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# A REVIEW OF SOME PIAGETIAN CONCEPTS* | 3

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## OVERVIEW

Our task was to examine Piagetian concepts in light of recent research and theory on cognitive development. This breathtaking assignment was made somewhat easier by the fact that elsewhere in the *Handbook* there are discussions of the first (sensorimotor intelligence) and last (formal operations) of Piaget's proposed stages of development. This allowed us to focus on Piaget's two intermediary stages of development, those of preoperational and concrete-operational thought. But we still had to make choices. In the end, we tried to put together a review that would reflect the impact of Piagetian theory as well as our own views on the current status of the theory. The result is a review that is critical, yet in agreement with some of the fundamental tenets of the theory. Thus, we accept the position that there is much to be learned about cognitive development by studying the acquisition of such concepts as number, space, time, and causality. We also have no quarrel with the idea that cognition involves structures that assimilate and accommodate to the environment; indeed, we do not see how it could be otherwise. However, we do question the notion of there being broad stages of development, each characterized by qualitatively distinct structures. As we will see, the experimental evidence available today no longer supports the hypothesis of a major qualitative shift from preoperational to concrete-operational thought. Instead, we argue for domain-specific descriptions of the nature as well as the development of cognitive abilities.

Our review of Piagetian concepts starts with matters of *structure* and ends with matters of *function*, or development proper. That is, we take up first the

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*what* and then the *how* of cognitive development. We begin by examining some of Piaget's ideas about the nature of preoperational and concrete-operational thought. We then review in some detail the research that has been conducted in several cognitive domains, including numerical and quantitative reasoning and classification. In the final section, we examine Piaget's ideas about the sources of cognitive structures and the processes—assimilation, accommodation, equilibration, and so on—that account for their development.

## ASSESSMENT OF THE CHARACTERIZATION OF CONCRETE OPERATIONS

When tested on the standard Piagetian tasks in the standard way, preschool children typically err in their responses. Thus, when asked whether a bouquet composed of six roses and four tulips contains more roses or more flowers, they quite invariably answer more roses. Similarly, when presented with two even rows of chips and asked, after watching the experimenter spread one row, whether the two rows still contain the same number of chips, preschoolers typically respond that the longer row has more.

No one seriously questions the reliability of these (and other similar) observations, which have all been widely replicated. What is very much at issue, however, is how preschoolers' failure on the standard Piagetian tasks should be interpreted. The fact that children less than 6 years of age typically fail these tasks and that children 6 years of age and older typically succeed on these tasks suggests that there are important differences in their cognitive capacities. The question is, How should these differences be characterized?

Piaget's account of the differences involved granting the older child reversible structures, or operations, while limiting the younger child to irreversible structures: hence the use of the terms operational and preoperational to describe the cognitive capacities of the older and the younger child respectively. Piaget believed that children's (at first concrete and later formal) operations are organized into well-integrated sets, or structured wholes, and he and his colleagues developed logicomathematical models to characterize these wholes. (The reader who is not familiar with these models is referred to Flavell, 1963; Gruber and Vonèche, 1977; and Piaget, 1942, 1957).

Evaluation of the theory of concrete operations has proceeded along several lines. One has been to assess whether success on different Piagetian tasks (e.g., conservation, classification, seriation, perspective taking) is indeed related. Another has been to explore the preschool child's alleged intellectual incompetence relative to the older child. Still another line of evaluation, closely related to the third, has been to devise training studies that might bring to the fore unsuspected competencies. In the next sections, we review some of the work that has been done along each of these lines.

### Are There Structures d'Ensemble?

#### Do Multiple Correlations Obtain?

Many studies have been conducted to compare children's ability to classify, seriate, conserve, measure, give predictions and explanations, assume another's visual or social perspective, and so on. Most such studies have failed to show high intercorrelations between the various abilities tested (e.g., Berzonsky, 1971; Dimitrovsky & Almy, 1975; Jamison, 1977; Tomlinson-Keasey, Eisert, Kahle, Hardy-Brown, & Keasey, 1979; Tuddenham, 1971). Such findings are not really inconsistent with Piagetian theory. Piaget never really claimed (1) that all concrete-operational abilities are based on, or are derived from, a single underlying structure; or (2) that all concrete-operational abilities emerge in a strictly parallel, perfectly synchronous fashion (Vyuk, 1981). To the contrary, Piaget's writings are filled with theoretical claims concerning the order of emergence within each developmental stage of distinct cognitive abilities, with the earlier abilities viewed as precursors of, or as prerequisites for, the later abilities. For example, Piaget (1952a) argued that numerical reasoning is the product of the joint development of the child's classification and seriation abilities. In addition, Piaget often noted in his empirical writings that cognitive abilities, once acquired, are not always applied uniformly in all contexts. Instead, cognitive abilities are frequently applied in one context at a time, with considerable décalages between successive applications. Thus, Piaget (1962) reported that children do not conserve number before the age of 6 or 7; mass, before the age of 8; weight, before the age of 10; and so on.

All of these theoretical and empirical claims obviously mitigate against the possibility of anyone finding high correlations between children's performance on many or all of the concrete-operational tasks. Contrary to what is sometimes held to be the case, investigators' repeated failure to find high correlations across tasks does *not* constitute definite evidence against the notion of a concrete-operational mentality in the (relatively diffuse) sense intended by the theory. Still, such consistently negative results do raise difficulties when it comes to the interpretation of certain studies. Psychologists and educators often attempt to relate children's performance on a given task to their level of cognitive development (e.g., preoperational, concrete-operational) as assessed by any of the standard Piagetian tasks. Were it the case that performance on all standard Piagetian tasks was highly correlated, then, obviously, any task would be as good as any other as a test of children's mastery of concrete-operational thought. But as we just saw, that is far from the case. For this reason, studies that report relationships between, say, children's ability to use metamemorial strategies and children's ability to conserve (taken to demonstrate their entry into the concrete-operational stage) are difficult, if not impossible, to interpret vis-à-vis Piagetian theory.

### Are Sequences as Predicted?

The studies we discussed in the previous section tested for the synchronous emergence of different abilities during the concrete-operational period. Other studies have tested whether the order in which abilities develop within that period is as predicted by Piagetian theory. Several investigators have focused on the development of numerical reasoning in the child. As mentioned earlier, Piaget (1952a) maintained that the concept of number develops from the coordination of classification and seriation structures. According to Piaget (1952a), the construction of number

> consists in the equating of differences, i.e., in writing in a single operation the class and the symmetrical relationship. The elements in question are then both equivalent to one another, thus participating of the class, and different from one another by their position in the enumeration, thus participating of the asymmetrical relationship. (p. 95)

Piagetian theory generally assumes that success on standard number-conservation tasks indexes a true understanding of number and that success on standard class-inclusion tasks indexes a true understanding of classification. If Piaget's (1952a) account of the development of the concept of number was correct, one should not find children who pass standard number-conservation tasks well before they pass standard class-inclusion tasks. As Brainerd (1978a) recently pointed out, however, exactly the oppostie sequence obtains. The vast majority of children conserve number by age 6 or 7; but it is not until age 9 or 10 that they truly understand the principle of class inclusion (see also Markman, 1978; Winer, 1980). Such facts clearly call into question the claim that numerical reasoning is the product of the joint development of classification and seriation abilities. Additional evidence against this claim comes from a study by Hamel (1974).

Hamel (1974) analyzed Piaget's (1952a) account of number and concluded that it predicts a strong relationship between: (1) number conservation; (2) provoked correspondence; (3) spontaneous, that is, unprovoked correspondence; (4) seriation; (5) cardination-ordination; and (6) class inclusion. The correlations between the various number tests were significant and quite high (.50 to .80). Likewise, correlations between the multiple-classification tasks and the various number subtasks were also significant, ranging from .45 to .66. However, there were no significant relationships between the class-inclusion task and *any of the other tasks*. Dodwell (1962) reported similar results.

There are other studies that fail to observe some of the between-task predictions derived from the theory (e.g., Brainerd, 1978a; Kofsky, 1966; Little, 1972). There are even studies that fail to observe the same sequence of development across children—whether or not the sequence is predicted by the theory. For example, in a longitudinal study, Tomlinson-Keasey, et al. (1979) found that 13 of 38 subjects passed a class-inclusion task before they conserved amount, 12 passed it after, and 13 passed it at the same time.

What should we make of investigators' failure to confirm the between-tasks sequences predicted by the theory? Should we take it to suggest that Piaget was wrong in claiming that the concrete-operational stage is characterized by the coordinated emergence of superficially disparate but structurally related cognitive abilities? Not necessarily. It could be argued that to do so would be to confuse the issue of whether or not specific abilities develop in the order predicted by Piagetian theory with the more general issue of whether or not abilities from different cognitive domains develop in a well-integrated, coordinated fashion. Piagetian theory could be right in supporting the general issue and still be wrong in any of its specific predictions. Piaget's (1952a) account of the development of the child's understanding of number could be wrong—and as we will see, Piaget (1975a, 1977) himself later abandoned his earlier account—but the general hypothesis that development in other domains contributes to the emergence of the child's concept of number could still be right.

There obviously is no rebuttal to this argument. As the saying goes, the proof is in the pudding. What

Piagetian theory must provide is a satisfactory account of numerical (or causal, or spatial, or logical, etc.) development that posits real, nontrivial interactions between domains. To the extent that such an account can be provided, then to the same extent will the notion of a stage of concrete operations be reinforced. (As we will see below, however, the trend in recent years has been to move away from stage-like, across-the-cognitive-board accounts of development. More and more, investigators appear to focus on the possibility of parallel, domain-specific lines of development.)

### Test of the Logicomathematical Model

It is sometimes argued that the reason why investigators have failed to find high correlations between various concrete-operational abilities or have failed to confirm the order in which their abilities develop has to do with the way in which abilities are measured (see Flavell, 1972; Jamison & Dansky, 1979; Tuddenham, 1971). Different investigators use different tasks. Further, it is not always clear whether the tasks used provide a good test of the abilities under study. In addition, there are statistical nightmares. How does one estimate measurement error? Is it constant across tasks? And what if one finds only one child whose performance contradicts the expected pattern—should the theory be rejected?

One way to get around some of these difficulties is to work directly from the logicomathematical model of concrete operations Piaget and his collaborators proposed. Osherson (1974), for instance, used Grize's (1963) axiomatization of these operations. The choice of this axiomatization was based in large part on Piaget's (1967) endorsement of it. Further, Grize's axioms are easily interpreted into statements about classes and relations.

To start, Osherson (1974) derived a set of theorems that followed from Grize's (1963) axioms. He then translated a subset of the theorems into a set of length-inclusion and class-inclusion tasks designed to embody the derived theorems and, thus, provide a test of children's ability to use them. Finally, he made predictions about the patterns of successes and failures that should obtain. That is, he specified which tasks children should pass or fail, given that they had passed or failed certain other tasks. The predictions were based on the analysis of which and how many axioms a particular theorem was derived from. To illustrate, assume Theorems 1 and 2 were derived from Axioms 1 and 2, respectively and Theorem 7 was derived from Axioms 1 and 2. The child who passed the task designed to test for Theorem 7 should likewise have passed the tasks designed to test Theorems 1 and 2 by themselves.

Osherson (1974) found that despite an overall comparable success rate on the length-inclusion and class-inclusion tasks, the patterns of errors made in the two sets of tasks were *not* comparable. These findings suggest that the logicomathematical structures proposed by Piaget and his collaborators are not appropriate for modeling performance in these two task domains. Indeed, one might take these results to call into question the idea that the *same* structures underlie children's ability to solve length-inclusion and class-inclusion problems.

At this point, however, one might point out that Osherson's findings need no longer be taken into account as there have been changes in the formal theory of concrete-operational thought, as well as further developments in the efforts to axiomatize the theory (Piaget, 1977; Wermus, 1971). In addition, one could argue (as before) that even if Piagetian theory, in spite of its recent revisions, still fails to provide an adequate formal description for the logicomathematical structures underlying concrete operations, one need not conclude that no such structures exist: perhaps one has not yet succeeded in finding their proper characterization.

Whether or not the revised Piagetian model serves as a better model has yet to be determined. But as Sheppard (1978) pointed out, it is not clear that the more recent axiomatizations are all that different from the original ones.

### Are Within-Domain Relations as Predicted?

Investigators' repeated failure to verify the developmental sequences described by Piagetian theory has led many authors to doubt the claim that cognitive abilities emerge in a coordinated, orderly fashion across domains. Perhaps for this reason, some authors have sought to test the developmental sequences predicted by the theory *within* domains rather than *across* domains. If one interprets Piagetian theory to mean that performance within each domain is based on operations that are organized into a well-integrated, reversible structure, then one might expect to find relatively high correlations between tasks testing abilities assumed to be derived from that same structure. However, attempts to verify this particular hypothesis have not faired well.

Consider, for instance, the work of Hooper, Sipple, Goldman, and Swinton (1979) and Kofsky (1966), who tested Inhelder and Piaget's (1964) description of the development of classification abilities. Kofsky (1966) found that although she could discern a rank order of difficulty for her different classification tasks, only 27% of her subjects fit this pattern. Hooper and his colleagues (1979) later replicated Kofsky's overall developmental sequence.

Some of their findings also led them to doubt that this sequence represented the development of only one common classificatory structure. For instance, Hooper et al. found that the ability to multiply classes as assessed in a cross-class matrix task does *not* predict the ability to solve class-inclusion problems. Indeed, they, like many others (e.g., Brainerd, 1978a; Dimitrovsky & Almy, 1975; Dodwell, 1962; Hamel, 1974; Kofsky, 1966; Tuddenham, 1971; Winer, 1980) found that class-inclusion tasks are much more difficult—and are accordingly solved much later—than are other concrete-operational tasks. They concluded that some four separate factors contribute to the development of classificatory abilities.

Studies that examined the development of ordering abilities have yielded comparable results (Dimitrovsky & Almy, 1975; Tuddenham, 1971). Tuddenham reported a .28 (nonsignificant) correlation between the ability to seriate and solve a transitive inference task. Dimitrovsky and Almy compared children's ability to seriate and reorder, that is, place back in order stimuli that are mixed up before them. Of the 408 children tested, 134 passed the seriation task; in contrast, only 41 passed the reordering task.

Attempts to confirm Piaget's (1952a, 1975a, 1977) prediction that the ability to compensate precedes or co-occurs with the ability to conserve have also been unsuccessful. According to Piaget, the child who truly understands that the amount of liquid in a glass is conserved when it is poured into a container of different dimensions also understands the principle of compensation: "conservation . . . involves quantities that are not perceptive, but have to be constructed by compensation between two different dimensions" (Piaget, 1967a, p. 533). In his first presentation of this position Piaget (1952a) predicted that all children who conserved liquid would reveal an understanding of compensation. This meant that a child could pass a compensation task and fail a conservation task but not the reverse. In a subsequent presentation of the argument, Piaget considered the kinds of predictions children at different stages in the development of conservation should make before the transformation phase of both the conservation and compensation tasks (e.g., Inhelder, Bovet, Sinclair, & Smock, 1966; Piaget & Inhelder, 1974). At an initial stage, the nonconserver should predict that there will be conservation after the transformation and that the water level in the new beaker will *not* change. At the second stage, the nonconserver should predict that there will not be conservation and the water level *will* change. Finally, the true conserver should predict that the water level will change *and* that conservation will obtain in the face of this perceptual change. In either version of the conservation account, one should not observe a child who passes the conservation task and, nevertheless, fails the compensation task. Piaget and Inhelder (1963) reported that all but 5% of children who conserved were able to anticipate the level of water that would be reached if the contents of a standard beaker were poured into a beaker of different dimensions. Although details of the data are not presented, Piaget (1952a) noted that almost all children who conserved passed a compensation test that required children to pour as much water into an empty beaker as there was in a standard beaker of different dimensions. Piaget and Inhelder (1971) also reported a study of the ability to pass conservation and compensation tasks in support of their account of conservation. However, there are now many studies that do not support their account.

Acker (1968) found children who conserved but failed the anticipation task used by Piaget and Inhelder (1963). Lee (1971) found that when children were required to pass both tests of conservation and compensation in order to be judged true conservers, the proportion of conservers fell from 11 of 15 to 6 of 15. Gelman and Weinberg (1972) reported that 17% of their subjects who conserved failed to compensate, that is, failed to match the water level of the standard when pouring the "same amount" into a beaker of different dimensions.

More recently, Acredelo and Acredelo (1979) tested the extended version of Piaget's account of the relationship between the abilities to conserve, compensate, and anticipate conservation or compensation. They reported that 37.5% of their sample revealed success and failure patterns *not* predicted by Piagetian theory. These disconfirming patterns were expected with their alternative identity theory of conservation however. This alternative theory allows children to conserve even if they fail to compensate. Such children are viewed as being in an early stage of conservation; they focus on the absence of an addition/subtraction operation or the irrelevance of displacement transformations and pay little attention to the perceptual conflict that obtains after the transformation. Children then go on to learn that compensation is a consequence of conservation. This fits with Gelman and Weinberg's (1972) observation that the understanding of the compensation principle, as manifested in verbal statements, continues to develop well after the age at which the child's ability to conserve liquid may be taken for granted. Further, it removes the puzzle of how a child could understand compensation without presupposing an equivalence relation—as Piaget would have them do.

In sum, even when we assess the Piagetian account within a single domain (e.g., classification, seriation, conservation), the results do not lend support to the theory. The idea that concrete-operational thought is not dependent on one or even several structures d'ensemble is probably related to the turn away from Piaget's stage theory (e.g., Brainerd, 1978a, 1978b; Feldman, 1980; Fischer, 1980; Flavell, 1982; Siegler, 1981; but see also Davison, King, Kitchener, & Parker, 1980). Evidence that preoperational thought may not be preoperational makes it even harder to maintain the stage account.

### Is Preoperational Thought Really Preoperational?

To say of a child that he is preoperational is to say more than that he has no concrete operations. Preoperational thought is not defined (or explained) solely in terms of what it lacks; it is also said to possess several dominant characteristics. According to Piagetian theory, the preoperational child is egocentric or (to use the more recent label) centered. His reasoning processes are perception bound: he is easily distracted by the perceptual or spatial properties of objects and, for this reason, often fails to detect more abstract, invariant relations among objects. In addition, the preoperational child is usually unable to coordinate information about states and transformations.

Are preschoolers truly preoperational? A host of recent investigations have raised questions about the validity of this characterization. In general, these studies show that under certain conditions, even young preschoolers behave in a nonegocentric manner, ignore misleading perceptual cues, integrate information about states and transformations, and so on.

Consider the claim that preschoolers are egocentric. In the perspective-taking task designed by Piaget and Inhelder (1956), children are shown a model of three mountains. A doll is placed at various positions around the model and children are asked to indicate how the mountains look to the doll from each of the positions. Children less than 6 years of age tend to choose a picture or small replica that depicts their own view rather than the doll's view. According to Piaget and Inhelder (1956), the young child is "rooted to his own viewpoint in the narrowest and most restricted fashion, so that he cannot imagine any perspective but his own" (p. 242). Similarly, when asked to describe the workings of a water tap or to repeat to another child a story he has been told, the young child does terribly. This is because "he feels no desire to influence his listener nor to tell him anything: not unlike a certain type of drawing room conversation where everyone talks about himself and no one listens" (Piaget, 1959, p. 32).

Do young children really believe that an observer standing in a different location than theirs sees the same thing they see? Recent work by Masangkay, McCluskey, McIntyre, Sims-Knight, Vaughn, and Flavell (1974) and by Lempers, Flavell, and Flavell (1977) indicates that the answer to this question is negative. In the study by Masangkay et al., a card with different pictures on each side was held vertically in front of children who were asked: "What do *you* see?" and "What do *I* see?" All of the 3-year-olds and half of the 2-year-olds tested responded correctly. In the study by Lempers et al., children 1 to 3 years of age were given hollow cubes with a photograph of a familiar object glued to the bottom of the inside. Children's task was to show the photograph inside the cube to an observer sitting across from them. Lempers et al. found that virtually all children 2 years and older turned the cube opening *away from themselves* to face the observer. These results indicate that the young child is not so egocentric as to believe others see whatever *he* sees. What then could be the source of the young child's difficulty on Piaget and Inhelder's (1956) mountain task?

Flavell (1974) distinguished between the child's identification of *what* object another sees and the more complex concept of *how* the object is seen. The findings of Masangkay et al. (1974), Lempers et al. (1977), and others (e.g., Coie, Constanzo, & Farnill, 1973) indicate that the rudimentary ability to determine what another person sees is present by age 2. The ability to recognize how an object or a scene appears to another person develops much more slowly. Borke (1975) showed that the age at which children demonstrate nonegocentric perspective-taking ability is heavily influenced by such task variables as the nature of the test displays and the type of response required. Borke's (1975) procedure was the same as that of Piaget and Inhelder (1956), with two important exceptions. First, two of the three displays Borke used were scenes containing familiar toy objects. Display 1 consisted of a small lake with a toy sailboat, a model of a house, and a miniature horse and cow. Display 2 contained different groupings of miniature people and animals in natural settings (e.g., a dog and doghouse). Display 3 was a replica of Piaget and Inhelder's (1956) three mountains. Second, Borke asked her subjects to indicate the doll's perspective by rotating duplicates of the displays. On Displays 1 and 2, Borke found that 3- and 4-year-old children correctly assessed the doll's perspective for all three positions tested between 79% and 93% of the time. In contrast, on Piaget and Inhelder's display, 3-year-olds gave 42% and 4-year-olds 67% correct responses for the three positions. Borke concluded that her results "raise considerable doubt about the validity of Piaget's conclusion that young children are primarily egocentric and incapable of taking the viewpoint of another person. When presented with tasks that are age appropriate, even very young subjects demonstrate perceptual perspective-taking ability" (p. 243). Additional support for Borke's conclusion comes from a recent study by Flavell, Flavell, Green, and Wilcox (1981). Flavell and his colleagues found that preschoolers understand that objects with different sides (e.g., a house) look different from different perspectives, whereas objects with identical sides (e.g., a ball) look the same from all perspectives.

