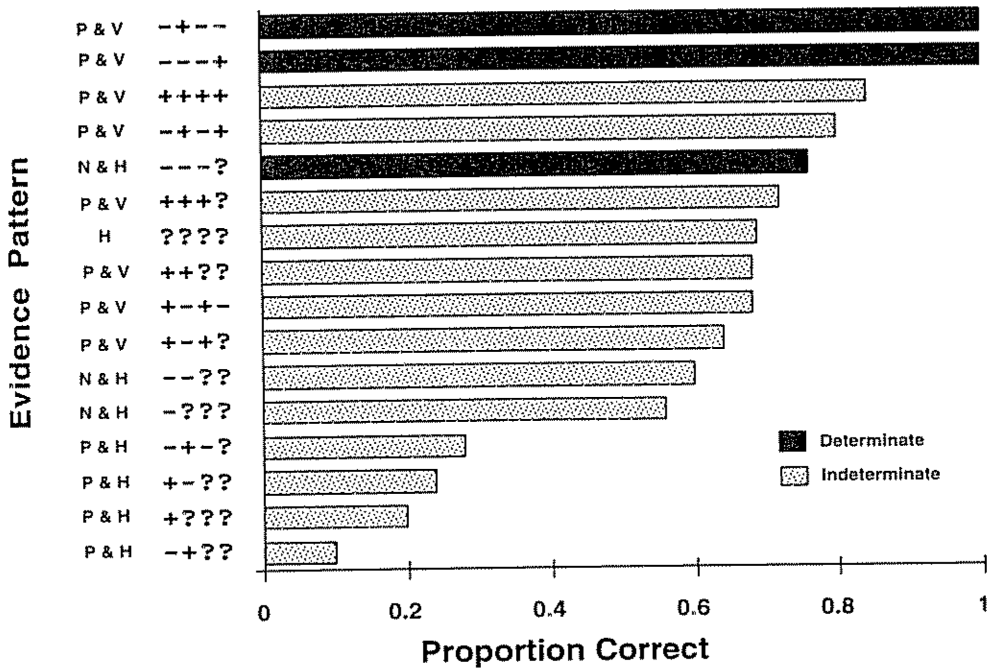

FIG. 3.—Proportion of correct responses on determinate (dark bars) and indeterminate (light bars) problems for each unique evidence pattern (Experiment 2): +, positive evidence in open box visible; −, negative evidence in open box visible; ?, unopened box.

unopened boxes. The results, depicted in Figure 3, are arranged from top to bottom in order of decreasing proportion of correct responses. For determinate problems (dark bars) proportion correct corresponds to "can tell" responses, whereas for indeterminate problems (light bars) it corresponds to "can't tell" responses. For example, the two topmost bars show that on fully exposed determinate problems 100% of the responses were correct, while the bottommost bar shows that for the − + ?? pattern, only 10% of the responses were correct.

The range of variation in children's responses to different patterns of indeterminate evidence is striking: from over 80% correct responses to the fully exposed Indeterminate 4 pattern (+ + + +) to only 10% correct responses to the − + ?? pattern. A repeated-measures ANOVA comparing the proportion correct on each type of evidence configuration revealed a significant difference in proportion correct as a function of type of evidence, $F(3, 24) = 14.87$, $p < .0001$. Pairwise contrasts on types of indeterminate patterns revealed that performance was better on the Hidden (????) than on the Positive & Hidden (+???, + − ??, − + ??, − + − ?), $t(25) = 5.4$, $p < .0001$; performance was better on the Positive & Visible (− + − +, + − + ?, + − + −, + + ??, + + + ?, + + + +) than on the Positive & Hidden, $t(25) = 5.9$, $p < .0001$, and performance was better on the Negative & Hidden (− ???, − − ??) than on the Positive & Hidden, $t(25) = 4.2$, $p < .0001$.

Children's performance on the Positive & Visible patterns indicates that they accurately encoded and evaluated determinate and indeterminate situations when the difference between them was visible—that is, when there was no indeterminacy about indeterminacy. However, when they had no visible evidence to support indeterminacy and they had to reason about potential evidence, children had great difficulty. According to the three-process model, the difference in performance between visible indeterminacy and hidden indeterminacy can stem from either encoding or evaluation failures. In the next set of analyses we attempt to locate the source of the difficulty.

opened; (*c*) − ??? occurs on Determinate 4, Determinate 2, and Indeterminate 2, 4 after box 1 is opened; (*d*) − + ?? occurs on Determinate 2 and Indeterminate 2, 4 after box 2 is opened; (*e*) − + − ? occurs on Determinate 2 and Indeterminate 2, 4 after box 3 is opened. Proportions for multiply occurring patterns are averaged over all the instances of that pattern.