Taken together, the results of Borke (1975) and Flavell et al. (1981) clearly indicate that children as young as 3 years of age (1) are aware that an individual looking at a display (e.g., a house) from a position other than their own will have a different view of the display; and (2) are able to compute how the display looks to this individual under certain optimal conditions. With time, children become more and more proficient at identifying how a display appears to another individual. It should be noted that this ability continues to develop well into the school years. Huttenlocher and Presson (1973, 1978), for example, found that school-aged children do better on perspective-taking tasks if they are allowed to walk around the covered display before giving their response.

Similar nonegocentric results have been obtained in other types of perspective tasks. Markman (1973a) found that preschoolers correctly predicted that 2-year-olds would fail on a memory task but would achieve some degree of success on a motoric task. Shatz and Gelman (1973) reported that 4-year-olds used shorter and simpler utterances when talking to a 2-year-old than when talking to peers or adults. Speech to the 2-year-olds typically involved remarks aimed at obtaining and maintaining the child's attention as well as show-and-tell talk. In marked contrast, adult-directed speech usually involved comments about the child's own thoughts and requests for information, classification, or support. Speech to the adults also included hedges, which are commonly assumed to mark the speaker's recognition that the listener is better informed, older, and so on (Gelman & Shatz, 1978). Maratsos (1973) reported that 3- and 4-year-olds pointed to indicate the positions of toys to a sighted adult. When the same adult covered her eyes, however, children tried—as best as they could—to describe the toys' respective positions. Likewise, Marvin, Greenberg, and Mossler (1976) reported that children as young as 4 recognized that a person who did not see an event did not know this event: Knowledge of the event could be shared only by those who had witnessed it. These are hardly the sorts of things one would expect fundamentally egocentric thinkers to be able to do (for further evidence see Donaldson, 1978; Shatz, 1978; *Shatz, vol. III, chap. 13*).

In all fairness to Piaget, we should point out that our criticism of the characterization of the young child as egocentric is addressed more to interpreters and followers of Piaget than to Piaget himself. In our survey of the Genevan literature since 1965, we never encountered the term egocentric. As Vyuk (1981) noted, Piaget switched to the term *centered* in his later writings to avoid the surplus meaning of the term egocentric.

What evidence is there that the preoperational child is *centered*, in the sense Piaget intended? One version of the centration hypothesis holds that the preoperational child's failure to conserve number or quantity is due, in part, to a proclivity to center on one dimension (e.g., length in the case of number conservation, height in the case of liquid conservation) and ignore the other dimension (e.g., density in the case of number conservation, width in the case of liquid conservation). However, Anderson and Cuneo (1978) provide compelling evidence against this version of the centration hypothesis. In one study, children 5 years of age and older were shown rectangular cookies that varied systematically in width and in height. Their task was to rate how happy a child would be to be given the different cookies to eat. During pretesting, children were taught how to use the rating scale. This scale consisted of a long rod with a happy face at one end and a sad face at the other. The children's task during the test was to point to the place on the rod that reflected their judgment of how happy or sad a child would be if he ate a cookie of a given size. Analyses of the ratings yielded significant effects of both width and height—even for preschool subjects. In a subsequent study, Cuneo (1980) obtained similar results with 3- and 4-year-old children. Analyses of the children's ratings indicated that they were using a height + width rule to evaluate the area of the test cookies. As before, there was no evidence of centering on one dimension.

What of the characterization of the preoperational child as perception bound? An early conservation training study by Bruner et al. (1966) appeared to lend support to this characterization. Children were shown two identical beakers filled with water and were asked whether or not they contained the same amount. Next, children were shown a third, empty beaker of different dimensions. This new beaker was placed behind a screen, and the contents of one of the original beakers was poured into it. Children were then asked whether the screened and the unscreened beakers contained the same amount of water. It was found that children were less likely to give up their initial judgment of equivalence with the screen present.

A conservation study by Markman (1979) makes it difficult to accept the Bruner et al. position that children's failure to conserve reflects the perception bound quality of their thought processes. Markman asked 4- and 5-year-olds to participate in one of two versions of the number conservation task. The only difference between the two versions was the terms used to label the displays. In one version—the standard Piagetian version—*class* terms (e.g., trees, soldiers, birds) were used. In the other version, *collection* terms (e.g., forest, army, flock) were used. Children in the class condition did poorly. In contrast, children in the collection condition averaged 3.2 correct judgments out of 4 *and* were able to provide explanations for their judgments. Because both versions of the task involved the exact same displays, one cannot explain the class subjects' failure to conserve on the ground that preschoolers are perception bound. Subjects in both experimental conditions obviously had equal opportunity to become distracted by the perceptual appearance of the posttransformation displays. The fact that the collection children did not raises doubt about the validity of the characterization of the preoperational child as fundamentally perception bound.

Additional evidence that preschoolers are not always perception bound comes from studies that examined their ability to distinguish between appearance and reality. Fein (1979), for instance, found that by age 3 children have no difficulty distinguishing the pretend activities involved in play from other activities. Flavell, Flavell, and Green (in press) reported that even 3-year-olds have some ability to distinguish between real and apparent object properties. In one experiment, children were shown a white paper that looked pink when placed behind a piece of pink plastic. More than half of the 3-year-olds tested correctly differentiated between the appearance (pink) and the reality (white) of the paper. In a similar vein, Gelman, Spelke & Meck (in press) found that 3-year-olds recognize that a doll and a person are more alike perceptually than are a doll and a rock. But they also understand—as evidenced by spontaneous comments to this effect—that a doll can only "pertend" walk, sit, eat, and so on.

Work by Gelman, Bullock, and Meck (1980) raises questions about yet another characterization of preschool thought, which is that preschoolers have serious difficulty relating states (in Piaget's terms, figurative knowledge) and transformations (operative knowledge). The experiment was based on Premack's (1976) finding that chimpanzees are able to select the appropriate instrument (e.g., a scissors) to relate two different states of an object (e.g., a whole apple and a cut apple). In the Gelman et al. study, 3- and 4-year-olds were asked to select one of three choice-cards to fill in the missing element in three-item picture sequences. Test sequences had either the first, second, or third position empty. Each completed sequence consisted of an object (e.g., a cup), an instrument (e.g., a hammer), and the same object transformed by the application of the instrument (e.g., a broken cup). Half the sequences depicted familiar events (e.g., cutting a piece of fruit), half depicted unusual events (e.g., sewing the two halves of a banana together or drawing on a piece of fruit). Performance in both age groups was nearly perfect, indicating that the children could reason about the relationship between object states before and after the application of various instruments.

In a second experiment, Gelman et al. (1980) showed 3- and 4-year-olds picture sequences in which the deleted item was always the instrument. The children's task was to relate the two object states first from one direction (e.g., whole apple, cut apple) and then from the opposite direction (e.g., cut apple, whole apple). As in the first experiment, performance in both age groups was very good, indicating that children could represent reciprocal transformations. Gelman and her colleagues concluded that although preschoolers may not *always* be able to represent the same object states with reference to reciprocal transformations (e.g., pretransformation and posttransformation displays in a clay-conservation task), there are clearly cases where they can do so.

In this section, we have reviewed a number of studies that indicate preschool children are not fundamentally egocentric, centered, or perception bound. The general implication of these studies is that the mentality of the preschool child is qualitatively more similar to that of the older child than Piagetian theory leads one to suspect. This is not to deny, obviously, the cognitive limitations of the young child. After all, preschool children do fail standard conservation, classification, and seriation tasks. As we will see in the next section, however, it is no longer clear what such failures signify because more and more investigators discover that startlingly modest amounts of training are sufficient to make conservers out of nonconservers, seriators out of nonseriators, and so on.

### Inducing Success on Concrete-Operational Tasks

According to Piagetian theory, learning involves the assimilation of novel information to a previously existing structure, with concomitant changes in the structure as it accommodates to the incoming information. Hence, if there is no cognitive structure relevant to an input, there can be no assimilation and likewise no accommodation—in other words, no learning. One implication of this view is that children who possess part of a structural capacity (e.g., transitional conservers) are more likely to benefit from training than are children who possess none (e.g., nonconservers) (Inhelder, Sinclair, & Bovet, 1974).

We would like to turn the Piagetian argument on its head. That is, we would like to argue the following: to the extent that preschoolers can be shown to benefit from training on some concrete-operational task, then to the same extent they can be assumed to possess (at least part of the) structural capacities relevant to this task. If it is true that the mental structures of preschoolers are more like those of older children than was traditionally assumed (as we concluded at the end of the previous section), it should be possible to design simple training conditions that induce success on concrete-operational tasks—and thus reveal hitherto concealed competencies. As we will see later, that is indeed possible.

It used to be commonplace to claim that training had no effect on concrete-operational abilities (see Flavell, 1963, for a review of the early training literature). In recent review sources, however, just the opposite conclusion is reached (e.g., Beilin, 1971, 1977; Brainerd & Allen, 1971; Modgil & Modgil, 1976; Murray, 1978). Since these review sources are available, we focus on a select number of studies.

Gelman (1969) worked with 5-year-olds who failed on pretests to conserve number, length, liquid amount, and clay amount. Children in the experimental group received a learning-set training on length and number tasks that was designed to focus attention on quantity-relevant relations and away from quantity-irrelevant relations. In all, the experimental children received 32 problem sets with 6 trials in each set; half the problems involved length, half number. On each trial the children were asked which two of three rows of chips (or sticks) had the same (different) number (or length); feedback was then provided. On Trial 1 of each set, the arrays were arranged to elicit a correct answer, even if the child was attending to irrelevant properties of the display. This was done by arranging the displays so that the relevant and irrelevant cues were redundant. Thus, for example, two rows containing the same number of equally spaced chips were aligned one above the other. A third row containing a different number of chips was placed so that its ends were not aligned with the ends of the other rows. On Trials 2 to 5 of the problem set, the children watched as the experimenter transformed one or two displays so that the number-relevant (length-relevant) cues were now in conflict with the number-irrelevant (length-irrelevant) cues. Then, if children responded on the basis of number-irrelevant cues, they made an error. On Trial 6, irrelevant cues were not present at all, allowing Gelman to determine whether the children could accurately respond to length and number.

Because Gelman created a conflict between perceptual and quantitative cues within each problem set, she thought she was providing children with attention training (Harlow, 1959; Trabasso & Bower, 1968). As we will see, there are other interpretations. But whatever the interpretation, the training worked. During learning-set training, nonconserving children quickly reached plateau; when asked to choose two arrays that contained the same (different) number (length), they responded on the basis of quantity. Further, they transferred what they learned on posttest conservation tasks. Performance on length- and number-conservation tasks were near ceiling and children were able to justify their choices. The majority of liquid- and clay-conservation trials also yielded correct choices and explanations. Finally, the effects of training were maintained over a period of 2 to 3 weeks.

The Gelman (1969) training experiment is typically classified as one in the learning theory tradition (e.g., Beilin, 1971, 1977; Modgil & Modgil, 1976). It is no longer obvious to Gelman (Gelman & Gallistel, 1978) that this characterization holds. Recall that within each problem set, Gelman created a conflict between perceptual and quantitative cues. Feedback probably guaranteed that the child noticed the conflict. Perhaps the study accomplished what Piagetian theory requires for training to be effective—that the child encounter a conflict between schemes. Beilin (1977) makes a similar suggestion about the learning-set procedure. But note that for this interpretation to hold, it is necessary to assume that the subject had begun to develop some quantity schemes. Otherwise, there could have been no conflict for the subject.

Piagetian training studies focus on highlighting contradictions or conflicts. And the evidence is good that this training can be effective, especially with children who show some initial evidence of having moved from preoperational to operational thought (Inhelder, Sinclair, & Bovet, 1974). However, it is not clear that such training is either sufficient or necessary. In a thorough review of the vast array of conflict-training procedures, Beilin (1977) pointed out that some conflict-training procedures work (e.g., Lafèbvre & Pinard, 1974; Smedslund, 1961a, 1961b; Winer, 1968) and others do not (e.g., Beilin, 1965; I. D. Smith, 1968; Wohlwill & Lowe, 1962). Further, a variety of training procedures that do not induce conflicts also work. Reversibility-training studies are a clear case in point.

The Wallach and Sprott (1964) study was probably the first successful reversibility-training study. It involved a series of problems, each using two displays, one of $N$ dolls and one of $N$ beds. The number of items per array varied from problem to problem. Within each problem, children were first shown that each doll fit in a bed; then the dolls were removed from the bed and either the row of beds or the row of dolls was spaced further apart or closer together. Children who said there were no longer as many beds as dolls were shown that each doll did have a bed. The idea was that the children would learn reversibility and, thus, be able to predict that the dolls would always fit back in beds. Roll (1970) followed up on the Wallach and Sprott (1964) study and included transfer tasks to see if the learning was resistant to the Smedslund (1961b) extinction method. There still was considerable transfer.

A variety of investigators have studied the effect of having a nonconserver watch models who do conserve (e.g., Murray, 1972, 1981; Silverman & Geiringer, 1973; Silverman & Stone, 1972). In general, the opportunity to interact with, or simply watch, conservers and nonconservers was found to help induce conservation. Botvin and Murray (1975) assigned black first-graders who failed to conserve mass, weight, amount, and number to one of two kinds of modeling conditions. In one condition, two nonconservers and three conservers participated in a discussion. The discussion began with the experimenter's request that each child participate in the mass-conservation and weight-conservation tasks. The children were then left on their own to discuss their different answers and reach an agreement. A second group of nonconservers watched while the experimenter tested another group of children. These children did not participate in a subsequent discussion. Both groups showed a dramatic amount of specific transfer (to weight and mass tasks) as well as general transfer (to number and length tasks). Comparison of the explanations given by the original conservers and the trained conservers ruled out the possibility that the trained conservers were simply mimicking what they had heard. The original conservers were more inclined to give compensation and reversibility accounts in justifying their judgments; the trained conservers were more inclined to point out that nothing had been added or subtracted or that the transformations were irrelevant. The latter kinds of explanations were also prevalent in Markman's (1979) collection condition, and her subjects were even younger.

Are results like Botvin and Murray's (1975) consistent with the Piagetian hypothesis that conflict conditions caused development? Those children who participated in the discussion condition probably did enter a state of conflict and because they eventually reached agreement with the conservers, they could be said to have also resolved the conflict. However, we find it more difficult to maintain this position for the children who simply watched the testing of conservers and nonconservers. Even if we allow that some "inner" conflict occurred and was resolved, a problem remains. How could the opportunity simply to watch a conserver be effective so quickly unless the child already had some understanding of quantitative invariance?

Like us, Gold (1978) maintains that it is appropriate to conclude that a child has an understanding of quantity if very little pretest experience leads her to focus on quantity: "If this occurs, it seems likely that the successful 'training' was due simply to the reinterpretation by the subject of the experimenter's question, and not to the acquisition of a conservation concept as such" (p. 407). A similar argument is made by Donaldson (1978) and McGarrigle and Donaldson (1974) who show that 4- to 6-year-olds are much more likely to conserve if the transformations are made accidentally by a "naughty" teddy bear.

A simple training study by Gold (1978) yielded results consistent with his position. Subjects (around 5½ years of age)[2] were given eight pretest trials. The pretest displays resembled posttransformation displays in the standard equivalence and nonequivalence conservation tasks, that is, the two rows were different or the same length respectively. During the pretests, the child was told to count the items in each row and then was asked whether the two rows had the same cardinal values or not (where the numbers in each row were different). A control group of children was shown the same pretest displays and was simply asked whether the rows had the same number or not. That is, they were not asked to determine the specific values in each display before being asked the standard posttransformation conservation questions. The transfer tests yielded remarkable results. Of the 29 children in the experimental group, 22 and 20 respectively, conserved on the two standard number-conservation tasks. What is more, when retested 6 weeks later, 22, 20, and 19 children conserved on the number, beads, and liquid tasks respectively. And 14 weeks later, conservation scores were slightly better on all three tasks! In contrast, none of the control group ($N = 29$) conserved on any task at any time.

Gelman (1982) gave 3- and 4-year-olds a brief pretest experience much like the one Gold (1978) used. Children were asked to count one of two displays; indicate its cardinal value; count the other display; indicate its cardinal value; and then decide whether the number in each row was the same. In the pretest phases, children worked with set sizes of 3 and 4. The standard conservation tasks involved set sizes of 5 (and 4 on conservation of difference trials) and 10 (or 8). To Gelman's surprise, the pretest experience transferred to *both* the small and the large set trials. In addition, children gave the same sort of explanations observed by Markman (1979).

The vast majority of training studies have focused on the conservations. But there have also been successful training studies of children's ability to draw transitive (or related) inferences.

Bryant and Trabasso (1971) suggested that young children's difficulty with transitive inferences was more a problem of memory than logical inference. Accordingly, they gave their subjects memory training. They showed their subjects pairs of sticks from a set of five sticks (A, B, C, D, E) that differed in length and color. Using a discrimination learning procedure, they taught children which of a pair of sticks was the longer (or shorter) stick. To start, children were taught the AB pair, then the BC, CD, and DE pairs. Subsequently, they were shown a random selection of pairs of sticks (other than the BD pair) and were again required to learn which of the two was the longer (or shorter) stick. Children were never shown the actual lengths of the sticks during training; the bottoms of each pair of sticks were hidden in a box and their tops protruded to the same height. Thus, they had to learn to code the relative heights that corresponded to the different colors. Following training, children were tested without feedback on all 10 possible pairs of sticks. As before, only the tops of the sticks were visible so that children had to rely on the color of the sticks to decide which was longer or shorter. The crucial test involved the BD pair and the adjacent BC and DC pairs. Recall that children were not trained on the BD comparison. Furthermore, during training, the B, C, and D sticks were as often the longer as the shorter stick in an array. The correct responses on the BD comparison ranged from 78% to 92% (well above chance). As predicted, success on the critical test pair was highly correlated with a child's ability to remember the relative values of the elements in the BD and CD pairs.

De Boysson-Bardies and O'Regan (1973) tried to account for the Bryant and Trabasso (1971) results without granting the children transitive inference abilities. We think their alternative interpretation presumes that young children go out of their way to make their task difficult for themselves. Consider the three assumptions made by de Boysson-Bardies and O'Regan. First, they assume the children only learn the pairs of stimuli AB, BC, CD, and DE. They also associate *long* with A, *short* with B; *long* with B, *short* with C; and so on. Second, children treat sticks that are labeled both *long* and *short* as nonentities. The effect of this step is to eliminate labels for all sticks but A, which remains *long*, and E, which remains *short*. Finally, children learn to associate *long* with the stick that is paired with A and *short* with the stick that is paired with E. Thus, they assign B (of the AB pair) a *long* label and D (of the DE pair) a *short* label. Having done all this, they can pass the critical transfer trials on the basis of a paired-associate learning strategy as opposed to a transitive-inference one. Harris and Bassett (1975) found no evidence to support this alternative account.

The de Boysson-Bardies and O'Regan (1973) account was motivated by the claim that the Bryant and Trabasso (1971) subjects did not use the operation of transitivity. Without accepting their paired-associate hypothesis, it is possible to make this point in another way, as Trabasso (1975) showed. Trabasso tested the hypothesis that children construct ordered linear images of stimuli and then "read" their answers off these images. This, indeed, seems to be what children do; but then adults do likewise. Both children and adults have been found to construct ordered linear representations when confronted with a wide variety of materials that represent differences in height, weight, happiness, and even niceness

(Riley, 1976). Even if one does not want to claim that Bryant and Trabasso's (1971) subjects used the operation of transitivity, there is no getting around the fact that they were able to construct an ordered set of mental objects. On the Piagetian assumption that performance reflects available structures, it must be that children had available at least an ordering relation (see Gelman, 1978, for further evidence).

Some may object that the Bryant and Trabasso (1971) study provided extensive training and feedback. With so many feedback trials, perhaps the concept of transitivity was trained in and not simply uncovered. Findings from a study by Timmons and Smothergill (1975) argue against such a possibility. These authors worked with kindergarten children who did poorly on tasks requiring them to seriate six values of brightness or length. The children were given same/different judgment trials on either or both dimensions without feedback. This training was sufficient to facilitate seriation performance. Because Timmons and Smothergill did not run a transitive-inference task during posttesting, one might still object that the seriation performance was not based on an operatory scheme. We submit this is unlikely given Brainerd's (1978a) and Bryant and Kopytynska's (1976) demonstrations of the early use of transitive inference (see Brainerd, 1978a for a review). Hooper, Toniolo, and Sipple (1978) also reported kindergarten children receiving scores of 3.65 and 4.46 out of 5 on length and weight transitivity tasks.

As for conservation and transitivity, it is now clear that preschoolers benefit from training designed to alter their typical classification solutions. Nash and Gelman (cited in Gelman & Gallistel, 1978) gave 3- to 5-year-old children experience at sorting a set of eight wooden blocks that varied in size, shape, and color. To start, the children were told to "put the blocks together that go together." If necessary the experimenter showed the child a way of doing the task or even asked the child to copy her sort. Sorting experience continued until the child had successfully sorted the blocks in two ways. On a subsequent day, the child was asked to place 25 toys into one of five clear plastic boxes. The toys represented five categories (fruits, vehicles, kitchen furniture, flowers, and animals) and were withdrawn one at a time from a bag. The block-sorting experience helped children sort consistently by taxonomic category, as did the opportunity for children to sort the toys until they achieved a stable sort on two successive trials. Of the 3-, 4-, and 5-year-olds who had block-sorting and toy-sorting experience, 66%, 83%, and 89% respectively, used taxonomic categories.

As in the case of conservation and transitivity training, classification training need not be extensive consistently. Smiley and Brown (1979) showed that preschoolers prefer to sort materials according to thematic as opposed to taxonomic relations. Nevertheless, they can and do use both kinds of relations. Further, they can be trained to use taxonomic relations consistently. Smiley and Brown's training involved showing children triads that represented both a taxonomic and a thematic relation. In each triad, an experimenter demonstrated and explained the taxonomic response (or thematic response in the control group). The opportunity to observe the experimenter use taxonomic criteria influenced the children's choices—these were then predominantly taxonomic. Markman, Cox, and Machida (1981) reported a shift from graphic sorts to consistent taxonomic sorts in 3- and 4-year-olds when asked to sort objects in plastic bags rather than on a table. Apparently, the latter condition encourages the use of spatial and configurational relations.