Responses to the Probe Question

To what extent could children encode multiple alternatives but still fail to evaluate them appropriately? As in Experiment 1, the probe question ("Could I have used any of these other boxes?") was designed to investigate this issue. In order to test whether encoding and evaluation are independent processes, we compared children's responses to the test question and the probe question for each evidence pattern once the first box had been opened. For 17 of the 20 times that the pair of questions was asked, the correct response was "can't tell" to the test question and "yes" to the probe question. (The other three times the questions were asked there was sufficient information to make a determinate response, and so they were not used in the analysis.) Children's proportion of correct responses on the 17 test and probe questions were analyzed using a repeated-measures ANOVA, with the type of question as the repeated factor. As predicted, performance was significantly better on the probe question than on the test question ($Ms = .81$ vs. $.47$, respectively), $F(1, 24) = 40.1$, $p = .0001$. Thus, children were accurately encoding the alternatives as possible but failing to evaluate the situation as indeterminate.

We also coded children's test and probe response on each indeterminate problem when all the boxes were open. Children's responses were categorized as belonging to one of four categories: Can Tell–Yes, Can Tell–No, Can't Tell–Yes, or Can't Tell–No. Children were placed into a category if at least two of their three response pairs matched the category. If the ability to encode multiple alternatives is a separate and prior acquisition to the ability to evaluate their implications, then no child should respond "can't tell" to the test question and "no" to the probe. Seventy-five percent of the children were categorized as Can't Tell–Yes, 17% were Can Tell–No, 8% were Can Tell–Yes, and no children were categorized as Can't Tell–No, Fisher exact test ($N = 24$), $p = .0014$.

We next examined the relation between children's responses on the probe and test questions under three types of saliency: (1) prior to seeing a visible match (Hidden and Negative & Hidden); (2) after seeing a single visible match (Positive & Hidden); and (3) after seeing multiple visible matches (Visible & Positive). Figure 4 shows the mean proportion correct by question for these three conditions. A within-subject repeated-measures ANOVA with Question (test vs. probe) and evidence (Hidden and Negative & Hidden; Positive & Hidden; Visible & Positive) as the within factors revealed main effects for question, $F(1, 24) = 42.3$, $p < .0001$, and evidence, $F(2, 24) = 25.0$, $p < .0001$, as well as a question × evidence interaction, $F(2, 48) = 5.8$, $p < .005$. When there were no matching boxes or when there were multiple matching boxes, children said "can't tell" 63% and 73% of the time, respectively. In contrast, when only a single matching box was present, children said "can't tell" only 17% of the time. When responding to the probe questions, children were more likely to respond that some other box might yet render the problem indeterminate. Nevertheless, as with the test question, children's responses to the probe were also affected by the pattern of evidence. Children were more likely to say "yes" to the probe when there were no matches visible ($M = .98$, $SE = .01$) than when there were multiple matches visible ($M = .86$, $SE = .04$), $t(24) = 3.2$, $p < .005$, and they were least likely to say "yes" to the probe when only a single visible match was present ($M = .63$, $SE = .08$), $t(24) = 4.6$, $p < .0001$, and $t(24) = 3.05$, $p < .01$, for single match versus no visible matches and multiple visible matches, respectively.

Probability-Based Evaluation?

As noted earlier, it is possible that children view their task as gambling that they can correctly guess the outcome to a problem before all the evidence is in. The probability analysis described earlier provides a baseline against which to assess such an evaluation process. We will show that the evidence does not support children's use of such a strategy.

If children were sensitive to the underlying probability that a problem might turn out to be determinate, then they might have used a strategy in which they responded "can tell" whenever the probability exceeded some threshold. If children followed a probability-matching strategy and had different individual thresholds, then the mean proportion of "can tell" responses for each pattern of evidence would be correlated with the actual probability of determinacy associated with each pattern. However, the correlation between probability of determinacy and proportion of "can tell" responses for the 13 indeterminate patterns is low, $r(df = 11) = 0.39$, N.S., and there are large and systematic deviations from the response pattern that would be predicted by probability-

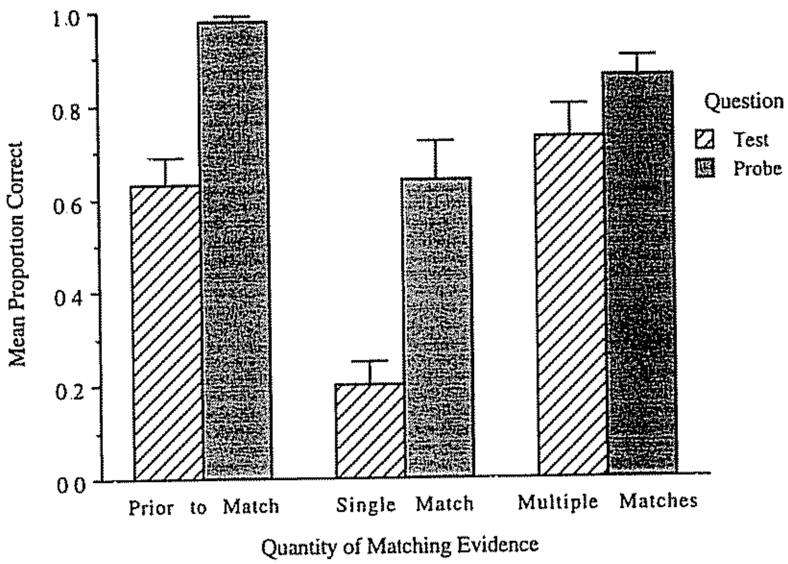

FIG. 4.—Mean proportion correct responses to indeterminate configurations by quantity of visible matching evidence by question (Experiment 2). Error bars represent the standard errors of the means.

based responding strategies. Of particular interest is the fact that the four Positive & Hidden patterns (− + −?, + − ??, + ???, − + ??) have relatively high proportions of (incorrect) "can tell" responses (.72, .76, .72, .90) that are highly discrepant from their probabilities of determinacy (.50, .25, .13, .25). These large discrepancies between the probabilities and the proportions of indeterminate judgments rule out the types of probability matching strategies considered here.

Saliency of Visible Indeterminacy

The materials in Experiment 2 were designed to investigate whether children's evaluation process is influenced by the amount of visible matching evidence. We have already established that children find it harder to reason about potential evidence than about visible evidence, but the question remains about whether the evaluation process is influenced by the *amount* of visible evidence for indeterminacy. In order to address this question, we compared each child's response on the problem where the saliency of the indeterminacy was high (+ + + +) with his or her response on problems where it was low (+ − + − and − + − +). Paired sign tests revealed that the differences were not significant: (+ + + +) versus (+ − + −), $p > .06$, and (+ + + +) versus (− + − +), $p > .1$. Although there is a slight trend in the expected direction (percent of children correct = 84, 80, and 68 for + + + +, − + − +, and + − + −, respectively), the saliency effect is very small, at least in this limited range. This finding suggests that children evaluate multiple matches as indeterminate, regardless of the actual number.

Relation between Search Strategies and Performance

As in Experiment 1, we examined the relation between search and performance on determinate and indeterminate problems. For the determinate problems, 54% of the justifications were based on Confirmative search: children justified their "can tell" responses by focusing on the match between the object and the box contents. Forty-four percent of the justifications were based on Eliminative search: children justified their "can tell" responses by focusing on the unique match (e.g., "It's the *only* box with green sticks") or the mismatches of all the other boxes. Finally, 2% were Noninformative: children either failed to justify their responses or said they "just knew" or "because." Unlike Experiment 1, there was no relation between the type of search used on the determinate problems and test responses on the indeterminate problems. That is, children who used Confirmative search on the determinate problems were as likely to get the indeterminate problems correct as children who used Eliminative search on the determinate problems. The failure to find this relation may be due to the sequential opening of the boxes. When a nonmatching box was opened, children would use Eliminative search to justify why the box couldn't have been used (e.g., "It can't be this box because it doesn't have red beads"). Thus when the final box was opened, they had already eliminated all the impossible boxes, leaving it unnecessary for them to justify their response by eliminating them again.

Across the three indeterminate problems, 68% of the justifications were Confirmative, focusing on the matching boxes, 23% were Eliminative, focusing on the failure to eliminate, and 9% were Pseudo-Eliminative, focusing on nonexistent differences between the boxes and the object as a means for eliminating the boxes. Children's search strategies were related to their performance on the indeterminate problems. When they used a Confirmative strategy, children were correct 80% of the time, and when they used an Eliminative strategy they were correct 86% of the time. In contrast, when they used a Pseudo-Eliminative strategy they were correct only 29% of the time. As in Experiment 1, even when children incorrectly responded "can tell" on the indeterminate problems, their response was based on their encoding of one box as uniquely matching the target. This finding, that children justify their determinate responses on the basis of a unique match, suggests that they have a correct evaluation process but that they inaccurately encode the contents of the boxes.

Individual Response Strategies

To what extent do *individual* children match or deviate from the conclusions based on the aggregate analysis presented thus far? In order to address this question, we performed a rule analysis. It is a procedure that attempts to produce a parsimonious set of rules or strategies that can characterize individual children according to their patterns of responses to a set of stimuli. Rule analysis has been used to study children's thinking in a variety of domains, including several Piagetian tasks (Siegler, 1976, 1981), sequence extrapolation (Klahr & Wallace, 1970), problem solving (Klahr & Robinson, 1981), and arithmetic (Brown & Burton, 1978; Ellis & Klahr, 1993). In this section, we apply rule analysis to the domain of indeterminacy. First we describe the rules, and then we describe the process whereby we determined which rule each child used. We will show that our subjects can be classified according to a set of rules that reflect different levels of competence in the search, evaluation, and mapping processes.

Rule Set

Table 3 lists the rule set. For each rule, the table indicates the response that a child using that rule would give to each type of evidence pattern. The table also shows the number of subjects fitting each rule. The rules are:

1. *Know all*.—Children using the *know all* rule are completely insensitive to the stimulus and respond "can tell" to all configurations. This rule could result from inadequacies in any of the component processes: inadequate search, a faulty evaluation process, or biases in the mapping process.

2. *Matching*.—Children using the *matching* rule respond "can tell" to configurations with one or more matches. They respond correctly to fully exposed determinate problems, to Negative & Hidden problems, and to Hidden problems, but they get all other problems wrong. This rule is minimally sensitive to the evidence. The search process correctly represents the *absence* of positive evidence, and the evaluation and mapping processes respond correctly. However, as soon as search encodes *any* positive evidence the evaluation process identifies a single matching alternative and mapping produces a "can tell" response.