Odom, Astor, and Cunningham (1975) gave 4- to 6-year-old children repeated trials on a matrix classification task and found a significant decrease in errors over trials: "This strongly suggests that repeated presentations may be required to obtain a valid assessment of a young child's cognitive ability to classify multiplicatively" (p. 762). It likewise raises the possibility that the ability to classify taxonomically is underestimated in standard procedures where children are assessed on the basis of one or two sorting trials. As Worden (1976) points out, most classification studies with adults have them classify repeatedly until a stable sort is achieved. The failure to do the same with children may elicit immature preferences but these need not preclude the ability to assign correctly the extension of a given class.

The training literature on class inclusion yields results that are in line with what by this point is a consistent theme; it is possible to "train" a child on many concepts with limited training experience. Siegel, McCabe, Brand, and Matthews (1977) provided 3- and 4-year-olds with but six trials, with feedback to their answers to such questions as "How many red buttons are there?" "How many white buttons?" "How many buttons?" "Are the red ones buttons?" Both age groups benefited from training, although the 4-year-olds' gains were greater on a posttest. Judd and Mervis (1979) drew 5-

year-olds' attention to the fact that the results of counting the members of the superordinate and subordinate classes conflicted with their erroneous answer to the class-inclusion question. The experimental group received such training on but three problems. Yet 23 of the 30 children in this group were perfect on posttests.

Overall, the training literature supports the view that preschoolers are more competent than their failure on standard concrete operational tasks implies. Some authors go further and take these results to suggest that the differences in the cognitive structures of preschoolers and older children are minimal—if there are any at all. We believe that such a conclusion is premature. Preschoolers do fail the standard Piagetian tasks; they do in many cases need tailored pretest experience or training to reveal some competency and, even then, they often show limited transfer. Before we accept an hypothesis of no qualitative differences, it is necessary to take a close look at the abilities as well as the inabilities preschoolers show. Although we admittedly must grant more capacity to the preschooler, his or her capacities could still be limited compared to those of the older child. In the following sections, we focus on the development of quantity and classification concepts. We chose these Piagetian concepts because enough research has been done to permit a careful analysis of how cognitive development in these domains might proceed. In addition, the research is far enough along for us to start to address some of the general issues raised by Piaget about the nature of cognitive development.

## A CLOSER LOOK AT THE DEVELOPMENT OF SOME CONCRETE-OPERATIONAL CONCEPTS

### Conservations During Middle Childhood

Of all the Piagetian tasks, the conservation ones are those that have received the most attention. Hundreds and hundreds of studies have considered whether a nonconserver can be trained to conserve and, if so, under what conditions. A countless number of studies have investigated the effects of socioeconomic status (e.g., Gaudia, 1972; Hanley & Hooper, 1973); schooling (e.g., Price-Williams, Gordon, & Ramirez, 1969); IQ (e.g., Field, 1977; Inhelder, 1968; linguistic prowess (e.g., Siegel, 1977); and variations in the conservation tasks (Bryant, 1974; Mehler & Bever, 1967) on the emergence of conservation. Despite the abundance of research activity, there is one issue that has received very little attention outside of Geneva: that is, the relationship between the conservation of discrete and continuous quantities. This is a central question in much of the recent Genevan work on conservation (e.g., Inhelder et al., 1974; Inhelder, Blanchet, Sinclair, & Piaget, 1975):

> Some subjects had great difficulty in applying a reasoning which had proved adequate for problems dealing with discrete elements to other situations where quasi-continuous materials were used. This would suggest that the developmental link between the conservation of discrete and continuous quantities is neither simple nor direct. (Inhelder et al., 1974, p. 80)

We agree, although, as will become clear at the end of this section, for somewhat different reasons.

We question whether the understandings of discrete and continuous quantities are all that similar. In the case of discrete quantities, there is a way to obtain a specific representation of the quantities represented—that is, to count. It is also possible to use a rule of one-to-one correspondence to determine whether an equivalent number of items is present in two displays. No such quantification processes are available for continuous quantities. Siegler (1981) provides evidence that these differences at least matter to adults. He showed adults the posttransformation displays of the number-, liquid-, and mass-conservation problems he planned to use with children and asked them to judge whether the displays were equal or not (half were and half were not). The adults were always correct on the number problems, and they often counted. In contrast, they were correct on only 60% and 61% of the mass and liquid problems—presumably because they had no verification procedures.

Further, as noted by Schwartz (1976), the conditions of application of arithmetic operations differ, depending on whether discrete or continuous quantities are involved. Consider: "Two peaches and two peaches make four peaches" versus "A cup of water at 10° C added to a cup of water at 10° C make a glass of water at 20° C." The former is correct; the latter is not. Or consider: "Two peaches and three pears make five pieces of fruit" versus "100 cc of alcohol and 90 cc of water make 190 cc of liquid." At a more basic level, the natural numbers can be used by themselves as adjectives with count nouns (e.g., one boy, six apples), but not with mass nouns (e.g., one water). The use of count words with continuous quantities depends on the selection of some attribute over which to quantify (e.g., volume or density) and the correct choice of unit. Thus, it is acceptable to talk of one gallon or one glass of water, but not one water. These are but a few of the issues raised by Schwartz when comparing knowledge about discrete and continuous quantities. All such considerations lead to the view that the development of the understanding of discrete and continuous quantities could differ. Siegler's (1981) reexamination of the conservations of liquid, mass, and number points in this direction.

Siegler (1981) tested children ranging in age from 3 to 9 years on 24 number, liquid, and mass-conservation problems. Within each set of 24 problems, the trials were designed to obtain meaningful patterns of yes/no answers to the question of whether the posttransformation displays were equivalent or not. They were not always equivalent because Siegler used addition and subtraction transformations as well as the standard displacement ones. On the basis of his own previous work as well as that of others—especially Piaget's (1952a)—Siegler predicted that the children's judgments would be consistent with one of four different rules, with development involving a move from Rule I → Rule II → Rule III → Rule IV. The assignment of a rule to a given child was to be done on the basis of the pattern of his responses to the posttest transformations. Children who consistently judged on the basis of one dominant dimension (e.g., length on number problems and height on liquid problems) were to be classified as Rule I users. Children who also considered the subordinate dimension (e.g., density on number problems and width on liquid problems) when the values of the dominant dimension were equal were to be classified as Rule II users. Rule III children would be those who always considered both dimensions but could not resolve conflicts and, therefore, performed at chance on such trials. Children who responded to all trials on the basis of transformation type were to be assigned Rule IV.

As it turned out, judgments on the conservation of liquid and mass tasks could be characterized with but two rules, I and IV. That is, there was no evidence of transition rules; the tendency to use Rule I declined with age and the tendency to use Rule IV increased with age. In both cases, the trend to use Rule IV was not complete by 9 years of age.

The developmental sequence on the number-conservation tasks was decidedly different from that observed for the two continuous-quantity tasks. If children were observed using Rule I, they were the younger children. But even the 4- to 6-year-olds were more likely to use one of two advanced rules, either the expected Rule IV or a combination of Rules I and IV, which Siegler identifies as Rule IIIa. According to Siegler, Rule IIIa reflects a tendency to sometimes use Rule I and sometimes Rule IV. If anything was added to a row, it was judged to have more regardless of whether the rows became equal because of the addition or whether the rows differed in length. A similar strategy was invoked when subtraction occurred. When there was neither addition nor subtraction, children used Rule I.

Almost all 7-, 8-, and 9-year-olds used Rule IV on number trials. Parenthetically, the failure to identify any Rule II children suggests that the relative density of items in the displays had little salience (Baron, Lawson, & Siegel, 1974; Gelman, 1972b; Smither, Smiley, & Rees, 1974). Returning to the Siegler (1981) results for number conservation, the transitional children, that is, those who used a combination of Rule I and Rule IV, were better able to deal correctly with addition and subtraction than other transformations. No differential effect of transformation type occurred with the two continuous-quantity conservations.

As one might expect, number-conservation ability was advanced compared to the other conservation abilities. Children's performance in the two continuous tasks were remarkably alike, which gives more evidence for the hypothesis of a common structure for the liquid and mass tasks (Tuddenham, 1971).

Siegler (1981) provides a plausible account for the differences in strategies used across conservation tasks. On number-conservation tasks, a child can use up to three strategies correctly, that is, one based on counting, another based on one-to-one correspondence, and another based on the analysis of the transformations performed. In the liquid and mass tasks, only the latter is available. Thus, Siegler concludes that liquid and mass tasks may be harder than number conservation. Our objection to this account is simply that it does not go far enough. Presumably, the use of a given strategy reflects some underlying concept. Otherwise, why that particular strategy as opposed to some other strategy? What does the young child know about number that leads him or her to shift from one strategy to another as the need arises? Moreover, there is more to the understanding of continuous quantity than an appreciation of the roles of relevant and irrelevant transformations (Schwartz, 1976). In an effort to achieve some insight on the matter, we will go over what is known about the development of notions of discrete quantity. We will then return to considering concepts of continuous quantity.

### Number Concepts

#### Abstraction Versus Reasoning

Gelman (1972a) distinguished between two kinds of numerical abilities: (1) the abilities we use to abstract the specific or relative numerosity of one or more displays—Gelman and Gallistel (1978) call these our *number-abstraction abilities;* and (2) the abilities we use to reason about number—Gelman and Gallistel call these our *number-reasoning abilities*. These abilities, which derive from arithmetic *reasoning principles,* allow us to reach inferences about the effects of transformations, the relations that hold between sets, and the effects of a combination of operations. Thus, we know not only that addition increases and decreases set size but also that the effect of addition can be canceled by subtraction. One reason for making this distinction is to highlight the possibility that number-abstraction and number-reasoning abilities could interact—especially in young children. In particular, Gelman and Gallistel thought that a preschooler might be able to reason only about those set sizes for which he can achieve a specific numerical representation. When the task requires reasoning about nonspecified values, as is the case in many conservation tasks, the child might fail to reveal reasoning abilities. Such considerations led Gelman and her collaborators to investigate the processes by which preschoolers represent the number of items in a display and the effects set size has on their numerical reasoning abilities.

#### Counting in Preschoolers?

There are two primary candidate processes by which a preschooler could represent number. These are counting and perceptual apprehension. In the latter case, the argument is that young children might be able to recognize twoness and threeness by virtue of a pattern-detection process. If so, one could argue, as Piaget (1952a) has, that the young child has little, if any, understanding of number. First, the recognition of patterns could be directly associated with labels, just as is the recognition of a three-dimensional object. The child need not know that a display of 3 items contains more than a display of 2 items and less than a display of 4 items. Second, on the assumption that the range of set sizes that could be apprehended is related to the span of apprehension, the ability to represent "number" should be limited to small set sizes. Since this is, indeed, the case (see Gelman & Gallistel, 1978, for a review), the argument could be made that the young child has little, if any, numerical ability.

The idea that the preschooler perceives differences in numerosity without some concomitant understanding of number is discredited by a converging set of research findings however. First, although it is true that the young child's ability to judge accurately how many items there are in a display drops off rapidly around set sizes of 4 or 5, she still knows that a set size of 7 items contains more items than does a set size of 5 items; likewise, that a set size of 11 items is greater in numerosity than one with 7 items. As Gelman and Gallistel (1978) report, 3-year-olds in the Gelman and Tucker (1975) experiment tended to represent larger and larger set sizes with number words that come later in the counting sequence, even though they encountered the variations in set size in a random order. Thus, the 3-year-olds tended to use the number words two, three, four, five, six, ten, and eleven to represent set sizes of 2, 3, 4, 5, 7, 11, and 19 respectively. Older children were more accurate, although they too made errors in assigning numerical values. Such results hardly fit with the characterization of numerical ability that follows from an apprehension-only hypothesis. To the contrary, they suggest that young children know something about counting. How else can one account for the tendency to use number words of higher ordinal values for the larger set sizes? But to grant preschoolers some understanding of counting is to go against a common notion—that early counting is but rote counting, but the simple reeling off of words in a list without any appreciation of the fact that these words have numerical meaning. When researchers began to consider the possibility that very young children's counting involves something more than reeling off number words (e.g., Fuson & Richards, 1979; Gelman & Gallistel, 1978; Schaeffer, Eggelston, & Scott, 1974; Shotwell, 1979), they soon found that this was the case. Young children do have an implicit understanding of counting and its use in quantification.

What is involved in the understanding and use of counting? According to Gelman and Gallistel (1978), successful counting reflects the coordinated application of five principles: (1) the one-to-one correspondence principle—all items in an array must be tagged with unique tags; (2) the stable-order principle—the tags used to correspond to items in an array must be arranged and chosen in a stable order; (3) the cardinal principle—the final tag used in tagging the items in an array represents the cardinal value of the array; (4) the abstraction principle—the first three principles (i.e., the how-to-count principles) can be applied to any collection of discrete items; it matters not what the items are, whether they are homogeneous or heterogeneous, real or imagined, actual objects or only spaces between objects, and so on: and (5) the order-irrelevance principle—the order in which items are enumerated is irrelevant; it matters not whether a given object is tagged as one (1), two (2), three (3), and so on, as long as the how-to-count principles are honored.

There are three reasons for maintaining that preschoolers have some understanding of the counting principles. The first is that counting behaviors in young children are systematic. Perhaps the most compelling evidence for the claim of systematicity is the use of what Fuson and Richards (1979) call nonstandard lists and what Gelman and Gallistel (1978) call idiosyncratic lists. These appear in very young children (i.e., 2½-year-olds), when they count even small set sizes, and in somewhat older children when they count larger set sizes. Although the lists are nonstandard, they are nevertheless used systematically. Thus, for example, a 2½-year-old child might say "2, 6" when counting a 2-item array and "2, 6, 10" when counting a 3-item array (the one-one principle). The same child will use her own list over and over again (the stable-order principle) and, when asked how many items are present, will repeat the last tag in her list (the cardinal principle). The fact that young children settle on their own lists suggests that the counting principles are guiding the search for appropriate tags. Such errors in counting are like the errors made by young language learners (e.g., I runned). In the latter case, such errors are taken as evidence that the child's use of language is rule governed and that these rules come from the child herself. We rarely hear adult speakers of English (outside of psycholinguistic classes) say runned, footses, mouses, unthirsty, and so on. Gelman and Gallistel (1978) use a similar logic to account for the presence of idiosyncratic lists.

A second reason for believing that some basic principles of understanding serve to guide the young child's acquisition of skill at counting is that young children spontaneously self-correct their count errors and often are inclined to count without any request to do so. Indeed, they will apply the counting procedure to a variety of item types, be they toys, steps, pieces of candy, or what have you. Presumably, these self-generated practice trials make it possible for the child to develop skill at applying the principles. A third reason for crediting preschoolers with counting knowledge is that they can invent counting algorithms.

Groen and Resnick (1977) taught 4½-year-olds to use a counting algorithm to solve simple addition problems. The algorithm consisted of first counting two separate groups of objects, then combining the groups of objects into one collection, and then counting the number of objects in that group. Across sessions, half of the children spontaneously began to employ a more efficient algorithm than they had been taught. This was to count on from the cardinal value of the greater of the to-be-added numbers. Gelman (1977) also reports that 3- and 4-year-olds count spontaneously when confronted with unexpected changes in the set size of a given array. It is hard to maintain that the counting behavior of young children reflects nothing but rote learning. How, then to explain its spontaneous use to solve simple arithmetic problems? In this regard, it is of interest that Ginsburg and his colleagues (e.g., Ginsburg, 1982) report a similar use of counting algorithms in unschooled cultures.

### An Interaction Between Number Abstractors and Reasoning Principles

The strong version of the interaction hypothesis is that young children will not be able to reason arithmetically unless they reason about numerosities they can represent accurately. Working from this assumption, Gelman (1972b) focused on whether preschool children could apply a number-invariance scheme when asked to consider small set sizes (2 to 5 at most) but not larger sets. The paradigm used in these studies was developed to control for many of the possible confounding variables in the standard conservation paradigm, for example, the child's failure to understand the use of "more," and "less," the child's tendency to be distracted by changes in irrelevant variables, and so on (see Gelman, 1972a). The paradigm involved children in a two-phase procedure. During Phase I, children learned to identify one of two rows of items as the winner, and the other as the loser. Identification could be based on either a difference in the number of items or a redundant perceptual cue, that is, length or density. The identification phase involved covering and shuffling the two displays and then asking the child to guess which of the two covered displays (which were side by side) was the winner. Children's answers to probe questions revealed that they established an expectancy for two displays of specific numerical values during this phase. Phase II began unbeknownst to the children. Depending on the experiment and condition children were in, the experimenter made a surreptitious change in either one or both of the displays. Changes could be number irrelevant (e.g., lengthening or shortening the display, changing the color of an item, substituting a new object for a familiar one). They could also be number relevant (e.g., adding or subtracting one or more items).

Gelman (1977) found that when set sizes were small and when addition/subtraction involved but one item, even 2½- and 3-year-olds responded correctly when they encountered the unexpected changes in the array. Changes that were produced by number-irrelevant transformations were recognized as such. Changes that were produced by number-relevant transformations were likewise recognized as such. The children often intimated, in their own way, that there had to have been surreptitious addition or subtraction to produce the observed number change. One child claimed "one flew out." Another said "Jesus took it." When asked, they also said that the effects of addition (or subtraction) could be undone by subtraction (or addition). In the conditions where children encountered unexpected changes in the length of a display, color of items, or type of items, the children would say these were irrelevant because the numbers were the same as expected.

On the basis of these findings with the magic paradigm, Gelman and Gallistel (1978) maintain that preschool children do know that addition and subtraction are number relevant *and* that displacement and substitution are number irrelevant. This knowledge is, in turn, related to the ability to decide whether two arrays represent equivalent or nonequivalent numerical values and, if not, which is the greater (see Gelman & Gallistel, 1978, chap. 10, for details). Note that this statement applies for the magic paradigm where displays are placed side by side and where children achieve specific representations of number. Children's reactions during Phase II tell us that they know the conditions under which a specific numerosity is preserved and the conditions under which it is not. Such results do *not* tell us whether children know when an equivalence or nonequivalence relation between two sets is conserved.

It was the latter consideration that led Gelman and Gallistel (1978) to accept Piaget's (1952a) view that the number-conservation task requires the use of a principle of one-to-one correspondence. They further maintained that preschoolers could not use this principle because they could not reason about nonspecified numerical values: hence, their failure on the traditional conservation task. Our review of the training literature (see *Is Preoperational Thought Really Preoperational?*) makes clear that this hypothesis regarding number-abstraction abilities and the use of arithmetic-reasoning principles make too strong a claim.

The Gelman (1982) conservation-training experiment was designed as a test of the Gelman and Gallistel (1978) hypothesis. The idea was to encourage young children to recognize that the specific cardinal value of the two displays placed one above the other was either the same or different. It was hypothesized that children would then be able to conserve on small set sizes (4, 5) but not larger set sizes (8, 10). As it turned out, 3- and 4-year-olds conserved on all set sizes *and* gave explanations for their judgments. Because most children this age cannot count accurately set sizes greater than 4 or 5, the only way they could have conserved equivalence judgments for larger arrays was on the basis of one-to-one correspondence. And such explanations were offered, particularly by the 3-year-olds.

Gelman and Gallistel's account of conservation resembles somewhat Piaget's (1975a, 1977) more recent treatment of number. Piaget's (1952a) early treatment focused on the role of transformations. In his later writings, Piaget turned his attention to the conditions that a child must recognize before he or she can deal with transformations. He maintained the child first discovers the correspondences between two states to make comparisons. At this early stage, the child can determine correspondences but is unable to apply the rules of transformations. Next in development he can use transformations but only after he establishes correspondences. Finally, the child understands the system of transformations as it generally applies to quantity. We suggest that Gelman and Gallistel's distinction between number abstraction and reasoning principles parallels Piaget's distinction between correspondence and transformation.

By Piaget's (1975a) account, it should be possible to observe "precocious conservation" if a child can be brought to recognize that one-to-one correspondence indicates a corresponding number of items. Indeed, Inhelder et al. (1975) succeeded in producing precocious number conservation. Their experiments involved showing 4- and 5-year-olds displays in one-to-one correspondence and then a series of item-removal and replacement transformations. For example, one item in an array was removed and the child was asked if the number of items in both rows was the same; then that item was put back into the array but at a different position and again the child was asked about equivalence. The idea in these experiments was to highlight the "commutability" of items in a discrete set, that is, that the act of adding an item at one point (in space) is undone by taking out an item from another point in space. Note that tasks like these involve permuting the positions of items within the set. In contrast, the standard conservation task involves displacing items. According to Inhelder et al. (1975), "when one simply displaces the objects, the child only attends to their point of arrival and does not concern himself with the fact that they have been removed from an initial position to be added elsewhere" (p. 26).

Piaget (1977) takes the fact that experience with the "commutability" of items transferred to the standard task as evidence for the view that it is the understanding of commutability that underlies true conservation. We are not sure. First, Gelman (1982) did show children length changes. Second, no such training was required in Markman's (1979) study, indeed, no training at all was required. In addition, a closer consideration of the Inhelder et al. (1975) experiments makes clear that their children were also counting and representing cardinal values. Gelman (1982) argues that these three sets of results together show that there are some special conditions that make accessible the principle of one-to-one correspondence. The younger the child, the more likely the tendency to restrict arithmetic reasoning to conditions where the child can achieve specific representations of number. Nevertheless, there is some ability to work with nonspecified values—an ability that will eventually dominate the initial tendency to restrict arithmetic reasoning to conditions where the child can achieve specific representations of number. We suspect this is related to the fact that the young child's skill at counting and knowledge about counting go through a considerable amount of development.

### Some Implicit Knowledge Does Not Imply Full or Explicit Knowledge

*Counting.* Although Gelman and Gallistel (1978) claim that even 2½-year-olds can obey the how-to-count principles, they do not mean that children this age have explicit knowledge of the principles. Nor do they mean that little or no development occurs past this age—indeed, quite the contrary. Gelman and Gallistel point out that first there are limits on how many items a child can count, how long a tag list she can remember, how well she coordinates the many component processes involved in the counting procedure, and even how well she tags unorderly arrays (Potter & Levy, 1968; Schaeffer et al., 1974; Shannon, 1978). But with practice come skill and speed and greater efficiency (cf. Case & Serlin, 1979). The period over which this skill accrues is protracted at least into kindergarten (Fuson & Richards, 1979).