3. *Positive capture*.—Children using the *positive capture* rule are more discriminating than children using the matching rule. These children correctly respond "can't tell" on Negative & Hidden problems, on Hidden problems, and on Positive & Visible problems. However, they incorrectly respond "can tell" when there is only a single matching box and the remaining boxes are either all closed or a combination of nonmatching and closed (i.e., on Positive & Hidden problems). The single positive instance in the context of unopened boxes causes the search process to create a representation that the evaluation process fails to interpret correctly.

4. *Expert*.—Children using the *expert* rule produce correct responses to all problems.

Neither the matching nor the positive capture rules respond correctly to the "inference problem" in this set (the penultimate configuration in the Determinate 4 problem, in which three of the four boxes are open and no positive instance has yet been found). Therefore, we included two minor variants of matching and positive capture (*matching and inference* and *positive cap-*

TABLE 3

Responses to Each Type of Evidence Pattern by Each Rule and Number of Subjects Using Each Rule (Experiment 2)

Rule	Type: Determinate −+−− −−−+	Negative & Hidden (Inference) −−−?	Negative & Hidden −−?? −???	Hidden ????	Positive & Hidden −+?? −+−?	Positive & Visible +−+? ++??	No. of Subjects Matching Rule
Know All	Can tell	Can tell	Can tell	Can tell	Can tell	Can tell	5
Matching	Can tell	Can't tell	Can't tell	Can't tell	Can tell	Can tell	1
Matching and inference	Can tell	Can tell	Can't tell	Can't tell	Can tell	Can tell	2
Positive capture	Can tell	Can't tell	Can't tell	Can't tell	Can tell	Can't tell	3
Positive capture and inference	Can tell	Can tell	Can't tell	Can't tell	Can tell	Can't tell	12
Expert	Can tell	Can tell	Can't tell	Can't tell	Can't tell	Can't tell	1

Note.—Cell entries indicate the response that the rule would give to problem type shown at the top of the table. Correct responses are underscored.

ture and inference, respectively) that differ from their base rules only in that the evaluation process makes the correct inference about the contents of unopened boxes.

Fitting the rules to children's responses.—Each child generated five responses of "can tell" or "can't tell" to each of the five problems as the configuration changed from having all boxes closed to all boxes opened. Thus, each child's response pattern can be represented as a 25-bit binary vector. Similarly, when applied to the set of 25 configurations, each rule generates a 25-bit response vector. For each child, we computed the number of matches between the child's vector and all the rule vectors, and then chose the best-fitting rule that matched at least 18 of the 25 responses ($p < .02$).[8] If two rules equally matched the child's responses, we assigned them the more advanced rule. Twenty-four of the 26 children were successfully classified as follows: know all, five children; matching, three children; positive capture, 15 children; expert, one child. Two children were unclassifiable. Twelve of the 15 positive capture children and two of the three matching children fit the inference variant of their rules best.

Discussion

When presented with problems having sufficient evidence to make a determinate response, all children always correctly responded "can tell" and selected the correct box. Furthermore, on 67% of the trials where they were shown multiple alternatives that were consistent with the target object, children correctly responded "can't tell" and did *not* select a box. Thus, it appears that 5-year-olds' evaluation process can correctly distinguish among different types of representations produced by the search and encoding processes on problems in which all the relevant evidence is available. However, children have difficulty when there is no visible evidence to support indeterminacy and they have to create and evaluate representations for closed boxes. These results are in contrast with Byrnes and Beilin's (1991) summary of earlier findings that "virtually all children (including 10-year-olds) are found to respond with certainty on their first encounter with an uncertainty trial" (p. 198). The analyses presented here suggest that children's ability to reason about indeterminacy is dependent upon the kind of evidence they are given: when the indeterminacy is visible, rather than hypothetical, they are likely to respond correctly.

Not only did the 5-year-olds respond correctly to visible indeterminacy, but they also tended to use logical reasoning strategies to justify their "can't tell" responses, focusing on either the multiple matches to the object or the failure to eliminate all but one box as the correct box. This suggests that 5-year-olds do understand that in order to make a valid conclusion only one box can match the object. Those children who were incorrect on visibly indeterminate problems tended to justify their selection of a box by endowing the material in the box and the object with the same nonexistent characteristic and eliminating the other boxes because they did not possess this characteristic. Thus, even these children had some notion that a determinate response had to be based on evidence that only supported one box, but they used invalid evidence to make these judgments. This suggests that their evaluation processes do embody the implications of sufficient and insufficient evidence for making conclusions.

The rule analysis used in Experiment 2 revealed wide individual variation in 5-year-olds' strategies for solving these problems. Although 19% of the children were classified as using the know all rule, 58% of them (those classified as using the positive capture rule) showed some sensitivity to the configuration of evidence and were able to recognize indeterminacy when it was clearly evident, even though they were misled by a single visible match.

Learning across Trials?