Gelman and Gallistel (1978) found that the number of items in a set interacts with the tendency to apply the cardinal principle. As set size increases, the tendency to use the last tag to index the cardinal value of the set drops off. Some have suggested that this means the child does not yet have the cardinal principle as part of her counting scheme. Gelman and Gallistel maintain they do, but once again its application is at first variable. What evidence is there that the cardinal principle is available, even if it is applied sporadically? If Gelman and Gallistel are correct that the variable use of the cardinal principle in a young child derives from the performance demands of applying the counting principles, there should be conditions that elicit its consistent use. And when attention is drawn to the role of counting in quantification, the likelihood of its use should increase.

If 3- and 4-year-olds did not have the cardinal principle available, Markman (1979) should not have been able to show an increase in its use under a change in question conditions. Yet, she did. To expand, Markman reasoned that cardinal number tasks require children to think of a display as an aggregate to which a particular number applies. As we mentioned earlier, Markman contends that class terms, for example, children, trees, soldiers, emphasize the individuality of the members in an aggregate, whereas collection terms, for example, class, forest, army, lead one to think of a display as an aggregate to which a particular cardinal number applies. Accordingly, Markman (1979) predicted that children would find it easier to apply the cardinal number principle when collection terms, as opposed to class terms, were used to describe the display.

Children in Markman's collection-terms condition were instructed as follows: "Here is a nursery school class (forest, etc.). Count them. How many children (trees, etc.) in the class?" Children in the class-terms condition were told: "Here are some nursery-school children (trees, etc.). Count them. How many children (trees, etc.) in the class?" Set sizes were 4, 5, or 6. Collection-terms children gave the last number in their count list on 86% of the trials. In contrast, class-terms children were as likely to recount the array as to repeat the last number. The tendency of young children to recount a display when asked how-many questions has been cited as evidence that they do not yet have the cardinal principle (Fuson & Richards, 1979; Schaeffer et al., 1974). If so, Markman's (1979) results are inexplicable.

Recently, Gelman and Meck (1982) conducted a direct test of the idea that performance demands limit the young child's tendency to apply the cardinal principle. In their study, 3- and 4-year-old children watched a puppet count displays of 5, 7, 12, and 20 objects. Children were told the puppet often made mistakes when counting and their job was to tell the puppet whether it was right or wrong. They were also encouraged to correct the puppet's errors. Note that the children did not have to generate the counting performance themselves; they only had to monitor it for conformance to the counting principles. Children did very well. For example, the 4-year-olds attempted to correct 90% of the puppet's errors and did so correctly 93% of the time. The comparable figures for the 3-year-olds were 70% and 94% respectively. The failure for Gelman and Meck to find an effect of set size means that the children did as well on set size 7 as they did on set size 20. Obviously, the children had implicit knowledge of the cardinal principle.

When all facts are considered, it seems reasonable to say that young children do honor the cardinal principle but that their tendency to do so is restricted and first revealed in only certain conditions. Further, they need to practice the application of the counting procedure, presumably so as to automatize it and thereby limit the amount of attention required in its use (cf. Case & Serlin, 1979; Schaeffer et al., 1974). The effect of this is to make it easier to focus on the cardinal value—and, we suspect, acquire explicit knowledge of the cardinal principle.

In considering the foregoing, it is essential to recognize the distinction between implicit and explicit understanding of principles. This distinction is well known in psycholinguistics. Young children are granted implicit knowledge of linguistic structures well before they are granted explicit knowledge of any of these (cf. deVilliers & deVilliers, 1972; Gleitman, Gleitman, & Shipley, 1972). The explicit knowledge is often characterized as metalinguistic knowledge, a knowledge that continues to develop into adulthood and is a function of general education level, training in linguistics, and so on (Gleitman & Gleitman, 1979). A similar distinction regarding knowledge of the counting principles helps sort out some seemingly contradictory conclusions about counting principles (Greeno, Riley, & Gelman, 1981). When children as young as 3 years of age are asked to count repeatedly a set of given value, they are indifferent to the order of the items as it changes across trials. Such behavior is what one would expect if the child had an implicit understanding of the order-irrelevance principle. It does not index explicit understanding of this principle. Indeed explicit understanding is at best weak in the 3-year-old child. However, the development of explicit understanding of this principle is well advanced by 5 years of age. This is illustrated in the 5-year-olds' performance on a modified counting task (see Gelman & Gallistel, 1978, chap. 9).

The modified count task requires that a child first count a linear array of $x$ heterogeneous items (e.g., 5). Almost all children do this by starting at one end or another of the array, thereby setting the stage for the modified count trials. These start with the experimenter pointing to some item in the middle of the array and saying, "count all these but make this be the 1." On subsequent trials, the child is asked to make the designated item the 2, 3, 4, . . . and $x + 1$, that is, 1 more than the cardinal value of the set. The 5-year-olds are nearly perfect on the modified count trials. Further, they try to say something about how movement of the items per se does not affect the tagging process. Perhaps most important in this context, they say they cannot designate any item $x + 1$ (6 in the case of a 5-item array) because "there are only 5. I need another 1." Clearly, these children have achieved an explicit understanding of cardinality vis-à-vis the counting procedure. Put differently, they know a count is conserved no matter how the items are arranged. Perhaps this is a stepping stone to the use of one-to-one correspondence in the typical number-conservation task.

Just as there is development from an implicit to an explicit understanding of the cardinal-count principle so there is, of course, for the other counting principles. Apparently, 3-year-olds can indicate which count sequences have double count, omit, errors, and so on, but only older children can say why (Fuson & Richards, 1979). Mierkiewicz and Siegler (1981) find that 3-year-olds are able to recognize some counting errors, especially the skipping of an item. They also find 4- and 5-year-olds can recognize a diverse set of counting errors (omitting or adding an extra tag, skipping an item, or doubly counting an item). What is more, they also recognize that it is all right to count alternate items and then back up to count the remaining in-between items or to start counting in the middle of a row. But it is not until children are school aged that they are able to say why an error-free count sequence that involves the alphabet as tags is a better count trial than one that uses the conventional count words but includes errors (Saxe, Sicilian, & Schonfield, 1981). Thus, we see the development of an understanding of the one-one and stable-order counting principles becoming more explicit. Saxe and Sicilian (in press) also found that, despite a young child's tendency to self-correct, the ability to say whether they were accurate develops after 5 years of age.

It is not only the explict understanding of the counting procedure that develops but also the appreciation of the fact that counting is an iterative process that is unbounded. Evans (1982) reports that kindergarten children typically resist the idea that each addition of one (1) item will increase number. Interestingly, their resistance is highly correlated with their ideas of what constitutes a big number. These are usually under 100 or made-up combinations like "forty-thirty-a hundred." Apparently, children need some experience with largish numbers before they can move on to the recognition that counting is iterative. At the next level of development, children talk about a million and other large numbers when asked what is a very large number. But even this advancement does not guarantee that they will accept the consequence of continued iteration, that is, that there is no upper bound on the natural numbers. Instead, they maintain that despite the possibility of another, and another, and another yet-larger number being created with each addition of one (1), there is, nevertheless, a largest number. Finally, by 8 or 9 years of age, children recognize and accept the possibility of nonending iteration. There seems to be a progressive boot-strapping of one level of understanding to the next with intermediate plateaus where children assimilate enough examples to achieve (in Piagetian terms) a *reflective abstraction*, of their earlier levels of knowledge to a new level of understanding.

Just as the understanding of counting develops through steps, so apparently does the understanding of arithmetic principles, equivalence procedures, and conservation.

***Arithmetic Principles.*** Fundamentally, the principles of addition and subtraction require that one understands that addition increases and subtraction decreases the numerical values of sets. Several studies support the view that preschool children have some understanding of these principles. Smedslund (1966) had 5- and 6-year-olds indicate whether two arrays of equal value ($N = 16$) were equal; then the arrays were screened. When one of the arrays was transformed by adding one object to it or subtracting one object from it, the children were able to indicate which array contained more objects. The same finding was obtained in 4- and 5-year-olds by Brush (1972) and in 3-, 4-, and 5-year-olds by Cooper, Starkey, Blevins, Goth, and Leitner (1978). Also, Gelman (1972a, 1972b; 1977) and Cooper et al. (1978) found that 3-, 4-, and 5-year-olds can infer the occurrence of a screened addition or subtraction by comparing the pretransformation and post-transformation values of arrays. Thus, preschoolers understand the directional effects on numerosity of addition and subtraction and can, under some conditions, infer their unobserved occurrence.

The value of the augend and minuend affect the preschool child's ability to solve simple tasks in mental arithmetic. Starkey and Gelman (1982) have tested 3-, 4-, and 5-year-olds on a variety of addition and subtraction tasks. Each task began by having the child establish the number of pennies held in the experimenter's open hand. The child was asked, "How many pennies does this bunch have?" The experimenter then closed her hand and thereby screened the augend (or minuend) array of pennies and placed the added array in the hand holding the augend while saying: (1) "Now I'm putting $x$ pennies in my hand; how many pennies does this bunch have?" or (2) "Now I'm taking $x$ pennies out. . . ." The two values to be added or subtracted were never simultaneously visible. Problems involving zero were not used. The majority of the 5-year-olds could solve problems that involved starting with 1 to 6 items and then adding or subtracting 1 to 4 items. The 4-year-olds did well on problems involving the addition or subtraction of 1 or 2 items to (from) set sizes of 1 to 4 items. At least 50% of 3-year-olds could manage $1 + 1$, $1 + 2$, $2 + 1$, $3 - 1$, $3 - 2$, and $4 - 2$. Thus, there was an interaction between set size and age. As expected, many children used a counting algorithm, even though the items were screened.

Preschoolers have at least some implicit understanding of the inverse relationship between addition and subtraction. Starkey and Gelman (1982) included some $x + 1 - 1$, $x - 1 + 1$, $x + 2 - 2$, $x - 2 + 2$ tasks in their experiment. The vast majority of 4- and 5-year-olds solved these problems where $x = 1$ through 4. And even the majority of 3-year-olds could arrive at the correct answer for values of $x = 1, 2$, and 3 and for problems involving a $+ 1, - 1$ sequence. The studies by Brush (1972) and Cooper et al. (1978) make it clear that inversion tasks are more difficult for preschoolers if the children have to represent two arrays (generated by an iterative, temporal one-to-one correspondence procedure) to start and then make judgments of relative numerosity after transformations are performed on one of the arrays, for example, $x$ and $x + 1 - 1$. And when arrays of equivalent $N$s are placed one above the other, thereby introducing a conflicting spatial cue, the tasks become even harder—although not impossible. A similar trend holds for compensation tasks, that is, where the two arrays are equal to start ($x = y$) and then the act of adding (or subtracting) of 1 (or more) items to array $x$ is compensated by the act of adding or subtracting some number of items to array $y$. Indeed, Starkey (1978) reports that compensation tasks wherein spatial cues conflict are harder than the standard conservation task.

So once again we see more arithmetic competence in preschoolers than expected; however, the development of understanding occurs over a protracted span of years—in some cases past the time the child conserves number (see Siegler & Robinson, 1982, for a similar point for older children). Regarding this latter observation, it is noteworthy that many of Evans's (1982) subjects could conserve number and still not accept the idea of continued iteration. We expect that research designed to follow the shift from an implicit to explicit understanding of inversion and compensation will reveal a similar pattern to that observed regarding the counting principles and iteration. That is, we expect that children need to have some experience with local rules before they can move on to recognize the generality of that rule. As in the case of the counting principles, they have the benefit of some implicit understanding of the principles of addition and subtraction as well as their own counting algorithms with which to steer the course of acquisition.

*Equivalence.* The developmental story regarding the understanding of equivalence involves a by now familiar account. At early ages, there is at least an implicit understanding of the equivalence relation; to start, this understanding has an on-again, off-again characteristic, and its development is protracted.

In their account of the preschooler's arithmetic-reasoning principles, Gelman and Gallistel (1978) maintain that the young child recognizes an equivalence relation. For evidence they point to the way young children behaved in those magic experiments when the surreptitious change involved transformations that were irrelevant to number, for example, lengthening, item-type substitution. In nearly all cases, the children regarded the altered array as still equivalent to the original array. When the children who noticed the changes were probed about the reason for their equivalence judgment, they characteristically indicated that the number of items was the same, even though other features of the display were not. In Gelman and Tucker's (1975) experiment, there was an opportunity for children to construct two equivalent displays to give themselves two winners. Half the children did just this. It is difficult to explain such findings without allowing that the young child's arithmetic-reasoning principles include an equality relation.

A similar line of evidence and argument led Gelman and Gallistel (1978) to maintain that preschool children recognize that a difference between numerosities does not satisfy an equivalence relation. Further, in the case where $x \neq y$, the child believes that either $x$ is more than $y$ or that $y$ is more than $x$. In short, the child recognizes that an ordering relation holds between $x$ and $y$. Siegel (1974) showed that preschoolers could consistently respond to a numerical-ordering relation between two sets. Bullock and Gelman (1977) showed that even 2½-year-olds can compare the set size pair of 1, 2 with 3, 4 and, therefore, select 3 (or 4) as the winner after first learning that 1 (or 2) was the winner. Interestingly, it will be a good while before the very young child will use correctly the terms "more" and "less" (e.g., Clark & Clark, 1977).

We have already discussed the two-candidates procedure by which preschoolers achieve a representation of numerical equivalence—counting and one-to-one correspondence. In Gelman's (e.g., 1972a, 1972b) magic experiments, there was no obvious way to use a rule of one-to-one correspondence; the arrays were placed side by side. Under these conditions, counting served as the algorithm by which children made judgments of equivalence or nonequivalence. Because the preschooler's ability to count accurately is limited, it is no surprise that his ability to use a counting algorithm to determine equivalence is too. Thus, Saxe (1979) finds that young preschool children can use the counting procedure to establish equivalence between a standard small set and another set. It is not until 5 or 6 years of age that children do the same with much larger sets.

Studies by Brush (1972), Bryant (1974), Cooper et al. (1978), and Starkey (1978) show that there are conditions under which preschool children can reach a decision about numerical equivalence or nonequivalence on the basis of one-to-one correspondence. Such conditions involve controlling for the potential conflict with spatial extent. Piaget (1952a) describes the various stages children pass through before they can use a principle of one-to-one correspondence in the face of conflicting cues.

Work by Russac (1978) and Saxe (1979) provides evidence that the ability to use a counting algorithm to determine equivalence develops ahead of the ability to use one-to-one correspondence. Russac's research is especially informative on this matter because he used a test of one-to-one correspondence that did not require the child to ignore competing spatial extent cues. The counting task involved showing 5-, 6-, and 7-year-olds cards with 7, 8, 9, or 10 dots. The children were then instructed to count the number of dots and put the same number in a box. In the correspondence task, the child was asked, without counting, to put as many items on a card as were already there; the instruction was to place the blue items beside the red items, thereby alleviating the possibility of confusion with spatial extent. The proportion of correct trials was .96, 1.00, and .95 respectively for the 5-, 6-, and 7-year-old groups. In contrast, the respective figures for the correspondence task were .125, .313, and .688.

An earlier study by Stock and Flora (1975) makes it clear that there is development in the ability to apply the one-to-one correspondence procedure. Whereas Russac (1978) had children produce equivalence, Stock and Flora did not. They showed children displays containing alternating red and blue dots where there were 3, 5, 6, or 8 pairs of dots. Control tasks had one extra red (or blue) dot. The subjects were in preschool ($\bar{x}$ age, 55.8 months), kindergarten ($\bar{x}$ age, 70.2 months) and first grade ($\bar{x}$ age, 81.5 months); their task was to indicate, without counting, whether the number of red and blue dots was the same or not. The proportions correct of equivalence judgments on this single-row correspondence task were .33, .66, and 1.00 for the preschool, kindergarten, and first-grade groups respectively. In contrast, the proportions correct for the double-row task used by Brainerd (1973) were .00, .07, and .18. Parenthetically, we should note that this Stock-Flora correspondence task was easier for the children than a length-ordination task. This reverses Brainerd's (1973) findings regarding the acquisition of ordinal and cardinal concepts and highlights the critical role of task complexity in assessments of developmental sequences (Brainerd, 1977).

Flora and Stock (1975) note that their single-row task elicited explicit explanations, for example, "there's 2, and 2, and 2, . . ." for a judgment of equivalence; "there's 2 and 2 . . . and 1 left over" for nonequivalence judgments. Clearly, the children were using a principle of one-to-one correspondence. Still, they did poorly on the double-row task, indicating that their ability to apply the correspondence principle was not yet completely general. We suspect it is a very, very long time before they will be able to follow Cantor's proofs regarding transfinite numbers. Again, there is some competence at an early age but this competence is restricted; it is not applied generally and is probably not explicitly understood.

*Conservation.* Markman (1979) suggests that the kinds of explanations offered by young conservers differ from those of older natural conservers. Her subjects justified their equivalence judgments either with reference to the irrelevance of the transformation (e.g., "you just spread them"), or the fact that nothing was added or subtracted, or a specific reference to number. She fails to report any reference to reversibility. Gelman (1982) found that her young subjects used the same kinds of explanations as did Markman's (1979). These two studies lend support to Piaget's (1975a, 1977) hypothesis that a child's understanding of number conservation goes through levels. The suggestion from the above studies is that explanations involving reversibility, and therefore an explicit understanding of reversibility, develop later—an account that is consistent with Piaget's. A similar conclusion was reached by Botvin and Murray (1975) regarding the conservation of continuous quantity. Their trained conservers referred to the absence of addition and subtraction as well as the irrelevance of a displacement operation; unlike their controls, natural conservers, they did not refer to reversibility and compensation arguments. Whether it is the case that reversibility explanations become prevalent at a later age is not known. Thus, as reasonable as the hypothesis may be, it needs further support.

The kinds of explanations offered by Gelman's (1982) preschoolers go against Gelman and Gallistel's (1978) account of what might distinguish precocious conservations from those obtained later. Recall that they hypothesized that preschoolers would not be able to use a principle of one-to-one correspondence when applying their reasoning principle regarding equivalence. Gelman (1982) finds that they did; indeed, if anything, the younger the child the greater the tendency. Of the 3-year-olds' explanations, 21% were of this type as opposed to only 9% of the 4-year-olds' explanations. Thus, the Gelman and Gallistel hypothesis has to be modified to acknowledge that there are some conditions where children as young as 3 can access one-to-one correspondence. It may be that Gelman and Gallistel are correct about the tendency of preschoolers to yoke their application of operational knowledge of number to quantification procedures that can determine whether, in fact, an equivalence relation holds. That is, they may be more dependent on having an empirical confirmation of a judgment of conservation than older children. In Piagetian terms, this would involve a dependence on using correspondence procedures when applying operatory knowledge. Older children can think solely in terms of operations. Perhaps this happens at the time when children likewise articulate one or more versions of a reversibility hypothesis as regards number conservation.

*Summary.* We have reviewed evidence on the young child's understanding of counting, addition and subtraction, equivalence and nonequivalence, and conservation. In all cases, it can be seen that the preschooler knows more about number than was assumed as little as 5 or 6 years ago. However, despite this early competence, there is considerable development that will occur. Indeed, it begins to look as if the development will be more protracted than one might have expected. Thus, there seems to be a paradoxical result, that is, more competence in the preoperational period but less in the concrete-operational period. We will return to what we make of this paradox in the final section of the chapter.

### Continuous-Quantity Concepts

#### Conservation

We have seen that preschoolers know that the operations of addition and subtraction change number, whereas those involving displacement or change in item type or color do not. Further, preschoolers can in some cases use this knowledge in explanations of their number-conservation judgment. Because in adult, scientific thought, quite similar reasoning principles are applied to a wide range of continuous quantities, for example, length, mass, heat, electric charge, one might think the generalization to continuous quantity would be a small step for the child. One might expect it to be easy to apply the same explanations with continuous quantities. In some cases, this seems to have happened. Gelman (1969) reported transfer from training on length and number items to length and number conservation as well as liquid and mass. The explanations regarding mass and liquid involved appeal to the irrelevance of the transformations of displacement, pouring, and the like. But if the only thing involved in the development of the understanding of conservation of continuous quantity were the recognition of the common status of such operations vis-à-vis length, liquid, and malleable clay, then surely the natural development of these would follow quickly after the stable understanding of number conservation. Training studies designed to build the development of an understanding of continuous quantity on that available for number conservation should be successful. Yet, judging from a series of Genevan training studies (Inhelder et al., 1974; Inhelder et al., 1975), this does not seem to be true. Before we look at these studies on the relationship between number and continuous quantities, a brief digression is in order.

The concept of length, which is probably the easiest of the continuous quantities to understand, can be understood at two levels (at least). A great deal of reasoning about length can go on without the notion of a unit—as Euclid long ago demonstrated. Lengths may be ordered, equivalent lengths recognized, and so on, without ever considering the question of how many units long a length is. To question how long a length is, is to consider length at the second level. The question of how long a length is requires the arithmetization of the concept of magnitude and the arbitrary choice of a unit. Euclid and the other Greek mathematicians, having discovered the problem of incommensurables—which rears its head when one tries to let numbers represent lengths—kept their geometry and arithmetic strictly separate (see Kline, 1972, for an excellent treatment of this topic).

At the second level we identify, the understanding of length entails an understanding of scaling, the processes by which numbers may be made to represent various continuous quantities. Historically, the development of processes for scaling continuous quantities has gone hand in hand with the development of a scientific understanding of those quantities. Although it is perhaps obvious to adults what length is and, therefore, how it must be defined for purposes of scaling and how in principle to scale it, once defined, the same cannot be said for heat or electric charge. Even liquid quantity, on extended consideration, behaves in a way that presents the would-be applier of numbers with perplexing problems. Recall that the abstraction principle of counting asserts that the identity of the unit is irrelevant. However, this is not true for liquid quantity. Three cups of water plus three cups of alcohol do not yield six cups of liquid. This is because liquid mass, but not liquid volume, is conserved when mutually soluble (i.e., missible) liquids are combined. Scaling (i.e., measuring) heat, electric charge, liquid volume, and so on, cannot be done satisfactorily in the absence of some scientific understanding of these quantities.