Although we never provided direct feedback on the correctness of children's responses, the sequential opening procedure did afford a form of feedback. Specifically, if children were sufficiently attentive to compare their early responses to a problem with their subsequent ones as each box was opened, then they might notice those cases in which they prematurely gave determinate responses to problems that turned out to be indeterminate. The results from Experiment 2 provided a mixed picture on this question. On their first problem, 40% (10 of 25) of the children responded "can tell" to the Hidden

[8] The null hypothesis is that for each pattern there is an equal probability that the child will respond "can tell" or "can't tell."

pattern (????) and selected a specific box. In almost all such cases, children's predictions of the correct box proved incorrect as additional evidence became available. By the final problem only 16% of the children gave a "can tell" response to the Hidden configuration. Of the eight children who changed their response from the first to the last problem, seven changed from "can tell" to "can't tell" (binomial test, $p < .05$). Although this improvement on the Hidden patterns suggests that children were learning something about indeterminacy from seeing each problem unfold as the boxes were opened, we found no evidence of learning for any other evidence configuration. More specifically, for each evidence pattern, we computed the binomial probabilities for the number of children who changed their response from "can tell" on the first presentation to "can't tell" on the last presentation out of the total number of children who changed their response. None of the evidence patterns reveal any significant change, $ps > .09$.[9] In Experiment 3, we modified the procedure so as to remove the sequential opening feature of Experiment 2, in order to explore this issue further. We also explored the extent to which we could identify the same types of response strategies in a younger age group.

Experiment 3

Children were presented with evidence patterns consisting of four boxes that could be in any of three states: open and matching the target object, open and mismatching the target object, or closed. The problem set included each of the patterns of matching, mismatching, and closed boxes that were used in Experiment 2, as well as some additional configurations. The patterns were presented in a randomized order, without any sequential dependencies. That is, in contrast to Experiment 2, successive patterns of evidence were unrelated to one another and did not depict the sequential opening of four boxes with a fixed set of contents. Therefore, children could not anticipate the opportunity to obtain additional evidence about a particular problem. Instead of using real boxes as in Experiment 2, we presented the evidence patterns, depicted as open and closed boxes, on a computer screen, creating an engaging "computer game" context for the children.

Method

Subjects

Twenty 4-year-old children (11 boys and 9 girls) from a university laboratory preschool participated in the experiment. Children ranged from 4.0 to 5.3 years ($M = 4.8$ years) and came from predominantly upper-middle-class families.

Apparatus and Materials

The problems were presented on an Apple Macintosh IIci, with a 12-inch color monitor. The keyboard was locked except for the Z and the slash keys. Two buttons were made from oval-shaped pieces of cardboard, approximately 1 inch in length, one displaying a picture of a light bulb, and the other a question mark. An audio tape recorder was used to tape the sessions.

The program interface.—A typical test problem is depicted in Figure 5. As in Experiment 2, there were four boxes and one target object. The boxes could be either opened or closed, and if opened, the box contents could either match or mismatch the target object. The target object, displayed directly below the boxes in the center of the screen, could be one of four objects (ball, stick, triangle, or diamond) in one of four colors (blue, red, green, yellow). At the bottom corners of the screen were two icons: a light bulb and a question mark (corresponding to the conventional cartoon icons for "know" and "guess"). The Z key and the slash key were covered with either the question mark button or the light bulb button. Half the children saw the light bulb icon and button on the right side and half saw it on the left side. When one of the buttons was pressed, the icon flashed and a tone sounded. Problems were advanced by the experimenter using the mouse button.

Problems.—The problems were constructed by forming every possible combination of matching, mismatching, and closed boxes (with the exception of all mismatching boxes).[10] The problem set is listed in Table 4, arranged by type of problem (Determinate or Indeterminate), and type of evidence (Hidden, Negative & Hidden, Positive & Hidden, and Positive & Visible). Every problem (except + + + −) had an equivalent in Experiment 2. For example, the Positive

[9] The ratios of the number of children changing from an incorrect to a correct response from the first to last presentation to the total number who changed their response are 3/3, 5/7, and 5/6 for the Positive & Visible, Positive & Hidden, and Negative & Hidden, respectively.

[10] Combinations, not permutations are relevant here. Thus the patterns −?+?, −+??, +−??, etc. are all the same pattern: one match, one mismatch, and two closed boxes.

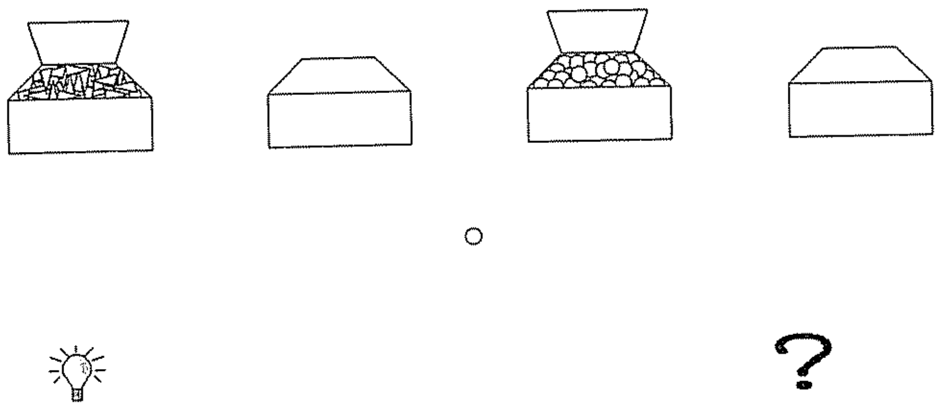

FIG. 5.—The layout of the computer screen presenting a test problem, Experiment 3 (evidence pattern shown is − ? + ?).