The point of these remarks is that the application of arithmetic reasoning to continuous quantity is not as straightforward as it may seem at first. Even in the case of length, the child must have the idea of magnitudes that can be counted, that is, measured. As we will see, the problem of the unit is not trivial, even in the case of length or sweetness (Strauss & Stavy, 1981). Now back to the Genevan studies that have focused on trying to lead the child from his ability to make ordinal comparisons to ones involving an understanding of the fact that a given continuous quantity can be considered in terms of units.

The findings of Inhelder et al. (1974) highlight the difficulty a child who conserves number can have with length tasks. They also show that it is not enough to be able to count and conserve number to be able to conserve length. In one experiment, children were shown two roads made up of the same number of matchsticks, laid end to end to yield two continuous roads. A small wooden house was glued

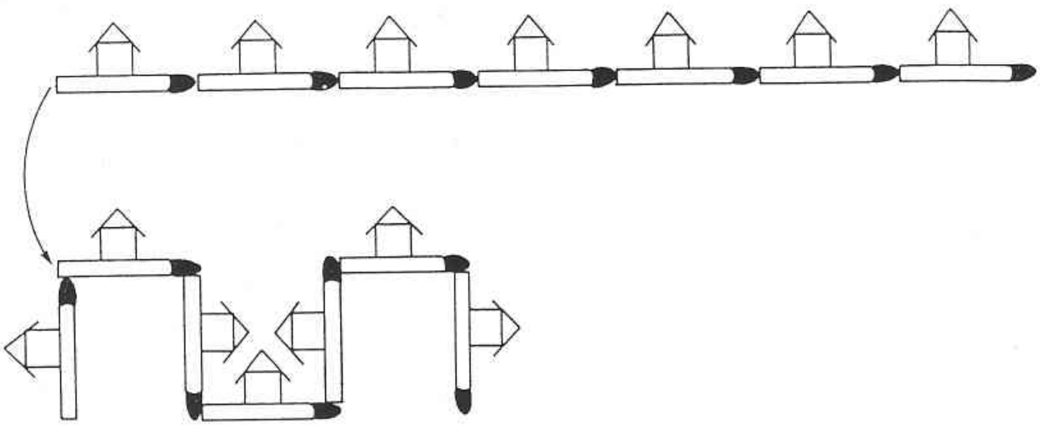

Figure 1. Illustration of the effect of transforming one row of matches and houses. (After Inhelder, Sinclair, and Bovet, 1974, p. 138.)

to the middle of each matchstick. Thus, the same number of houses appeared on two roads of equal length. The experimenter then rearranged the sticks in one row into the pattern shown in Figure 1. There were children who maintained that after the rearrangement, the number of houses in the two displays remained the same but that the length of the roads did not; the resulting road in Figure 1 was said to be shorter. Some children said that both were the same because there were the same number of matches—as if to take the length task and treat it as a number task. This may seem a perfectly good answer if we assume that the child realized that there were an equal number of equal units in each. However, a further task showed that the children who responded this way were indifferent to the issue of equality of the units. Consider a condition where the length of the individual sticks (i.e., of the units) in each row varied themselves in length. Thus, a row with 5 matchsticks stretched end to end was as long as one with 7 shorter pieces of wood also laid end to end. Believe it or not, some children said that the latter would be a longer road to traverse because it had 7 pieces. These children failed to realize that the units in both rows were of different sizes themselves. Therefore, the comparison was not valid, a fact that the children seemed not to know.

Findings such as the above led Inhelder et al. (1974) to conclude that the relationship between conservation of number and length was quite complex. In a subsequent set of experiments, Inhelder et al. studied the relationship between number and the continuous quantity in a malleable clay ball. This work takes off from Piaget's (1975a) more recent account of number conservation, that is, the need for the child to realize that items within a display are commutable. The issue was whether the argument could be developed to explain the understanding of continuous quantity. The experiments that were designed to inform the issue involved different small colored pieces of clay. These pieces could be left as such for tests of number conservation or put together for the continuous tests. It turned out that "in going from the discontinuous to the continuous, subjects regress and substitute for the 'operatory envelop' (a collection whose quantity equals the sums of the parts, and which is conserved during form or shape transformations) a 'preoperatory envelop' where the total quantity is, in general, more" (Inhelder et al., 1974, p. 46). To get beyond this, the child has to understand that the small pieces which were rolled into a clay ball are "commutable" under displacement. To do this requires knowing that it does not matter to where the pieces are moved nor does it matter what shape the pieces or the whole object are as they are moved.

We confess that we have a less than full understanding of the recent Piagetian theory of what takes the child from nonconservation to conservation of continuous quantity and how this, in turn, relates to the understanding of discontinuous quantity. For us, the recent experiments highlight the difficulty children have with the notion of a unit of a quantity, a fact that is not dealt with in this new account of conservation. The child who says that 7 short matchsticks cover more ground than 5 long matchsticks is making a fundamental error by comparing units of different extents. This, we submit, occurs because he does not yet think of length in our second sense, where relative lengths are considered with reference to a countable unit of a fixed magnitude. If the child lacks this idea of length, then he cannot begin to understand that he is mixing apples and oranges let alone comprehend the conditions under which he might be able to compare numbers that count comparable units (Schwartz, 1976). Similarly, when asked to compare two clay balls that are each made up of three smaller pieces, we doubt that the child recognizes that the ability to decompose the continuous quantities into pieces in this situation is an example of a general principle, that is, that continuous quantities can be represented in units which thereby renders them measurable. Indeed we doubt that the child who quantifies discrete sets realizes that he has both encountered a unit problem and solved it.

Given that the counting principles are applied indifferently to different types, shapes, colors, and so on, of objects, a child need not know that counts involve the iterative production of yet another one (1). The problem of the unit in counting (and, therefore, discrete quantification) is solved for the child by virtue of the abstraction principle. Yet, this could be, and probably is, an implicit understanding of the principle at first. Recall that it is a while before children come to realize that the successive natural numbers are generated by an iterative process. It would seem hard to understand that continuous quantities can be represented in terms of concatenated units without the latter being implicitly understood; but even this is not enough. The child has to know what dimension to quantify and, as shown by the examples of heat, electrical charge, and even liquid volume, this is far from obvious.

We seem to be in disagreement with the Genevans on two matters. First, although they do point out the quite different status of the notion of unit vis-à-vis discrete as opposed to continuous quantities, they maintain "the fact that the unit is given in discrete quantities, and must be constructed in continuous quantities is important, mostly with respect to measurement which comes in long after conservation" (Inhelder et al., 1974, p. 54). As indicated, we see a closer relationship between the development of an understanding of continuous quantities and the development of measurement concepts. Strauss & Stavy, (1981) provide a lovely example of this relationship in their work on the child's concept of sweetness. As children develop the ability to use more powerful scales, for example, ordinal versus interval scales, so they come to understand the variables that do and do not affect the sweetness of a liquid. Second, the Genevans seem to suggest that the understanding of a given continuous concept is an all-or-none matter. Work by Shultz, Dover, and Amsel (1979) highlights the danger of such an assumption. They point out that changes in shape can and do alter quantity under certain conditions, and likewise, that some properties of a container can profoundly affect whether the liquid in it is conserved over time.

If the same amount of water is poured from a tall, narrow container into a very wide but shallow dish, as opposed to a yet taller and narrower glass, there will be a difference in the amounts in each container when both are measured 24 hr. later. For the greater the exposed surface of the water, the greater the rate of evaporation. Shultz et al. (1979) report that 10-year-old children who passed the standard liquid conservation did poorly in predicting the 24-hr. difference that would obtain as a function of differences in degree of exposed surfaces. Lest one think that such tricks can be performed only under conditions of the passage of time, it should be sobering to know that some shape transformations that involve continuous quantity alter the amount immediately. Shultz et al. go over the fact that the shape changes of two-dimensional closed figures can alter the area or perimeter of that figure. Because most of us either did not learn or have forgotten the relevant geometric proofs, we are likely to do as the McGill University undergraduates did—maintain a judgment of conservation when we should not. Shultz et al. (1979) were able to teach their subjects about the effects of shape transformations on closed two-dimensional figures, and they did so "on the premise that the effects of shape transformations could best be grasped if the quantities were readily identified in standard unit measures" (p. 113).[3]

We have come a long way from the Siegler (1981) paper on conservation. We were dissatisfied with his account of the difference between conservation of number and the two continuous quantities of liquid and clay amount. It was not because we thought what he said was wrong. Rather, it was because we thought it was just the beginning of a longer account of how children think about the processes of quantification—an account that will have to allow for the continued development of some conservation beliefs as a function of knowledge about a given domain and how to define units in that domain.

**Other Concepts of Continuous Quantity**

Given the possibility that children will go through two levels at least in their understanding of continuous quantity, is there any evidence for the understanding of the first level at an early age? Work by Brainerd (1973) and Trabasso (1975) show preschoolers able to order the relative lengths of sticks when they cannot know their exact lengths. Indeed, the evidence of an early ability to make transitive inferences about length and weight fit well in this context. And the work on functions of Piaget et al. (1977) is motivated by the need to explain the primacy of order judgments (i.e., relative extents) over judgments based on quantification during the preschool years. Piaget wants to argue that concepts of number and extent are not yet differentiated. In a sense we agree.

If we are right that concepts of continuous quantity are at first not recognized as quantifiable in terms of some unit, we should begin to see results reporting findings of such early concepts of other continuous quantities. Levin's research on the development of time concepts can be interpreted in this context (Levin, 1977, 1979; Levin, Israeli, & Darom, 1978). Levin (1977) presented 5- to 6½-year-olds and 8½-year-olds with three different tasks. These were the still-time, rotational-time, and linear-time tasks. Each successive task was designed to be more complex than the previous one. We focus on the still-time task, which asked children to decide whether two dolls slept as long as each other and if not which slept longer. The children were asked to answer these questions after witnessing four conditions: (1) the dolls went to sleep and woke up at the same time, (2) the dolls went to sleep but one woke up first, (3) one doll went to sleep first but both woke up together, and (4) one doll went to sleep first and woke up before the other, however both slept as long. Even the 5-year-olds did well on the first three problems. Moreover, their explanations made it clear they were taking succession into account and rationalizing their duration judgments in terms of the relative starting and ending times. As task complexity increased—in item 4 of the still-time task as well as in other tasks that put time and other factors, like speed and extent, into conflict—the younger children's performance scores decreased. Levin and her colleagues argue that much of the decrease is due to the young child's tendency to be distracted by irrelevant variables. We also suspect that the development of time-measurement skills is involved for much the same reasons outlined above regarding other continuous quantities.

Further evidence for an early ability to perform relative comparisons of continuous quantities comes from experiments that require children to match a standard with another display. Gelman (1969) found that her 5-year-old subjects could select the two of three sticks of the same length if none of the sticks overlapped. Anderson and his colleagues (e.g., Anderson & Cuneo, 1978; Cuneo, 1980; Wilkening, 1981) repeatedly report children of this age able to indicate how much area, time, distance, and so on, is represented in a given display or event; children as young as 3 are able to point reliably to different relative positions on a scale. Thus, for example, Cuneo (1977) had young children indicate how happy (or sad) they would be eating a particular cookie where over trials the area of the cookie varied systematically.

Wilkening's (1981) work raises the possibility that 5-year-old children make *implicit* use of arbitrary units. As such, it could be that later development of this ability is better thought of as the development of an *explicit* understanding of the role of measurement vis-à-vis decisions of relative amounts. Wilkening points out that all research on the child's understanding of the relationship between time, speed, and distance involves a choice paradigm wherein the child is required to choose that animal, that train, or what have you, that went further or faster or took longer, and so on. He suggests that these paradigms may have failed to reveal an early ability to integrate information from two of the dimensions in order to reach an inference about the third because they are not appropriate tests of this ability. Instead, he argues that they are tests of the child's ability to ignore one or more dimensions (cf. Levin, 1979). The proof of the argument lies in Wilkening's (1981) results. Subjects in each of three age groups (5, 10, and adults) were tested on three tasks that required subjects to integrate velocity, distance and time. We consider the first.

The velocity-time integration task involved a display of a dog sitting close to the exit of its den. The dog and its den were on the left side of a 3-m by 1-m screen. A bridge led out of the den across a lake. A metal strip, fixed to the bridge, served as a scale to which subjects were to attach an animal—a turtle, guinea pig, or cat. Subjects were told that these animals were afraid of the dog whenever it barked, and that, whenever the dog barked, the animals started running across the bridge and stopped when the barking stopped. Note that the three animals have differential natural speeds. In a pretest, even the 5-year-olds could arrange the animals in the correct order. Not only does this mean they can represent relative velocities, it means Wilkening could do his experiment. Children (and adults, of course) listened to the dog bark for either 2, 5, or 8 sec. and then placed a given animal at the spot on the bridge he could have reached during these barking intervals. Because a centimeter scale was attached to the back of the metal strip, the distance in centimeters served as the true dependent variable. All age groups implicitly integrated time and velocity values with a multiplicative rule. This is revealed by significant interaction effects in an analysis of variance between time and velocity. How did such young children do this? Wilkening's eye-movement data show that the children (as well as the older subjects) followed the imaginary movement of an animal along the bridge. When the dog stopped barking, they pointed to the position their eyes had reached. Because they adjusted the rate of their eye movements as a function of animal, the fact that the time × velocity interactions were significant is explained.

Wilkening points out that the ability to integrate distance and velocity to judge time requires the use of a division rule, likewise the ability to judge velocity as a function of distance and time. Furthermore, the definition of the unit is more complex, as are the information processing demands of tasks that require these integrations. The youngest group did not succeed on distance, that is, the velocity task, where success is defined in terms of the use of a division rule. Whether these velocity tasks require an explicit understanding of the relevant units of measurement remains a question for further research. What is clear now is that even young children can, under some conditions, make correct judgments of relative amounts of continuous quantities. Still, there is much room for development.

### Classification

In an earlier section (*Assessment of the Characterization of Concrete Operations*), we discussed the role classification structures play in Piaget's (1952a) theory of the development of numerical reasoning. In this section, we focus on Inhelder and Piaget's (1964) theory of the development of classification skills, and on the implications this theory has for concept acquisition.[4]

Concepts have traditionally been characterized in terms of classes and class-inclusion hierarchies. Like classes, concepts are said to have both an intensional and an extensional component. The *intension*, or definition, of a concept specifies the criterion elements must satisfy to be regarded as members of the concept. The *extension* of a concept consists of all the elements that are appropriately described as members of that concept. (The reader is referred to Schwartz, 1977, for a review of a philosophical work that proposes an alternative approach to concepts, and to Smith & Medin, 1981, for a review of psychological research conducted within this approach.)

To Vygotsky (1962), Inhelder and Piaget (1964), and Olver and Hornsby (1966)—all of whom shared the traditional view of concepts as classes—the study of children's classifications was of special interest for two reasons. First, it was thought that analyses of the structure of children's classifications would shed light on the structure of their concepts and, more generally, would show how this structure successively approximates the logical class structure of adults' concepts. Second, it was hoped that an examination of the basis of children's classifications would reveal something of the content—whether concrete or abstract—of their concepts. Because the young child was viewed as locked in a concrete, immediate reality (e.g., Piaget, 1970; Bruner et al., 1966), it was predicted (e.g., Olver and Hornsby, 1966) that young children would establish equivalences on the basis of perceptual similarities, whereas older children would make use of more abstract criteria.

#### Background

*Structural Properties of Children's Groupings.* According to Inhelder and Piaget (1964), classification begins when the child groups together two objects that look alike in some way. The child's ability to discover similarities between objects is *not* regarded as sufficient, however to warrant the conclusion that the child can classify. True classification is said to involve the active construction of classificatory systems.

Inhelder and Piaget (1964) began their investigation of classification skills with a detailed examination of children's productions in free-sorting tasks. They found three main phases in the development of free classification. In the first phase (2 to 5½ years), graphic collections, three types of grouping were obtained: alignments, collective objects, and complexes. All three types are based on configurational variables rather than similarity. The child becomes distracted by the spatial arrangement of the objects, or by the descriptive properties of the whole, and builds without regard for similarity. The geometric design objects form or the representative, situational content they evoke (e.g., a train, a cake, a castle) sway the child's attention away from the perceived likeness and differences of the objects themselves. In the second phase (5½ to 7 years), nongraphic collections, the child is no longer misled by considerations of patterns: objects are assigned to groups on the basis of similarity alone. Inhelder and Piaget list four types of nongraphic collections. At the least advanced level, a number of small groups are formed, each based on a different criterion. Further, only some of the objects that constitute the array are assigned to groups. The second type of nongraphic collections again involves various small groups based on a multiplicity of criteria. At this level, however, there is no unclassified remainder: all of the objects in the array are classified. At the next level, fluctuations of criterion are eliminated. Objects are now assigned to groups on the basis of a single, stable criterion without any remainder and without overlap. At the fourth and most advanced level, groups formed on the basis of one criterion are subdivided according to a second, stable criterion.

Children are, thus, able, by the end of the nongraphic collections phase, to form stable, nonoverlapping collections and to divide these into subcollections. Can children, at this point, be said to be able to classify? Inhelder and Piaget argue that, although these children's classifications may be so differentiated and hierarchized as to closely resemble class-inclusion hierarchies, they are *still* preoperational. According to Inhelder and Piaget, "the true criteria by which we can distinguish such preoperations from true classification are the ability of the subject to appreciate the relations 'all' and 'some,' and his power to reason correctly that A < B [i.e., that the subclass is smaller than the class in which it is included]" (Inhelder & Piaget, 1964, p. 54). That is, the preoperational child is still unable to grasp fully the logical relation of inclusion. When shown 12 roses and 6 tulips, for example, and asked, "Are there more flowers or more roses?," the preoperational child typically answers, "more roses." He is capable of adding subclasses to form a larger class (flowers = roses + tulips), but he is unable to simultaneously perform the inverse transformation (roses = flowers − tulips). As a result, he is unable to make a quantitative comparison of the class and its larger subclass. For such a comparison requires that the child separate the class into its subclasses to isolate the larger subclass, while at the same time maintaining the integrity or identity of the class, the other term in the comparison. In other words, the child must be able to attend at once to the part and to the whole, and that is precisely what the preoperational child cannot do. As soon as the subclasses are isolated, the child loses sight of the whole. As a result, he compares the two subclasses rather than the class and the larger subclass. It is only when both operations (addition and division of classes) are present and fully coordinated that the child becomes capable of contemplating at once the class and the subclass and of comparing the two. At this point (the third and last phase of development of classificatory abilities), the child's groups are no longer simply juxtaposed but constitute well-articulated, logical, class-inclusion hierarchies.

Using somewhat different procedures, Vygotsky (1962) and Bruner et al. (1966) have also studied the development of classification abilities. Although there are many differences in the types of classificatory responses reported across the three programs of research, there are also striking similarities. In particular, all three studies suggest that young children go through an initial stage in which they are caught by relationships among the elements themselves—whether spatial arrangements, thematic relations, or idiosyncratic resemblances. Further, all three studies indicate that children go through an intermediary stage in which groups are formed on the basis of similarity alone, but the criterion for grouping fluctuates. During the last stages, children progressively learn to group objects into stable, exhaustive classes and to organize the classes thus formed into logical hierarchies.

*Basis of Children's Groupings.* Olver and Hornsby (1966) maintained that children's classifications exhibit semantic as well as syntactic properties and that both sets of properties undergo developmental change. The syntax of classification is defined as the formal structure of the class or grouping formed. The semantics of classification are the features of objects or events children use to establish equivalences.

Working with the theory of cognitive development of Bruner et al. (1966), Olver and Hornsby proposed that in the early stage, when the child's mode of representation of the world is essentially ikonic, children would group objects solely on the basis of perceptual properties. Older children, whose mode of representation is symbolic, were expected to use more abstract criteria. In particular, it was assumed that what uses objects have and what functions they serve constitute a more abstract notion and require more "going beyond the information given" than what objects look like. Accordingly, it was predicted that younger children would form concepts based on perceptual attributes whereas older children would form concepts based on functional attributes.

Olver and Hornsby (1966) report the results of two experiments, one by each author. In Olver's study (see also Bruner & Olver, 1963) children aged 6 to 19 were presented with a series of concrete nouns and were asked how each new item was similar to, and different from, the items previously introduced. For example, the words banana and peach would be presented, and, then, the word potato would be added to the list. At this point, the child would be asked, "How is potato different from banana and peach?" and "How are banana and peach and potato all alike?" This procedure was continued until a list of nine items had been presented (e.g., banana, peach, potato, meat, milk, water, air, germs, and stones). Hornsby's procedure was closer to that of Inhelder and Piaget (1964). Children of 6 to 11 years were shown an array of 42 drawings representing familiar objects (e.g., doll, garage, bee, pumpkin, sailboat, etc.). The children's task was simply to select a group of pictures. Their grouping completed, children were asked how the pictures they had chosen were alike. The pictures were then returned to their original position in the array, and children were asked to form another group. The entire procedure was repeated 10 times.

In both Olver's and Hornsby's tasks it was found that 6-year-olds based more of their groupings on perceptual attributes (color, size, shape, position in space) than did older children. In Olver's verbal task, the use of functional attributes increased steadily from 49% at age 6 to 73% at age 19. Conversely, the use of perceptual attributes decreased steadily from roughly 25% to 10%. In Hornsby's picture task, there was again a steady decline in perceptually based equivalence from 47% at age 6 to 20% at age 11. In contrast, the use of functional and nominal attributes increased from 30% and 6% respectively to 48% and 32% respectively. Comparing these two sets of findings, Olver and Hornsby noted that the same pattern of development obtained whether words or pictures were presented and whether items were presented in random or predetermined order. They described this pattern in the following terms:

> Equivalence for the six-year-old reflects a basis in imagery, both in what he uses as a basis for grouping and in how he forms his groups. . . . With the development of symbolic representation, the child is freed from dependence upon moment-to-moment variation in perceptual vividness and is able to keep the basis of equivalence invariant. (1966, p. 84)

We are not convinced that Olver and Hornsby's data support the notion of a stage-by-stage progression from a perceptually based to a functionally based equivalence. At no age were children's groupings based solely on perceptual properties. To the contrary, even Olver and Hornsby's younger children produced a sizable percentage of functional responses. (Indeed, the largest category of responses produced by the 6-year-olds in Olver's study was functional [49%], *not* perceptual [25%].) What these results suggest to us is that if there does exist a difference between younger and older children with respect to the basis they select for classifying objects, it is one of degree and not of kind. Younger children may use perceptual criteria somewhat more frequently than do older children; but they clearly do not use perceptual criteria to the exclusion of all others. What specific criterion is selected as basis for equivalence in any given situation appears to reflect less a particular mode of representing reality than the interplay of a large number of factors. These include the mode of presentation (verbal versus visual) of the stimuli; the readiness with which the stimuli presented can be subsumed under a single, conventional label (both factors seem to have influenced subjects' performance in Olver and Hornsby's studies); the child's style of conceptualization (e.g., Kagan, Moss, & Sigel, 1963) or organizational preference (Smiley & Brown, 1979); and so on. Support for this interpretation comes from a study by Miller (1973).

Miller (1973) gave 6-year-olds and college students eight oddity problems. Each problem involved a set of four objects (e.g., an orange, a plum, a banana, and a ball), and subjects were asked to remove "the thing that doesn't belong." The same question was repeated twice, and subjects were encouraged to take out a different object each time. The sets of four objects were constructed in such a way that removal of one object left a perceptual subset (e.g., an orange, a plum, and a ball) and removal of a different object left an abstract subset (e.g., an orange, a banana, and a plum). In general, the 6-year-olds had little difficulty forming both types of subsets. Indeed, in two of three problems where reliable differences were obtained between the 6-year-olds and college students, the significant result was due to the children's inability to generate a perceptual subset. Both children and adults tended to form abstract subsets on their first correct trial. Taken together, these results suggest that: (1) 6-year-olds *can* form categories on the basis of both concrete and abstract criteria and (2) 6-year-olds do not necessarily differ from college students with respect to the kind of criterion they *prefer* to use.

A variable that may have contributed to the 6-year-olds' superior performance, in Miller's (1973) task, is the use of modeling. Miller took children through two training problems prior to testing and showed them how two different solutions (one perceptual, one more abstract) could be provided for each. There is little doubt that such careful coaching must have left children in no uncertainty as to the nature of the task or the types of responses that were expected from them (Nash & Gelman, cited in Gelman & Gallistel, 1978; Smiley & Brown, 1979).

### Classification and Basic Categories

The work of Inhelder and Piaget (1964) gave rise to much experimental interest in the development of the structure of children's free classifications. By and large, the evidence collected supported Inhelder and Piaget's claim that young children are unable to sort objects into classes (see Flavell, 1970, for a review of the free-classification research published prior to 1969). However, recent work by Rosch, Mervis, Gay, Boyes-Braem, and Johnson (1976) and Sugarman (1979) indicates that even very young children can, and do, sort objects taxonomically when presented with appropriate sets of stimuli.

Rosch and her colleagues (1976) noted that the stimuli used in classification experiments were typically stimuli (e.g., a table, a dresser, a bed) that could be grouped taxonomically only at the superordinate level (e.g., furniture). They pointed out that taxonomies of concrete objects include a level of categorization (e.g., chairs, apples, shirts) that is less abstract than the superordinate level; categories formed at this level are referred to as *basic* categories. In a number of experiments, Rosch and her colleagues found basic categories to be the most inclusive categories whose members (1) possess significant numbers of attributes in common, (2) are used by means of similar motor movements, and (3) possess similar shapes.

Rosch and her colleagues (1976) predicted that basic-level categories would be the first to develop. Rosch et al. reasoned that if young children encode the world by means of sensorimotor schemes (e.g., Piaget, 1970) or images (e.g., Bruner et al., 1966), then basic objects should be learned easily. In one experiment, kindergartners and first-, third-, and fifth-graders were assigned to one of two sorting conditions (basic or superordinate). Stimulus materials were color photographs of clothing (shoes, socks, shirts, pants), furniture (tables, chairs, beds, dressers), vehicles (cars, trains, motorcycles, airplanes), and people's faces (men, women, young girls, infants). Subjects in the superordinate condition were given one picture each of the four different objects in each of the four superordinate categories. Subjects in the basic condition received four different pictures of a basic object in each of the four superordinate categories. The results were straightforward. As in previous studies, only half the kindergarten and first-grade subjects could sort objects at the superordinate level. In contrast, there were no developmental differences in the ability to sort basic-level objects—basic-level sorts were virtually perfect at all age levels. In a second experiment, 3- and 4-year-olds as well as kindergartners and first-, third-, and fifth-graders were given oddity problems with either basic-level or superordinate relations. Again, basic sorts were virtually perfect at all age levels. For the 3-year-olds, the percentage correct was 99%; for all older age groups, it was 100%. As expected, the 3-year-olds performed poorly (55% correct) on triads that could only be sorted at the superordinate level. It is interesting to note, however, that the 4-year-olds' performance was almost perfect, with 96% correct.

Recent findings indicate that even 1½- to 3-year-old children may be capable of consistent sorting at the basic level (e.g., Nelson, 1973; Ricciuti, 1965; Ross, 1980; Stott, 1961; Sugarman, 1979). In Sugarman's (1979) study, children between 12 and 36 months of age were given six grouping tasks. Materials in each task were eight small objects evenly divided into two classes, for example, four dolls and four rings. Each task involved (1) a phase of spontaneous manipulation and (2) a phase during which children were given several grouping-elicitation probes. Two types of classificatory activity were examined: (1) the order in which objects were manipulated (sequential classification) and (2) the arrangement of objects in space (spatial classification). Spontaneous and elicited performance usually coincided. In general, the results suggested a shift in children's classifications from a sequential, stimulus-bound organization of single classes to an anticipatory representation and coordination of the two classes in the array. The 12-month-olds showed a reliable tendency to manipulate identical objects successively: they repeatedly selected items from one of the two classes, generally that with greater tactile-kinesthetic salience. Their arrangement of objects in space, however, was haphazard. Complete spatial groupings of single classes (e.g., all the dolls *or* all the rings) did not appear until 18 months of age. By 24 months, sequential selection of similar objects extended to both classes and objects within a basic category were spatially grouped. Finally, whereas all but one of the younger children who grouped two classes at any point in the experiment arranged the objects one class at a time, more than half the 30- and 36-month-olds shifted between classes as they sorted. These children clearly could attend to both classes at once. Whether they contructed one-to-one correspondences between dissimilar objects (e.g., a doll in each ring) or sorted identical objects into spatially distinct groups, their actions were always swift and deliberate. Indeed, it often appeared to Sugarman as if the older children had mentally constructed some classification in which both classes were represented and, seizing objects more or less at random, were arranging them according to the scheme they had formed.

Inhelder and Piaget (1964) themselves reported having observed, along with the graphic-collections characteristic of the first phase of development of free classification, other, less frequent productions that are quite similar to those reported by Sugarman (1979). Specifically, Inhelder and Piaget (1964) found that young children would at times successively select similar objects and then toss them into a pile or hold them in their hands without attempting to build them into a configurational structure. Inhelder and Piaget minimized the significance of these productions, which they viewed as a very primitive type of nongraphic collection. They argued that the similar objects were manipulated sequentially on the basis of "successive assimilations" and were not formed into a classification (collection) proper.

Should the classifications produced by Sugarman's (1979) infants also be construed as resulting from successive assimilations? After all, each of the arrays Sugarman used in her grouping tasks contained two classes of identical objects, and Inhelder and Piaget (1964) have never denied the fact that children, even very young children, can discern physical similarities between objects. One could argue that where such similarity is high, as was obviously the case in Sugarman's (1979) experiment, the young child successively explores similar objects precisely because the perceived resemblance is particularly salient and catches and holds her attention. Conversely, where the similarity between objects is low, as was the case in Inhelder and Piaget's (1964) own experiments (recall that the stimuli used could only be sorted at the superordinate level), the child becomes distracted by the configurational properties of the objects and as a result builds without regard for similarity.

We do not believe that the productions Sugarman (1979) obtained resulted solely from sequential, stimulus-bound assimilations, which mimic classifications based on similarity. One might doubt that successive manipulations of identical objects unambiguously reveal classificatory behavior. But add to this the ability to place the groups in two separate locations, thereby using space to keep the two categories separate, and it becomes hard to deny a true classificatory competence with basic-level objects. Sugarman's data demonstrate that sequential classifications, with no spatial arrangement of the objects, occur only at the earliest ages. By 18 months of age, infants successively selected *and* grouped together spatially all of the objects that belonged to one of the two classes in the array. For us, such findings support the notion that significant classificatory competencies are present from the earliest ages (which is not to say, obviously, that no development remains to take place). This conclusion is supported by the recent reports of Cohen and Younger (1981) and Ross (1980). Both studies used habituation and recovery-from-habituation responses to show that infants do categorize some sets of objects.

The work of Rosch et al. (1976) and that of Sugarman (1979) demonstrate that children as young as 3 years of age can sort objects according to a consistent criterion and without remainder or overlap. Indeed, there is evidence that still younger children can do the same. These demonstrations clearly challenge Inhelder and Piaget's (1964) description of the development of free classification. At the very least, they force us to abandon the notion that a stage of graphic collections invariably precedes that of nongraphic collections. In addition, they provide clues about some of the processes that contribute to the young child's acquisition of knowledge—in both factual and linguistic domains.

### Primacy of Basic Categorization

According to Rosch and her colleagues (1976) basic categories are the primary cuts we make on our environment. We can and do establish equivalences at higher and lower levels of abstraction, but the basic level is the *primary* level at which we form equivalences—the primary level at which we chunk objects in our environment. There is some support for the notion that our most spontaneous or immediate categorization of the world is in terms of basic categories. Experiments with adult subjects have shown that concrete objects are typically first recognized as members of their basic-level category and are normally referred to by their basic-level name (Rosch et al., 1976; Shipley, Kuhn & Madden, 1981). Is there evidence that infants and young children carve their world into basic categories? We think so. First, there is the infant's often spontaneous (Sugarman, 1979) sorting of arrays into basic categories; second, there is the infant's differential and appropriate reactions to different objects; and third, there is the young child's use of basic-level terms for basic objects.

We have already discussed the infant's sorting behavior. Young children also reveal their classificatory competence through their actions—other than sorting—upon objects. We might say that sorting is an object-independent action in the sense that all classes of objects—roses, books, cups, and so on—can be sorted in the same way. By contrast, actions, such as drinking, rolling, and so on, are object dependent or object specific. When we talk here about the infant's actions on objects, we have in mind these object-specific responses. When given a new instance of a familiar category, for example, a shoe, or a cup, 1-year-old children may try to put it on their feet, or bring it to their lips respectively. In other words, they behave differentially and appropriately when presented with new examples of presumably known basic categories (Nelson, 1977). Of course, there is the question of what this capacity means. Inhelder and Piaget (1964) maintained that the infant's assimilatory activity is only analogous to classification. We believe that the infant's assimilation of novel objects to existing sensorimotor schemas is in fact a *primitive form* of classification.

Rosch et al. (1976) reasoned that if by the time the child begins to acquire words, he or she has available mostly basic-level concepts, then basic-object names should be the first nouns acquired. Rosch and her colleagues (1976) carefully analyzed Brown's (1973) protocols of the spontaneous speech of his subject, Sarah, during her initial period of language acquisition. Two judges read Sarah's protocols, and utterances of an item in any of the taxonomies Rosch et al. (1976) had studied were recorded. The results were straightforward. Basic-level names were essentially the only names used by Sarah at that stage. Similarly, vocabulary studies reviewed by Clark (1978) suggested that of the first 50 or so object words that children learn, many of them are basic-level terms. Additional support for the primacy of basic-level names in children's acquisition of concrete nouns is provided by the study of Rosch et al. (1976) of the names 3-year-olds give to pictures of objects. Of the 270 names collected, all but one was a basic-level name. True, not all of the names provided by the children were correct, but errors were typically basic-level names for objects other than those pictured (e.g., blueberries instead of grapes).

On a comprehension test, Anglin (1977) found that young children responded accurately when asked about a dog as opposed to collie or animal. In seeming contrast, more were accurate when asked about an apple as opposed to fruit or food. Anglin concluded that young children tend to use terms at that level of generality which maximally discriminates among objects in their everyday environment. Rosch et al. (1976) also noted that what objects are treated as basic level does not necessarily coincide with the biological definition of superordinates and subordinates. As an example, individuals who think trees are those objects one sits under to avoid the penetrating heat of the sun probably do not know whether the trees they sit under are maples, oaks, and so on. For these individuals, the seeming superordinate is psychologically a basic-level concept (i.e., a tree is a tree is a tree).

Young children's overgeneralizations of nouns are sometimes held as evidence against the view that early noun usage reflects the availability of basic concepts. Recent evidence points to a different interpretation of children's generalizations however. Briefly, it appears that these reflect the child's attempt at using as meaningful a label as he can when he does not yet know the appropriate label. Instead of selecting a label at random, he selects one from within the same hierarchy. Two lines of evidence support this hypothesis. First, 2- and 3-year-old children who produce overextensions, nevertheless, accurately comprehend adult terms (Gruendel, 1977; Huttenlocher, 1974; Thomson & Chapman, 1977). Second, several investigators (Bloom, 1973; Gruendel, 1977; Rescorla, 1980, 1981) have observed that a period of relatively accurate use of category name is often followed by overextensions to exemplars of a common superordinate. For example, the initial accurate use of the term car is followed by its use for many diverse objects within the broader category of vehicle. This overextension could signify either the formation of, or an already-present, superordinate category. Recall that Rosch et al. (1976) found that children's labeling errors typically involved using inaccurate basic-level names, such as blueberries instead of grapes. Both names reflect basic level categories from the same superordinate category. These results suggest that some early concepts may be more richly organized than the basic-level analysis suggests. Children of a very young age may be capable of using hierarchical-classification schemes to at least represent and organize their knowledge about objects. Put differently, what young children's overextensions may reveal is their implicit use of an organization scheme long before that organization can be explicitly accessed and used in sorting tasks.

We have reviewed evidence that indicates that even very young children are capable of forming categories according to stable, consistent criteria. We submit that this finding is surprising only in the context of an expectation to the contrary. It is hard to see how the child could master her environment as quickly and as efficiently as she does if she were incapable of forming stable categories. For the most economical means of mastery must necessarily involve the generalization to all novel, unfamiliar instances of what is known or what has been discovered to be true about a small set of familiar instances. Clearly the formation of categories that are at least consistent is indispensable if such generalization is to bear fruit. We want the child to be able to generalize from old cup to new cup that which is true about cups and from old shoe to new shoe that which is true about shoes. In each case, the recognition that the old and the new objects belong to the same category creates a basis for generalization. In other words, the fact that the child can categorize upon the basis of similarity—however that similarity may be recognized—means that she does have a capacity for projecting or generalizing information to appropriate instances. A child who always categorized objects on the basis of their spatial configurations would make one erroneous generalization after the other.

We have also considered evidence that suggests that the first categories the child learns are basic categories. Rosch et al. (1976) describe characteristics of the basic categorization process that help elucidate why it is that basic categories are primary, why it is that so many of our perceptions and conceptions involve basic categories, and why—we add—it is especially adaptive for the young child to form basic categories as opposed to categories at other levels of abstraction.

Rosch and her colleagues (1976) argue that, far from being unstructured, the world we live in is highly determined: real-world attributes do *not* occur independently from each other. Creatures with feathers are more likely to have wings than creatures with fur; and objects that look like chairs are more likely to have the property of sit-on-ableness than objects that look like birds. Given that combinations of attributes do not occur uniformly, it is to the individual's advantage to form classifications that mirror (at some level of abstraction) the correlational structure of real-world objects. For such classifications would enable the individual to predict from knowing any one property an object possesses many of the other properties that may be present.

The level of abstraction at which categories are formed that best delineates the correlational structure of the environment is *not* the basic level but the *sub*ordinate level. Objects that belong to the category of rocking chair share a larger set of attributes than do objects belonging to the basic category of chair. However, the gain in correlational value between the features of members of a category, as one goes from a basic to a subordinate category, is accompanied by a severe loss in generality or inclusiveness. It makes intuitive good sense that one should wish one's categories to be, on the whole, as inclusive as possible. Clearly, the broader the category, the larger the number of items for which a summary description is simultaneously provided. Superordinate categories obviously are more inclusive than basic categories. However, their members share fewer attributes in common. Thus, Rosch et al. (1976) argue for the priority of basic categories. They are at the most inclusive level that still delineates the correlational structure of the environment.

Put somewhat differently, the argument is that basic categories dominate as a consequence of two opposite principles. On the one hand, categorization must help reduce the near-infinite variety of the environmental array to behaviorally and cognitively usable proportions. Attempts at fulfilling this goal lead to the formation of a few very large categories, with the greatest possible number of discriminably different objects being assigned to the same category. On the other hand, it is obvious that the more differentiated an individual's categories, the greater his ability to predict and, generally, control occurrences in his environment. Fulfillment of *this* particular goal calls for the formation of a larger number of small, distinct categories that correspond to detailed discriminations among stimuli. The basic level of categorization is the level that maximizes the conflicting demands of information richness and cognitive economy.

Thus, following Rosch et al. (1976), formation of categories at the basic level, as opposed to higher or lower levels of abstraction, presents significant adaptive advantages for the young child. At birth, all the objects, places, and events that the child experiences are novel. The first years of life must be largely devoted to resolving these novel experiences into familiar, recognizable forms and predictable events. A child who is inclined to form basic categories is effectively breaking down or parsing his environment into the most functional units, units that allow him to generalize the largest amount of information to the largest number of objects.

### Classification and Hierarchies of Classes

Inhelder and Piaget (1964) recognized that were one "to find a mixture of graphic and non-graphic collections from the beginning . . . one could argue that classificatory behavior owes its origin to non-graphic collections alone" (1964, p. 31). The previous sections indicate that a mixture of graphic and nongraphic collections *is* found from the beginning. Whether young children group objects on the basis of similarity alone (nongraphic collections) or on the basis of some other criterion, such as the objects' joint contributions to pleasing spatial configurations (graphic collections), depends heavily upon the nature of the arrays they get. Objects that can be sorted at the basic level of categorization are typically, and often spontaneously, sorted into consistent, exhaustive categories; objects that can only be sorted at the superordinate level are not. Why?

As Inhelder and Piaget (1964) claimed, it could be that the child's grasp of classificatory is not fully adequate. However, many extralogical factors appear to contribute to the ease or difficulty with which the child builds hierarchical classifications. In the next sections, we discuss some of these factors.

*Competing Behavioral Tendencies.* One possibility as to why young children do poorly on hierarchical sorting tasks is suggested by the work of Ricciuti. Ricciuti (1965) tested infants between 12 and 20 months of age with a procedure very similar to that used by Sugarman (1979) and obtained essentially the same results. He subsequently retested some of his 20-month-old subjects when they were 40 months old (Ricciuti & Johnson, 1965). Not surprisingly, complete spatial groupings of both object classes were by then far more frequent. What was surprising, however, was that children also produced groupings that were distinctly illogical from a classificatory point of view. They would, for instance, form two separate groupings, each containing two objects from each class. Moreover, the objects within each grouping would be arranged in such a way as to form, as Flavell (1970) put it, "what looked suspiciously like a 3-year-old's version of an interesting design or pattern" (p. 993).

Ricciuti and Johnson's (1965) findings suggest that young children develop, around the ages of 3 or 4, a taste for interesting, novel configurations. Instead of simply grouping the identical objects in an array in different locations, the child combines them in creative, fanciful ways. Her grouping activity, in other words, is no longer governed by a classificatory scheme alone; other dispositions or tendencies compete with, and at times prevent (as Ricciuti and Johnson have shown), the formation of logical classifications.

Assume for a moment that 3-year-olds do prefer building creative designs or patterns to forming symmetrical logical classifications. It seems reasonable to suppose that the more heterogeneous the array of objects, the greater the likelihood of a child forming some illogical configuration or other. Both Sugarman (1979) and Ricciuti and Johnson (1965) used arrays that contained two different classes of identical objects. Such arrays, it would seem, offer only limited possibilities in the way of figural masterpieces. Were one to increase the perceptual *dis*-similarity between the objects in the array, one might expect to find fewer and fewer logical classifications. To put the matter differently, whether 3-year-olds group objects together on the basis of common attributes *or* on the basis of their joint contribution to the creation of pleasing spatial configurations might depend on the nature of the objects used. Arrays that are composed of highly similar subsets might elicit classificatory responses; arrays composed of dissimilar objects, might elicit varying building responses.

Recall that Rosch et al.(1976) demonstrated that objects belonging to the same superordinate category tend to possess few perceptual attributes in common to have highly dissimilar shapes. Hence, a superordinate sorting task confronts the young child with perceptually dissimilar objects—the kind we propose as likely to elicit building as opposed to classificatory responses. If this account has merit, it is reasonable to conclude that the young child's well-documented failure to sort objects taxonomically at the superordinate level is due *not* to an inadequate grasp of classificatory logic but rather, in part, to the emergence (and continued intervention), of competing behavioral dispositions (Bever, 1970).

One implication of the preceding argument is that a reduction in the salience of the perceptual contrast between objects would facilitate the production of taxonomic sorts. Some support for this is provided by a study by Markman, et al. (1981). They asked 3- and 4-year-olds to sort the same set of objects twice, once on pieces of paper placed on a table, and once in transparent plastic bags. The objects to be sorted fell into four superordinate classes: furniture (kitchen chair, easy chair, table, couch), vehicles (motorcycle, car, plane, truck), people (boy, woman, man, fireman), and trees (evergreen, rust-colored trees, a deciduous tree, and a tree with needlelike leaves). Markman et al. reasoned that having the children sort the objects into transparent bags that did not readily allow for spatial arrangement would tend to reduce the impact of perceptual and configurational variables. The result would be to facilitate the formation of logical classifications. As predicted, there was a marked improvement in both 3- and 4-year-olds' sorting when they sorted into plastic bags. The authors concluded that young children fail to sort objects taxonomically in part because they become distracted by spatial variables and not because they have different principles of classification.