& Visible pattern (+ + ??) corresponds to Experiment 2's Indeterminate All after the second box was opened. Note that, as in Experiment 2, the Positive & Visible category does not include *only* patterns in which all boxes are open. It includes patterns in which there is sufficient visible evidence to render an unambiguous decision about whether the problem is determinate or indeterminate. Thus, some of the Positive & Visible indeterminate patterns have closed boxes. Note also that we classify the − − − ? evidence pattern as determinate Negative & Hidden because the problem determinacy can be inferred with certainty.

Because there are only two evidence patterns for determinate problems (− − − +, − − − ?), each was presented four times, with the matching box (or the closed box) occurring once in each of the four box positions. The positions of the open and closed boxes for the indeterminate problems were varied randomly.

Procedure

Children were given four practice problems followed by 20 test problems. For each problem, children were instructed to click on the light bulb button if they "knew for sure" which box was used to make the object or to click on the question mark button if they "could only guess" which box was used. For a subset of the problems the experimenter asked children to justify their response by asking, "Why is this a time that you know which box was used to make this?" or "Why is this a time that you had to guess which box was used to make this?"

Results

SCORING

Responses were scored as correct if the child selected the know (light bulb) button on the determinate problems or the guess (question mark) button on the indeterminate problems.

Overall Performance

Children correctly responded "know" to 79% of the determinate problems and "guess" to 39% of the indeterminate problems. A repeated-measures ANOVA, with problem type (determinate vs. indeterminate) as the repeated measure and propor-

TABLE 4

TWO TYPES OF DETERMINATE PROBLEMS AND 12 TYPES OF INDETERMINATE PROBLEMS BY TYPE OF EVIDENCE (Experiment 3)

	Type of Problem			
Type of Evidence	Determinate	Indeterminate		
Hidden		????		
Negative & Hidden	− − − ?	− ???	− − ??	
Positive & Hidden		+ ???	− + ??	− + − ?
Positive & Visible	− − − +	+ + ??	+ − + ?	+ − + −
		+ + + ?	+ + + −	+ + + +

tion correct as the dependent measure revealed that performance was significantly better on determinate problems than indeterminate problems, $F(1, 19) = 29.5$, $p < .0001$.

We next examined whether children's performance on indeterminate and determinate problems was affected by the type of evidence provided. Based on the results from Experiment 2, we expected that children's worst performance would occur on Positive & Hidden indeterminate problems. We also hypothesized that on determinate problems, children would perform better on the Positive & Visible than on the Negative & Hidden problems.

Figure 6 shows the mean proportion correct for the problems categorized by the type of problem and the type of evidence. A repeated-measures analysis using problem category as the repeated measure and proportion correct as the dependent measure revealed a significant effect for problem category, $F(4, 76) = 28.3$, $p < .0001$.[11] *T* tests comparing each pair of means revealed the following differences between the indeterminate problems: (1) performance was better on the Hidden and Negative & Hidden problems than on the Positive & Visible and Positive & Hidden problems, $ts(19) = 5.3$ and 8.0, respectively, $ps < .0001$; and (2) performance on the Positive & Visible problems was better than on the Positive & Hidden problems, $t(19) = 2.7$, $p < .005$. Performance was better on Positive & Visible and Negative & Hidden determinate problems than on: (1) Positive & Visible indeterminate problems, $ts(19) = 6.3$ and 3.4, respectively, $ps < .001$, and (2) Positive & Hidden indeterminate problems, $ts = 9.0$ and 6.1, respectively, $ps < .0001$. Finally, performance was better on the Positive & Visible determinate problems than on the Negative & Hidden determinate problems, $t(19) = 2.9$, $p < .005$.

Thus, 4-year-olds' evaluation of determinate and indeterminate problems was affected by the type of evidence presented to them, and their pattern of responses was similar to that found in Experiment 2. In general, children appeared to base their evaluations only on the quality of the visible evidence. When there was no visible matching evidence, children were likely to respond "guess." This is indicated by the high proportion of correct "guess" responses on the Hidden indeterminate problems (95%) and the relatively high proportion of incorrect "guess" responses on the Negative & Hidden determinate problems (35%). When there was one matching box, children overwhelmingly responded "know." On the Positive & Visible determinate problems children correctly responded "know" on 93% of the problems, and on the Positive & Hidden indeterminate problems children incorrectly responded "know" on 93% of the problems.

Individual Differences and Performance

The overall pattern of responses suggests that 4-year-old children are sensitive to the type of evidence that is presented to them. However, as in Experiment 2, individual children may be differentially sensitive to patterns of evidence. To examine individual strategies in responding to evidence patterns, we repeated the rule analysis described in Experiment 2. The same set of four basic rules was able to account for all but one child at the $p < .02$ level or better. The fit was as follows: know all, two children; matching, 11 children; positive capture, six children. There were no experts.