*Competing Hierarchical Organizations.* Until now, we have been concerned only with classifications based on relations of similarity, assuming (after Inhelder and Piaget, 1964) that classifications based on other relations were primitive productions whose existence was due to the child's inadequate grasp of classificatory logic. Recently, however, a number of authors (e.g. Nelson, 1978; Mandler, 1979, see also Mandler, vol. III, chap. 7.) have challenged the claim that the only, or even the most important, way in which our knowledge is organized is in terms of classes and hierarchies of classes. According to these authors, children and adults possess an alternative mode of conceptual organization—one which is based on *spatiotemporal* relations. The fundamental units in this type of organization are not categories but schemas. The tendency to use schemas might very well interfere with an ability to impose a classification structure on the environment.

Modern cognitive psychology's use of the construct *schema* is both like and unlike Piaget's use of scheme. (See Mandler, 1981; Mandler, vol. III, chap. 7 for a detailed discussion of the differences.) Both are taken to be mental structures that organize memory, perception, and action. However, for Piaget, the emphasis is more on the logico-mathematical structures that underly and constrain schemes. For schema theorists (e.g., Rumelhart, 1980, Rumelhart & Ortony, 1977, Schank & Abelson, 1977) the emphasis is more on the representations of everyday knowledge that are embodied in the schemas—be they face schemas, restaurant scripts or grammars for folktales. Some evidence for young children's sensitivity to spatiotemporal information . . . studies of causal reasoning in young children. Bullock and Gelman (1979) found that children as young as 3 select as cause the event that precedes rather than the event that follows the effect to be explained. Gelman, et al. (1980) also found that young children, when presented with pictures of an object and an instrument, have no difficulty selecting a third picture depicting the outcome of applying the instrument to the object. These and other similar findings (see Bullock, Gelman, & Baillargeon, 1982, for a review) suggest that children develop causal schemas that faithfully portray the sequencing of events in causal sequences and that specify what transformations can be applied to objects and with what effects.

A second source of evidence that children can detect and make use of temporal/spatial structure comes from studies that examine children's descriptions of event sequences. For example, Nelson (1978) analyzed preschoolers' descriptions of such event sequences as eating dinner at home, having lunch at a daycare center, and eating at MacDonald's restaurant. She found that the children generally agreed on where the sequence started and stopped and on the order in which events took place. To do this, children must have been able to keep track of event order. This conclusion would seem to go against Piaget's (1959) work on children's recall of stories. Piaget (1959) reported that his young subjects were very poor at maintaining the correct sequence of events when retelling stories. As Mandler (1981) pointed out, however, Piaget's subjects may have had difficulty keeping track of sequence because the stories used were poorly motivated and poorly structured. When 5- and 6-year-olds hear stories that contain clear and temporal and causal connections, they have no trouble retelling them correctly (e.g., Mandler & Johnson, 1977; Stein & Glenn, 1979).

The existence of an alternative mode of conceptual organization, one that emphasizes spatial and temporal relations, may well serve as another reason why young children fail to produce taxonomic classifications. Recall, for example, the representative constructions Inhelder and Piaget (1964) obtained (e.g., a train station); such productions can be attributed to the child's use of an alternative mode of organization rather than to a fundamental inability to grasp hierarchical relations between objects. Some support for this interpretation comes from Smiley and Brown (1979), who found that preferences for sorting materials into thematic or taxonomic groupings showed a curvilinear relationship across age. Younger children and older adults preferred thematic categories. It seems reasonable to suppose that what is changing is not the ability to classify objects logically but rather the choice of a basis to use in a task that allows for more than one possible organization. In other words, young children's tendency to produce thematic groupings may be due to in part to their greater preference for organizations that rely on spatial or temporal relations (Markman, 1981).

In a way, the two previous alternative accounts regarding the failure of a young child to classify reduce to one, that is, that the child's figural and thematic constructions both reflect a preference for a part-whole organization as opposed to a class organization (Markman & Siebert, 1976). When the young child is presented with meaningless objects, such as building blocks and geometric shapes, he uses them to build creative designs or configurations (e.g., Denney, 1972a; Inhelder and Piaget, 1964;

Ricciuti & Johnson, 1965); when presented with more meaningful stimuli, such as real objects or toy-size reproductions, he constructed scenes and situations with which he is familiar (e.g., Inhelder & Piaget, 1964; Markman et al., 1981); and when presented with verbal items and asked about similarities and differences among them, the young child relates the items in terms of a story that may be inspired or guided by the schemas he has formed (e.g., Bruner & Olver, 1963). In all cases, the organization that is imposed is not one of class relations but one in which parts are joined together to create some whole—whether a spatial configuration or a simple sequence of events, depending on the nature of the items with which the child is presented (Flavell, 1970). The relation between element and totality is one of part to whole rather than class member to class or subclass to class.

It is interesting, in this context, to consider Markman's (e.g., 1973a, 1980) work on collections. Recall that collections are the referents of collective nouns, such as forest, pile, family, and army. According to Markman, collections and classes differ in several ways. First, collections are organized into part-whole relations and classes are organized, obviously, into class-inclusion relations. Thus, we can say that petunias are part of a bouquet or that together they constitute a bouquet. We can also say that petunias are a type of flower or that they are instances of flowers; but we cannot say that petunias are kinds of bouquets or that they are instances of bouquets. This is because in a class-inclusion hierarchy, an element possesses (by definition) all of the properties that specify elements higher up in the hierarchy. That is, if element $X$ is a member of category $Y$, the defining properties of $X$ will include those of $Y$. In a part-whole hierarchy, however, the defining properties of the whole are distinct from the defining properties of the parts. We cannot say that petunias are a bouquet or are bouquets because the defining features of bouquets are not included in those of petunias and the "is a" relation cannot hold. Second, to form a collection, elements must be related to each other. For petunias to form a bouquet, for trees to form a forest, they must be in close spatial proximity; for children and adults to form a family, they must be related by some biological/parenting bond. To determine membership in a collection, then, one must consider the properties individual elements possess as well as the particular relationships that obtain between them. To determine membership in a class, one need only consider what properties individual elements possess—their relation to other elements does not enter into the decision. Finally, because of these differences in their internal structure, collections might be expected to have greater psychological stability, or coherence, than classes. That is, it should be simpler to conceptualize collections as organized totalities than to do so for classes. After all, classes are wholes only in an abstract sense. In contrast, collections are empirical, finite sets of elements that are characterized by specifiable relationships to one another.

According to Inhelder and Piaget (1964), children are unable to pass the class-inclusion test until 8 or 9 years of age because they lack the requisite concrete operations. Instead of comparing the superordinate class to its larger subclass (flowers and petunias), young children typically compare the two subclasses (petunias and daisies). Markman and Siebert (1976) suggested that this is because the superordinate class lacks psychological coherence once it is divided into its subclasses. If collections have greater psychological coherence than classes, then children should be better able to keep the whole in mind while attending to its subparts and, thus, should perform better on tasks that require comparing the whole to its subparts. Accordingly, Markman and Siebert gave kindergarten and first-grade children two different versions of the Piagetian class-inclusion task. Only children who failed a pretest consisting of two standard class-inclusion questions were included in the study. All children received four questions that involved part-whole comparisons (collection questions) and four questions that involved subclass comparisons (class questions). The same four sets of stimuli (e.g., a set of 10 blue and 5 red building blocks) were used for both types of questions. As an illustration, the collection question was, "Who would have more toys to play with, someone who owned the blue blocks or someone who owned the pile?" The class question modeled after the standard Piagetian question was, "Who would have more toys to play with, someone who owned the blue blocks or someone who owned the blocks?" Performance on the collection questions was reliably superior to that on the standard class questions. Markman and her collaborators have now completed several studies that show children able to solve problems with collections that they are unable to solve with classes. In all of these studies, children who heard class descriptions and children who heard collection descriptions viewed identical displays. Substituting collection terms for class terms markedly improved children's ability to answer correctly.

These results show that the part-whole structure of collections is easier for children to operate upon or reason with than the class-inclusion structure of classes. Recently, Markman et al. (1980) have suggested that part-whole structures might be easier for children to form as well. If part-whole relations do reflect a psychologically simpler principle of hierarchical organization, then one might expect that children left relatively free to impose their own structure on a novel hierarchy would construct a collection rather than a class hierarchy.

To test this hypothesis, Markman et al. (1980) taught subjects (aged 6 to 17 years) novel class-inclusion hierarchies. Four categories (each composed of two subcategories) were constructed. Nonsense syllables were used to refer to the four categories and eight subcategories. Children in each of the four age groups were assigned to one of two training conditions, ostension and inclusion. For children in the ostension condition, the experimenter simply pointed to and labeled the entire category and each of the two subcategories (members of each subcategory were grouped together, and the two subcategories were placed a few inches apart). Training continued until subjects were able to provide all three correct labels. Children in the inclusion condition went through the same pointing and labeling procedure as did children in the ostension condition. The only difference was that they were given additional information about category membership. That is, they were told: "A's are a kind of C"; "B's are a kind of C"; and "A's and B's are two kinds of C's" (where, obviously, A and B are the labels of the two subordinate categories that comprise the category C). This information was given immediately after the labeling and pointing.

Children in both conditions were tested with the exact same procedure. Each child was asked questions about an entire category (C) and its subcategories (A and B). For the entire category, the questions were: "Show me a C"; "Put a C in the envelope"; "Is this a C?" (pointing to an A); and "Is this a C?" (pointing to a B). For the subcategories the questions were: "Show me an A"; "Put an A in the envelope"; "Is this a B?" (pointing to an A); and "Is this a B?" (pointing to a B). It was expected that children in the inclusion condition, who were given class-inclusion information, would achieve class-inclusion interpretations of the material. In contrast, it was predicted that children in the ostension condition, who received minimal information about the hierarchical relation, might (erroneously) impose a part-whole collection organization upon it. The results confirmed the predictions. Subjects in the inclusion condition correctly interpreted the relation as one of class inclusion. Subjects in the ostension condition mistakenly imposed a collection structure on the inclusion hierarchies. Children as old as 14 years of age denied that any single element (A or B) was a C and picked up several elements when asked for a C or when asked to put a C in an envelope.

These results are especially surprising when one considers that plural labels were used during training, for example, "These are A's." "These are B's." "These are C's." And singular labels were used during testing, for example, "Show me a C." (this is analogous to saying, e.g., "These are petunias." "These are daisies." "These are flowers.") To impose a part-whole organization on the hierarchy, the subject had to systematically ignore the cues provided by the syntax.

The fact that the 14-year-olds in the Markman et al. (1980) study spontaneously and erroneously imposed a part-whole organization on the novel hierarchies they were taught certainly refutes any suggestion that the young child's classifications reflect a qualitatively distinct, more primitive conceptual organization that is based on part-whole relations and is replaced in time by an adult-type conceptual organization. Instead, it appears that both the collection and class modes of hierarchical organization are available from a very early age. Because the part-whole mode of organization is psychologically simpler, it is the preferred mode of organization—one that children and adolescents alike will impose when the situation does not unambiguously call for a class-inclusion hierarchy. Thus, the young child's tendency to group elements into wholes—stories, patterns, or scenes—rather than class-inclusion hierarchies, might be interpreted as indicative of a systematic and enduring preference for part-whole organizations. This preference might be rooted in the psychological characteristics of this type of organization, that is, the fact that it appears to be easier to operate on, to conceptualize, to establish, and so on.

We are not suggesting that very young children are just as good as teenagers at solving problems that involve part-whole or class-inclusion hierarchies. Clearly, the older children will be superior on most tasks. What we are suggesting, though, is that both types of organization are available to younger and older children and that all children may find it easier to, and may prefer to, impose part-whole as opposed to class-inclusion structures on hierarchies. Thus, whatever development there is in terms of establishing, maintaining, and operating on each type of organization, would take place over a considerable amount of time, and possibly would represent improvements in degree rather than kind.

*Finding a Basis for Classification.* Why do young children adhere to a criterion when sorting objects at the basic but not at the superordinate level? One explanation offered above is that there is greater perceptual dissimilarity among members of superordinate categories than among members of basic categories (Rosch et al., 1976). As the child takes in the different properties of the objects before him, his attention sways away from the property initially selected as basis for classification and is captured first by one property, then by another property, and so on. In short, the child keeps switching criteria. In addition, young children might fail to group objects according to a consistent criterion at the superordinate level, *not* because they are incapable of adhering to the same criterion throughout their classification, but because they are incapable of *uncovering* a criterion that could serve as basis for classification. By this account, the young child's failure to group objects consistently at the superordinate level is due to the child's having difficulty in coming up with a satisfactory criterion—not to his being unable to systematically apply the criterion selected. This explanation presupposes that once children have selected or hit upon a criterion by which to classify objects, they always know to apply it consistently. Given this assumption, inconsistent or haphazard groupings are naturally interpreted as reflecting the child's inability to discover in the array before him a basis for classification.

It is easy to see why the young child would have little difficulty coming up with a satisfactory criterion when presented with objects that must be sorted at the basic, as opposed to the superordinate, level. Children can group objects into basic categories according to any or all of a number of criteria: shape, function, motor programs involved in their use, and so on. A basis for classification is easily found as several are available and because the overall physical similarity of members of the same basic category is usually very salient. The child who is presented with an array containing objects that belong to (two or three) different basic categories is, thus, faced with highly contrasting subsets of objects that have perceptually clear-cut boundaries. It is not difficult for the child to identify the instances of each basic category represented in the array. These tend to be similar to one another along a number of separate dimensions as well as different from the instances of the other categories. On all these counts, it appears that it would be easy for the child to select a basis for classification and to carry out the grouping of basic-level objects consistently and exhaustively.

The superordinate categories with which we have been mainly concerned have all been categories of real-world, concrete objects. But the same argument regarding the criterion selected could be extended to categories of blocks that vary along a number of dimensions. For instance, one might say that the greater the number of dimensions that must be ignored, the less obvious or salient the basis for classification and the more difficult the task. Partial support for this hypothesis comes from traditional concept-learning experiments that have shown that adding irrelevant stimulus dimensions increases the difficulty of learning for adults (Haygood & Stevenson, 1967; Walker & Bourne, 1961) and for nursery-school and elementary-school children (Osler & Kofsky, 1965).

Additional support for the above hypothesis comes from Fischer and Roberts (1980) who assessed children between 15 and 75 months of age on a developmental sequence of classificatory skills. The sequence was predicted from Fischer's (1980) skill theory. A total of 12 distinct steps were differentiated and over 95% of the children tested fit the sequence perfectly. Because the first 4 steps of the sequence are the most relevant to our argument, we will be concerned exclusively with these. It was predicted that by 15 months of age children would be able to handle single categories (Step 1). When presented with blocks that varied along a single dimension (e.g., shape), children would group together all the blocks that belonged to the same category. For example, they would pick circles from triangles when the blocks were all the same color and size (recall Sugarman's [1979] finding that 18-month-olds will produce complete spatial groupings of one of the two classes in an array). At about 2 years of age, children were expected to be able to handle several categories simultaneously (Step 2). For example, with blocks like those in Step 1, children would sort blocks into three categories—circles, triangles, and squares (again, recall Sugarman's [1979] findings that by 24 months of age both classes in the array were spatially grouped). At 2½ years, children were expected to sort blocks into three categories, even if there were variations within each of the categories. For example, different types of triangles, circles, and squares might make up the three categories (Step 3). Finally, by 3 or 3½ years of age, the child was expected to handle not only simple categories but also categories where there were variations on an interfering dimension. That is, when the blocks varied in both color and shape simultaneously (but presented no within-category variations as in Step 3), the child was still expected to be able to sort them into three shape categories and then subdivide each category into three color categories (Step 4).

Fischer and Roberts' (1980) subjects were 70 children between the ages of 15 and 75 months. Each of the four tasks required the child to sort blocks into (one or more) boxes. Boxes were used to minimize the need for verbal instructions and to make the nature of the task as obvious and as simple as possible. A separate box was used for each category. For tasks that involved two or three categories, identical boxes were arranged in a line before the child.

The experimenter first demonstrated how the blocks were to be sorted and described how he had sorted them. Then, he put them in a scrambled pile before the child and said, "Put the blocks in the boxes so they go together like the way I put them in." If the child erred in sorting the blocks, the experimenter re-sorted them correctly and then urged the child to try a second time (cf. Nash & Gelman cited in Gelman & Gallistel, 1978). After the second trial, the experimenter went on to the next task. For every step, the child had to sort *all* blocks correctly to pass the step.

The performance profiles of all 70 children fit the hypothesized sequence perfectly. The results from this and a second experiment (which assessed later steps in the sequence predicted from skill theory) indicate that children acquire classificatory skills in a gradual sequence that starts by 15 months of age (if not before). These results clearly contradict Inhelder and Piaget's (1964) analysis of the development of classification. Other attempts at testing the sequence Inhelder and Piaget proposed (e.g., Hooper et al., 1979; Kofsky, 1966) have also failed to support it. However, the latter studies did report the same general trend from poor, inconsistent classification to skilled, consistent classification that Inhelder and Piaget found. Fischer and Roberts' (1980) results are particularly interesting in that they indicate that young preschool children possess far more classificatory ability than the results of previous studies (whether or not they found the developmental pattern predicted by Inhelder & Piaget, 1964) led one to expect. Fischer and Roberts. (1980) also show—and this is the point we wished to make—that this ability is somewhat dependent on the particular array of objects with which the child is presented. At first, the child can only sort arrays that are composed of single categories that represent variations along only one dimension, that is, the blocks are identical except for variations in one dimension, such as shape. Later on, the child can sort arrays into single categories and ignore irrelevant variations within each category, for example, different types of circles, triangles, or squares. Later still, the child becomes able (1) to tackle arrays that are composed of objects that vary along two dimensions and (2) to divide them first according to one dimension and then to subdivide them according to the other dimension.

It is hard to believe that the child learns anew at each step of the sequence how to sort objects into consistent, exhaustive classes. On grounds of parsimony alone, one would want to reject such an assumption. Instead, one might suggest that the child understands quite well that one should sort according to a stable, consistent criterion and does so from the earliest ages. What would change over time, then, is not the ability to adhere to a criterion throughout a classification, but the ability to parse more and more complex arrays—to uncover amidst the complexity a criterion or a set of criteria that would permit the child to sort the array without remainder and without overlap.

In other words, one might say that the ability to construct consistent, exhaustive classes is there very early on and that what improves in time is the ability to apply this competence to more and more complex arrays. Arrays that contain objects that vary simultaneously along a number of dimensions (some relevant, some irrelevant) require more complex processing than do arrays that are composed of two types of very distinct objects (such as those Sugarman, 1979, and Ricciuti, 1965, used). The nature of the psychological processes involved in the abstraction of a basis for classification in simpler and more complex arrays still remains to be specified. Once we have some idea of the nature of these processes and how they develop over time, we may have a much better idea of the nature of the young child's difficulty with superordinate sorting tasks.

At this point, one might make the following claim. If it is correct to assume that a child *always* applies a criterion consistently once she has succeeded in uncovering it, then were we to show or tell the child what the criterion is, she should have no difficulty in picking out the instances of the category and doing so consistently. However, this strong prediction of the hypothesis is not borne out by the facts. First, modeling a classification is not sufficient to get a child to classify objects correctly. In Fischer and Roberts' (1980) experiment, the experimenter first sorted the objects and then had the child do the same. The children could not always sort the blocks as the experimenter had; they followed a clear-cut developmental sequence in terms of the classifications they could imitate. Thus, more is involved than just the ability to use a criterion consistently.

Horton and Markman (1980) provide additional evidence that telling the child what the criterion is, is not necessarily helpful to the child. Horton and Markman investigated 4-, 5-, and 6-year-olds' acquisition of artificial animal categories. They found that (1) basic-level categories were acquired more easily than superordinate categories from exposure to exemplars alone; (2) the specification of the criterial features was beneficial for the acquisition of only the superordinate categories, that is, basic-level categories were not learned better when criteria were specified; and (3) only the older children benefited from the specification of the criteria, and then only when learning superordinate categories (this is the result that is relevant to the present discussion). The 4-year-old children did not benefit from the specification of criteria at the superordinate level. In contrast, both the 5- and the 6-year-old children were better able to learn superordinate categories when the criteria were specified.

Given that criterial information can be helpful in the acquisition of superordinate categories—as the older children's performance demonstrates—why the failure of younger children to use it? Horton and Markman (1980) rule out a failure in understanding. Children could understand the descriptions and could sort objects based on each individual criterion when so instructed. Horton and Markman argue that the information processing demands of the task were too great. In addition, it could have been a question of poor strategic skills. There are many instances in the literature where young children fail to make use of information or skills that are at their disposal. The rehearsal literature is a particularly good case in point (e.g., Flavell & Wellman, 1977). There is some evidence that the same might be going on here. For instance, Anglin (1977) asked preschoolers to define common nouns and later to classify objects into categories denoted by the terms they had been asked to define. Anglin reports that when classifying, the children often failed to use their own definitions for the categorization of the objects.

***Factual Knowledge and Classification Abilities.*** Above we argued that the child may have difficulty forming superordinate categories because the basis for classification is abstract and not immediately accessible to the young child. However, in some cases it may be the features that characterize a higher order category are inaccessible, not because they are abstract and difficult to discern but because the child has not yet acquired the necessary or relevant knowledge to appreciate their significance. Chi's (1980) study of preschoolers who are interested in dinosaurs makes this point. The more a child knows about dinosaurs, the more complex a classification scheme reflected in his recall of the names of dinosaurs. Carey's (1978) work on childrens' concept of "animal" helps illustrate how there could be an interaction between knowledge and the use of a classification structure.

Carey has done a series of studies on the development (from 4 to 7 years) of the understanding of the concept of animal (Carey, 1978; in preparation). In these studies, children were presented with a number of animate and inanimate objects, some familiar and some unfamiliar. For example, children were shown pictures of a person, a dog, an aardvark, a dodo, a hammerhead, a fly, a worm, an orchid, a baobab, the sun, clouds, a bus, a harvesting machine, a garlic press, a hammer, and a rolltop desk. They were asked several questions about each picture. Some questions involved properties of the particular object ("Is the sun hot?"); others involved properties of an immediate superordinate of an object ("Does a hammerhead live in water?"), or properties of animals ("Does a worm eat?"), or properties of living things ("Does a dodo grow?"). The animal properties probed were, eats, breathes, has a heart, has bones, sleeps, thinks, and has babies. The properties of living things were, is alive, grows, and dies.