As in Experiment 2, children in Experiment 3 clustered mainly in the matching and positive capture categories. However, children in Experiment 3 were more likely to be classified as using the matching rule rather than the positive capture rule, whereas their older counterparts in Experiment 2 showed the opposite pattern, $\chi^2(2, N = 46) = 10.1$, $p < .01$.[12]

Discussion

Both the 4-year-olds in Experiment 3 and the 5-year-olds in Experiment 2 correctly solved nearly 80% of the determinate problems. However, on the indeterminate problems the younger children in Experiment 3 did not do as well as the 5-year-olds in Experiment 2 (39% vs. 65%, respectively). We believe that this effect is primarily due to the age differences between the two

[11] Because there was only one Hidden indeterminate problem (????), the Hidden and the Negative & Hidden indeterminate problems were collapsed into one category

[12] In order to compare the rule distributions for Experiment 2 and Experiment 3, we classified children into three categories: matching, positive capture, and a combined category that included the three remaining initial classifications in which there were similar (and few) entries across experiments: know all, expert, and unclassified

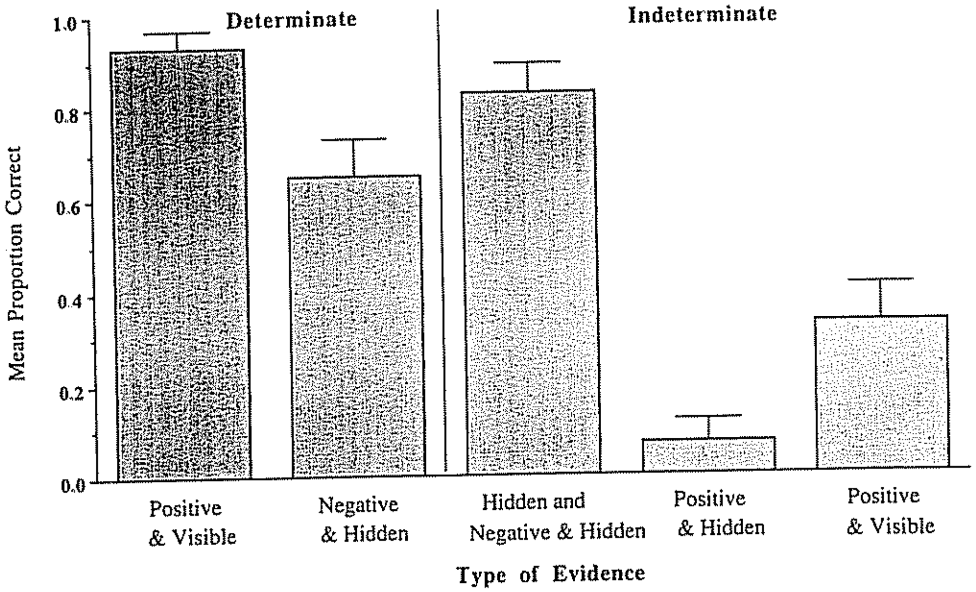

FIG. 6.—Proportion correct for each type of evidence (Experiment 3). Error bars represent the standard errors of the means.

groups rather than the differences in the materials and procedure. Two pieces of evidence support this hypothesis. First, if the type of materials (computer presentation vs. real boxes and objects) interfered with performance then performance on all problems should be affected, which was not the case. The differences in performance were limited to one type of evidence pattern. When given multiple matching boxes (i.e., indeterminate Positive & Visible problems), the 4-year-olds in Experiment 3 were more likely to incorrectly respond "know" than the children in Experiment 2 (67% vs. 33%, respectively). In both Experiment 2 and Experiment 3 most children responded *correctly* on indeterminate problems when there was no positive evidence (80% and 83%, respectively) and most children responded *incorrectly* on the "positive capture" problems (80% and 93% for Experiment 2 and 3, respectively). Second, if the nonsequential presentation of the patterns led to poorer performance (because the children had no opportunity to discover that a problem they had designated as determinate would turn out to be indeterminate), we would expect performance to be worse on the indeterminate patterns where there was no visible evidence supporting indeterminacy (i.e., Hidden, Negative & Hidden, or Positive & Hidden patterns). However, as shown above, the largest difference in performance between the younger and older children was on the Positive & Visible indeterminate problems, where the evidence that would render a problem indeterminate was already visible.

Overall, the results of Experiment 3 demonstrate that most 4-year-olds can accurately search and evaluate determinate situations and indeterminate situations when there is *no* positive evidence visible. However, as indicated by the high proportion of children fitting the matching rule, they have difficulty accurately evaluating positive evidence. As soon as the search process encodes any positive evidence the evaluation process identifies a single matching alternative, and mapping produces a "know" response.

General Discussion

The results of our experiments with preschoolers extend and amplify the results of previous investigations of children's understanding of indeterminacy. Our 4- and 5-year-old children found it easier to identify determinacy than indeterminacy—a pattern that many others (Byrnes & Overton, 1986; Piéraut-Le Bonniec, 1980; Scholnick & Wing, 1988) found with 7–10-year-olds. However, we do not attribute the difficulty young children have with indeterminate problems to their reluctance to give "can't tell" responses because the 5-year-olds in Experiment 2 correctly responded "can't tell" to almost 70% of the indeterminate problems with multiple visible matches, and even the 4-year-olds in Experiment 3 correctly responded "can't tell" to problems with no visible matches 83% of the time. Furthermore, many of the same children who incorrectly responded "can tell" to positive capture problems also incorrectly responded "can't tell" on the inference problem (− − − ?). Overall, we found that preschoolers did not hesitate to give "can't tell" responses when they thought (correctly or incorrectly) that the evidence warranted such a response.

Our studies have also provided new evidence about how preschoolers distinguish between determinacy and indeterminacy. First, we found that children's excellent performance on determinate problems does not derive from a single approach to such problems. Different children used different strategies to process determinate evidence. These strategies, in turn, predicted children's performance on indeterminate problems. Second, we discovered that evidence patterns in which a single positive instance is contrasted with one or more negative or unknown instances were particularly difficult for preschoolers to interpret. We found that many children used a decision rule—the positive capture rule—that produced consistent errors on this type of problem. The final contribution of this work is the specification of an information-processing model of reasoning about indeterminacy. We argue that the development of an understanding of indeterminacy derives from children's acquisition and coordination of three processes: search, evaluation, and mapping.

Search

Attending and Encoding

In our model, the search process consists of two subprocesses—attending and encoding. Search involves iteratively attending to and encoding aspects of the task environment and determining when there is sufficient evidence to terminate the process. Once a piece of evidence is attended to, an internal representation of the evidence is created. Several investigators have characterized one source of difficulty as premature termination of search (Lunzer, 1973, 1978). If children stop searching as soon as they find a match, they will fail to notice other possible matches and will tend to give determinate responses. Search failures lead children to inaccurately encode the evidence state and then map it onto its corresponding mental state (e.g., only encode one match and map that match onto a mental state of certainty).

The purpose of our probes was to assess the attending and encoding processes independent of evaluation and mapping. This enabled us to verify earlier reports (e.g., Acredolo & Horobin, 1987; Byrnes & Overton, 1986; Piéraut-Le Bonniec, 1980; Somerville et al., 1979) that children have little difficulty in recognizing cases in which there are multiple positive instances. In Experiment 1, for some children, the probe appeared to stimulate further attending and encoding, which in turn led children to revise their erroneous determinate responses. Nevertheless, many others persisted in giving determinate responses, even after they had correctly identified multiple alternatives. Although these children attended to the contents of both boxes, they encoded irrelevant features and used them to evaluate the problem as determinate.

In Experiment 2, a single match in the context of negative or unopened boxes increased the saliency of that single match and produced truncated searches, and in Experiment 3 any number of matches in the context of negative or unopened boxes led to premature termination of search. In contrast, patterns having only negative instances or unopened boxes did not contain any high-saliency elements, and children were less likely to terminate search prematurely.

Evaluation

This process evaluates the information produced by the attend and encoding processes and decides whether the solution is known or whether there is insufficient information to generate a single solution. It captures the essence of the underlying logic of indeterminacy. The present studies, as well as earlier investigations (e.g., Acredolo & Horobin, 1987; Somerville et al., 1979; Wollman et al., 1979), suggest that preschool children have incomplete versions of this component. Evaluation failures occur when children accurately encode the evidence but fail to create the appropriate internal representation. As noted above, many of our children seemed to be aware that multiple solutions existed but not that this evidence necessitated a knowledge state of uncertainty.

Mapping

Even when all these other processes are functioning properly, an inadequate mapping process may lead children to give determinate responses to indeterminate problems. The variety of evidence patterns used in Experiments 2 and 3 revealed that while a subset of 4- and 5-year-olds may have difficulty with this mapping, many more of them are able to make the correct mapping once they have created a correct abstract representation of determinacy or indeterminacy (via the evaluation process).

Conclusion

At the outset of this article, we noted the fundamental importance of the distinction between determinacy and indeterminacy for scientific reasoning. We believe that the positive capture problems evoke in children a drastically simplified form of reasoning error to which even seasoned scientists are vulnerable. The adult analog occurs when, having posed what we believe are two mutually exclusive and exhaustive hypotheses—of the kind all too common in psychology (Newell, 1973)—we find experimental outcomes that support one and not the other. This situation is formally equivalent to the − +?? pattern: one hypothesis that is not supported by the evidence (the − box), one that is supported by the evidence (the + box), and a space (formally infinite) of hypotheses yet to be discovered. Given the contrast between the + and −, we are easily convinced that we have, indeed, a logical basis on which to say "can tell" instead of "can't tell." Consequently, we fail to consider additional hypotheses (Nature's unopened boxes) that might render the situation indeterminate. Thus it may be that scientists, as well as children, are captured—in the short run at least—by a successful contrast between positive and negative instances to such an extent that they find it difficult to generate rival hypotheses (Huck & Sandler, 1979).

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