Animals that adults take as more peripheral exemplars of the class were systematically assigned fewer animal characteristics by the children. In addition, there was a marked absence of a clear differentiation among animal properties. Thus, Carey found a stable ordering of the animals in terms of how often they were attributed animal properties. Roughly, this ordering was: people, mammals, birds, insects, fish, and worms. Even though the most peripheral animals were credited with a particular animal property only 20% to 40% of the time, each child credited every animal with at least one animal property. That is, the ordering of the animals does not seem to reflect some children's failure to appreciate that the peripheral animals were animals. Although the animals were ordered, the properties were not. Subjects were no more likely to credit animals with eating than with having bones or thinking. Adults, on the contrary, attribute eating, breathing, and having babies to all animals, sleeping and having hearts to fewer, having bones to fewer still, and thinking to fewest of all. Thus, 4- to 7-year-olds were likely to attribute only one or two animal properties to the peripheral animals, but those properties were just as likely to be having bones and thinking as eating and having babies. The animal properties clearly were not differentiated from each other in the subjects' patterns of responses.

Carey takes her result to suggest that the child's concept of animal is embedded in a very impoverished biological theory. This follows from both the tendencies to underattribute animal properties to peripheral cases of animals and not to differentiate animal properties from each other. We agree with Carey's interpretation. But more important in this context, her findings have considerable implications for the way young children will behave on classification tasks.

If peripheral animals are not known to have a heart, they presumably will not be classified together with animals who are known to have a heart. Similarly, if children do not know that not all animals have bones, they may end up classifying items together that they should not. Children's erroneous classifications might be taken as evidence of an inability to apply criteria (e.g., "has-a-heart," "has-bones") consistently. But, in fact, this would reflect children's ignorance of biological facts rather than an inability to maintain a hierarchical classification scheme.

We have explored a number of reasons why the young child has difficulty sorting arrays that are composed of objects that can only be sorted at the superordinate level. We have argued that despite his poor performance in superordinate sorting tasks, the young child does possess (at least some of) the relevant logical abilities. Actually, we believe there is enough evidence in the young child of a capacity for hierarchical organization to suggest that what needs explaining is the fact that this ability is not *always* displayed—rather than the fact that it is not displayed at all. This argument was used to interpret results from a variety of free-classification studies with preschoolers (e.g., Denney, 1972a, 1972b; Fischer & Roberts, 1980; Nash & Gelman cited in Gelman & Gallistel, 1978). It is buttressed by studies that used simplified classification tasks as well as memory studies.

Oddity tasks and matching tasks are simpler than free-classification tasks in that they do not require the child to group objects together into consistent, exhaustive categories. All that is required is that the child be able to perceive that two of a small number of elements belong to the same category.

We have already presented oddity data that support the notion that young children are sensitive to, and can pair items on the basis of, superordinate relations. Recall the study of Rosch et al. (1976) in which children 3 years of age and older were given oddity problems. Performance on the basic-level problems was virtually perfect at all ages tested. Performance on the superordinate level problems was significantly worse, especially in the youngest age group. Still, the 3-year-olds' mean correct percentage was 55% and the 4-year-olds' was 96%. These data suggest that children find it easier to sort items that belong in the same basic, as opposed to superordinate, category—not that they are fundamentally unable to perform the latter kind of task.

Daehler, Lonardo, and Bukatko (1979) examined the difficulty very young children have in matching stimuli at several levels of perceptual and conceptual similarity. Four different types of relationships between stimuli were tested: (1) identical stimuli, (2) stimuli belonging to the same basic category, (3) stimuli belonging to the same superordinate category, and finally (4) stimuli bearing a complementary relation to one another (e.g., crayon-coloring book, hammer-nail). Subjects were 16 children at each of 3 age levels 21 to 22, 27 to 28, and 31 to 33 months. Stimuli consisted of real objects or toy objects. The exemplars for each basic-level category differed in size and color and, where possible, detail and shape as well. Stimuli were never labeled during test trials; the experimenter simply held out the standard to the child and instructed her to "find the one (of four choices) that goes with this one." Any child who failed to respond to the experimenter's instructions was led to the table as the instructions were repeated. A response was recorded whenever the subject placed the standard beside one of the four alternatives or touched or picked one of the alternatives. Correct responses were verbally reinforced. If the child made an error, she was asked to respond again. If she were still not correct, the correct response was modeled. At the completion of each trial, the correct response alternative was removed, a new item was added, and all four stimuli in the array were rearranged. Thus, all stimuli in the array were eventually relevant. Because children were invariably attracted to each new item, they were allowed to play with it briefly as prior testing indicated that the opportunity to become familiar with each new item before a trial helped reduce a substantial response bias for selecting it on the subsequent trial. There were 6 distinct trials for each type of relationship examined (24 altogether).

The results were straightforward. Performance improved with age in every condition. Moreover, the order of difficulty of conditions for each age group was consistent—identity matches were easiest, followed by basic-level, superordinate level, and complementary matches. Finally, children in all age groups responded above chance level in all four conditions, with the exception of the youngest age group matching complementary stimuli. The fact that performance on stimuli belonging to superordinate taxonomic categories was well above chance at all ages again suggests that from a very early age (in this case less than 2 years) children are able to detect and make use of superordinate relations. However, the equivalences selected by Daehler and his colleagues (1979) do lend themselves to alternative interpretations. Their superordinate pairs were camel-cow, fork-spoon, boat-truck, apple-banana, and pants-shirt. The underlined pairs appear especially ambiguous as they represent items that the child, no doubt, must have had ample opportunities to see together and so the basis of his matching, or equivalence judgment, is unclear.

Adults are better at remembering words from lists that contain subsets from the same taxonomic categories than words from randomly generated lists (e.g., Cofer, Bruce, & Reicher, 1966). In addition, if the words that are taxonomically related are separated in the list, adults tend to cluster them by meaning in output (e.g., Bousfield, 1953). It has been reported that young children do not remember words from lists with taxonomically related subsets better than words from unrelated lists (e.g., Hasher & Clifton, 1974; Nelson, 1969). In addition, the degree of clustering has been found to increase with age, from grade school through college (e.g., Bousfield, Esterson, & Whitmarsh, 1958; Neimark, Slotnick, & Ulrich, 1971). The preschooler's alleged inability to detect and benefit from the hierarchical organization of to-be-remembered lists has been thought to reveal a fundamental inability to appreciate or impose hierarchical relations on stimuli. Such conclusions, however, are beginning to look unwarranted (Huttenlocher & Lui, 1979).

There is now evidence that young children are better at remembering items that are all from the same taxonomic category than items that are unrelated (e.g., Cole, Frankel, & Sharp, 1971; Kobasigawa & Orr, 1973). In the study of Kobasigawa and Orr (1973), for example, kindergarten subjects were presented with 16 pictures in four category sets (e.g., animals: zebra, lion, camel, and elephant; vegetables: corn, onion, carrot, and pumpkin); or in a random order with one item from each category composing the four presentation sets. The categorically grouped presentation facilitated free-recall performance, both in terms of number of items recalled and the speed with which items were recalled; it also increased the amount of clustering in recall.

Even 2-year-olds have been found to recall pairs of objects better when they are from the same, rather than from different, categories. Goldberg, Perlmutter, and Myers (1974) tested children aged 29 to 35 months on a task requiring free recall of two-item lists. Each of the three trials consisted of the randomly ordered presentation of six boxes, each containing a pair of objects selected from three categories (food, animals, and utensils). For three of these pairs, the objects belonged to the same taxonomic category (e.g., cookie-lollipop; elephant-giraffe; fork-spoon). The three remaining pairs were formed of unrelated items from the same categories (e.g., M&M's-lion; apple-cup; dog-plate). (Pilot work showed that labels were readily produced for all pictures and that although fork and spoon were associated responses for a few children, none of the other items were given in response to each other.) The mean number of correct responses was higher for related items than for unrelated items.

Additional evidence that young children impose hierarchical organization on objects is Keil's (1977, 1979) finding that a hierarchical structure constrains the development of ontological knowledge. Keil had children make acceptability judgments of what predicates could be true about certain objects and events. Over and over again he found children's judgments reflected an underlying hierarchical structure. Thus, for example, they failed to assign animate predicates to inanimate objects and vice versa. Such results indicate that young children can make *implicit* use of a hierarchical classification scheme. They do not demonstrate *explicit* use of the same structure—a point to which we will return below.

**Class Inclusion Revisited**

For Inhelder and Piaget (1964), complete mastery of hierarchical classification is indexed by the mastery of the inclusion relation, and it is not attained until the stage of concrete operations. The preoperational child is incapable of class inclusion because she lacks the two reversible operations of class addition (e.g., flowers = petunias + begonias) and class subtraction (petunias = flowers − begonias). Until she acquires these two operations, the child is unable to attend simultaneously to the class and its subclasses and is, thus, incapable of making quantitative class-subclass comparisons (e.g., "Are there more flowers or more petunias?").

We do not believe that class-inclusion tests should be taken as criterial measures of the ability to classify objects hierarchically. Mastery of the class-inclusion relation, with all its implications, is a relatively late development (Winer, 1980); hierarchical classification, by contrast, emerges in the first few years of life. We have seen evidence of hierarchical organization in the 2-year-old's grouping of objects—in his correct usage of superordinate terms, in his free recall performance, and so on. As more ingenious methods of investigating the prelinguistic child's cognition and knowledge are developed, one may find that even younger children are capable of constructing simple, well-formed hierarchies.

Winer (1980) in an extensive review of the literature on class inclusion notes that "the studies showing late development far outnumber those showing early development," and concludes that "the results clearly refute the claim of Piaget and others that class-inclusion is developed by age 7 or 8" (p. 310). There is also evidence that children less than 11 years of age who do pass the class-inclusion test may still have only an incomplete grasp of the logic of inclusion. Markman (1978) tested whether children who render correct class-inclusion judgments do so on the basis of logical or empirical considerations. Because her earlier work (Osherson & Markman 1974–1975) showed that children often treat tautological statements as though they were empirical statements, Markman thought that children might also treat the greater numerosity of a class over its subclass as an empirical fact rather than as a logical consequence of inclusion.

Markman (1978) reasoned that children who do appreciate the logical necessity of the class being larger than its subclass (1) should be willing to make the class-subclass comparison, even when they have no empirical means of judging the relative numerosity of the two, (2) should understand that no addition of elements could ever result in the subclass containing more elements than the class, and finally (3) should be willing to compare a class to its subclass even when given only minimal information about the subclass. A study was designed to test each of these hypotheses. Results indicated that children take the greater numerosity of the class to be an empirical fact until about 11 years.

Although performance on the standard class inclusion task points to a relatively late development, there is evidence that even 4-year-olds are able to represent and implicitly evaluate inclusion relations. C. L. Smith (1979) tested 4- to 7-year-olds on three different tasks. The first task involved quantified inclusion questions of the form, "Are all *X*s *Y*s?" and "Are some *X*s *Y*s?," where *X* could be a subset of *Y*. No pictures were used; children answered on the basis of their knowledge of the terms and the objects they denoted.

The other two tasks were inference tasks. One was a class inference task. Children were given problems of the form, "A ______ is a kind of *X*. Does a ______ have to be a *Y*?" (where ______ was a real word children did not know). There were three types of problems, depending on whether the inference was valid (e.g., "A pug is a kind of dog. Does a pug have to be an animal?"); indeterminate (e.g., "A pug is an animal. Does a duplex have to be a fence?"); or invalid (e.g., "A pug is an animal. Does a pug have to be a cat?"). The other inference task was a property inference task. Problems were of the form: "All *X*s have ______. Do all *Y*s have to have ______" (where ______ was filled with a new word for a property). Again, there were three types of problems—where the inference was valid (e.g., "All milk has lactose. Does all chocolate milk have to have lactose?"); where the inference was invalid (e.g., "All milk has lactose. Do all sneakers have to have lactose?"); and, finally, where the inference was indeterminate (e.g., "All milk has lactose. Do all drinks have to have lactose?").

Smith reports group as well as individual data for each of the three tasks. However, the results that are most relevant to the present discussion are those that concern the children's patterns of responding *across* the three tasks. Overall, 90% of the 4-year-olds and all of the older children succeeded on at least one of the tasks. As Smith points out, such results definitely argue against characterizing young children as being unable to represent and reason about inclusion relations. For, if such a characterization were correct, children would have failed all three inclusion tasks. The fact that almost all children met criterion on at least one task and many children on more than one task suggests that children are able to represent inclusion relations. It also suggests that under favorable conditions children can solve problems that require them to evaluate such relations.

A subsequent experiment was designed to explore further 4-year-olds' ability to draw inferences on the basis of inclusion relations. In this experiment, 10 children, aged 48 to 56 months, were given four valid and four invalid inference problems. These problems were slightly different from those used in the first experiment; they gave the children additional information that, presumably, made the inference easier, for example, "A yam is a kind of food, but not meat. Is a yam a hamburger?" and "A pawpaw is a kind of fruit, but not a banana. Is a pawpaw food?" The results were quite striking; children were correct 91% of the time, and 8 of the 10 children made only one or fewer errors.

These results indicate that success on the standard Piagetian class-inclusion test should not be held up as the sine qua non condition of the ability to embed classes within one another. It is best to think of inclusion not as a unitary, all-or-none ability, but to think of it as one does classification, numerical reasoning, and so forth. One can devise tasks that will result in a very broad range of performance success—inclusion tasks that 4-year-olds solve without any difficulty (e.g., C. L. Smith, 1979) and inclusion tasks that children less than 11 years of age systematically fail. Recall also the Markman et al. (1980) unexpected result that even 14-year-olds will mistake a class-inclusion hierarchy for a collection hierarchy when the situation provides minimal information to guide or constrain their interpretation. There is reason to suppose that some inclusion ability is available at an early age but that this ability is at first relatively limited and is only displayed under limited, favorable conditions (see Trabasso, Isen, Dolecki, McLanahan, Riley, & Tucker, 1978, for a careful consideration of limiting conditions). As the child develops, he becomes capable of carrying out more and more complex computations on the inclusion relation between classes. The standard Piagetian test is only one of the many tests that require the child to evaluate and operate on inclusion relations.

We do not mean to suggest that the ability to classify objects hierarchically is fully present from the start. The bulk of the experimental evidence we have reviewed indicates that there is considerable improvement with age. However, the evidence also suggests that the improvement is one of degree, not of kind. As the child's information-processing capacities develop, as his knowledge of the world increases, and as his perceptual and cognitive strategies become more efficient, we find that his ability to detect, and make use of, hierarchical structure also develops.

It seems reasonable to suppose that as mastery of hierarchical classification is progressively achieved, the child becomes better able to represent for himself the relations that exist between classes at the same and different levels within hierarchies. Further, as the child's ability to represent interactions among classes develops, so does his ability to reason about such interactions. It is in this light (it seems to us) that one can best make sense of the empirical work on class inclusion. Quantitative comparisons of superordinate classes and their subclasses are not successfully performed until quite late—by contrast, inclusion tasks that involve simpler, less demanding comparisons are solved at an early age.

#### More on the Same Themes

Our review of some core concrete-operational concepts highlighted several themes. First, preschool children have more knowledge about quantity and classification than any of us anticipated—say 10 years ago. Second, despite the new-found brilliance of the young child, there is still much to develop within the various domains of cognition. The development will be protracted, in some cases taking until 13 to 14 years of age. Third, the younger the child, the fewer the task settings with which he can cope. That is, their abilities are uncovered within a rather limited set of situations. Fourth, what is known early is often implicit. That is, the child's behavior is systematically governed by underlying structures (e.g., the counting principles) that are not known to the child. Thus, at least in some cases, a part of development is making explicit what was initially implicit (for a similar argument see Flavell & Wellman, 1977, on the development of metamemory). Finally, the evidence on the relationships among abilities across domains is too weak to support a theory of overarching structures. This leaves open the possibility that there are domain-specific structures rather than domain-independent structures (cf. Chomsky, 1965; Keil, 1981).

We believe that many of the same conclusions will emerge as we gain further knowledge about various domains of cognition. Indeed, there is already sufficient evidence regarding the abilities to seriate and reason about physical cause-effect relations.

We have already noted the strong tendency of very young children to impose an order relation on objects (e.g., Bryant, 1974; Bryant & Trabasso, 1971). Additional evidence on the ability of young children to seriate comes from Cooper, Leitner, and Moore (1981), Greenfield, Nelson, and Saltzman (1972), Koslowski (1980). Greenfield et al. reported that even 3-year-old children could construct a series out of stacking cups and could correctly insert a new cup into the stack.

As Koslowski (1980) notes, early demonstrations of operational competence may not meet Piaget's definition. In the case of seriation, Inhelder and Piaget (1964) require that a child be able to perform a systematic seriation in a constant direction, insert additional items into an already-established series, and correct an erroneous insertion by someone else. Koslowski (1980) tested 3- and 4-year-olds on her own abbreviated tasks as well as the traditional tasks used by Inhelder and Piaget (1964). The difference between the two sets of tasks was simply in the number of sticks used. The traditional tasks require a child to work with a 10-stick series to start; Koslowski (1980) had them work with a 4-stick series to start. Otherwise, the two sets of tasks were identical and met the above crucial criteria. On the basis of their performance on the 10-stick tasks, Koslowski (1980) assigned children to the standard three Piagetian stages of seriation ability. Of the many children who were classified as Stage 1 (no ability to seriate), 75% could construct a systematic series of 4 sticks, 81% could insert 2 new sticks in a 4-stick series, and 100% could correct incorrect insertions. What we see here is a powerful effect of set size—one that yields contradictory classifications of the same children. It is hard to deny these young children a seriation scheme, even if it is applied in a restricted range.

Work by Cooper et al. (1981) leads us to conclude that despite the young child's competence vis-à-vis seriation, it is nevertheless fragile. These researchers find 3-year-olds able to discriminate between a seriated and nonseriated set of rods under some conditions. Yet, they have difficulty discriminating between series on the basis of the direction increase.

The theme that "the young know more and that the old know less" applies to seriation as does it to other domains. Recent work by Piaget (1980) supports this conclusion as well as the idea of development proceeding from the implicit to the explicit.

With Bullinger, Piaget (1980) studied the way children between 5 and 12 years solved a conflict over what they saw. Children were shown a display containing seven discs in a zigzag row. The thicknesses of all the discs were the same; the diameters increased progressively by steps of 0.2 mm—a nondiscriminable difference. Because the discs were arranged in a zigzag, the child could compare only adjacent pairs of discs and, therefore, would conclude that each pair of discs shared the same diameter. However, because the last disc could be removed and compared with the first in the display, the child could see that these two did differ in diameter. Children younger than 11 years had difficulty resolving the conflict between their initial *conclusion* that the first and last discs were equal in diameter and their *perception* that they were not. To resolve the conflict, one has to maintain that the discs *had* to get progressively bigger, even if one could not physically see this. That is, one had to impose a presumed ordering on the stimuli. It is hard to imagine how one could do this without an explicit understanding of seriation and the principle of transitivity. Piaget (1980) reports that only the older children (at least 11 years old) could resolve the conflict successfully. This leads us to suggest that an explicit understanding of the principle of transitivity is rather late in developing, a conclusion that is also supported by Moore's (1979) work.

Recent work on the understanding of physical causality reinforces the conclusion that order relations are quite salient for the young child. Bullock and Gelman (1979) had children watch the exact same event—a ball rolling down a runway and disappearing into a box—before *and* after Jack jumped up from the box. When asked to chose the ball that made Jack jump, 3- to 5-year-old children systematically chose the ball that was dropped first. They did this even when the order information conflicted with a cue of spatial contiguity, that is, when the *before*-event was in a runway that was separated from the jack-in-the-box but the *after*-event was not. Bullock and Gelman took these findings as evidence in favor of the view that preschoolers honor a principle of priority when reasoning about physical cause-and-effect relations. That is, young children implicitly apply the rule that causes cannot follow their effects but can only precede or coincide with their effects. Other lines of converging evidence are reviewed in Sedlak and Kurtz (1981) and Weiner and Kun (1976).[5]

Bullock, Gelman, and Baillargeon (1982) go beyond granting preschoolers the implicit principle of priority. Bullock et al. maintain that preschoolers also apply the principle that cause-effect relations are mediated by mechanisms. Those familiar with Piaget's early (1930) and recent work (e.g., 1974) on physical causality will recognize that this latter conclusion is at odds with his ideas about the development of the understanding of physical causality.

Piaget was probably the first psychologist to investigate systematically the development of the young child's conception of physical causality. He and his collaborators asked children to explain a variety of natural (e.g., the cycle of the moon, the floating of boats) and mechanical (e.g., the operation of bicycles and steam engines) phenomena. Analyses of the explanations collected led Piaget to characterize the young child's thought as fundamentally precausal.

According to Piaget, "immediacy of relations and absence of intermediaries . . . are the two outstanding features of causality around the age of 4 to 5 (1930, p. 268). Thus, the pedals of a bicycle are said to make the wheels turn without being in any way attached to them. A fire lit alongside an engine is said to make the wheels of the engine turn, even if it is 2 ft. away; the sun is said to follow us as we walk down the street. "Not a thought is given to the question of distance or of how long the action would take in travelling from cause to effect" (Piaget, 1930, p. 268).

In his early work on child causality, Piaget

(1930) claimed the young child had no assumption of contact between cause and effect. The idea was that the young lacked an assumption of mechanism. With development, the young child came to learn about chains of intermediary events. In Piaget's more recent treatment of causality (e.g., Piaget, 1974), the account of development is different. However, the young child is still characterized as lacking a principle of mechanism. By his most recent account, children have to come to attribute to objects the operations they have mastered. According to Piaget, "There is a remarkable convergence between the stages of formation of operations and those of causal explanation; the subject understands the phenomena only by attributing the objects . . . operations more or less isomorphic to his" (Piaget, 1974, p. 4). In one experiment used to make this point, children were asked to explain why the last of a row of still marbles rolled away after the first was hit by a moving marble. Children in the initial stage (4 to 5 years) explained this as if they believed the moving marble acted at a distance. Children in the subsequent stage (6 years) assumed each marble in the row pushed the one next to it. According to Piaget (1974), it was not until they reached the next stage (i.e., until the advent of operational transitivity, 7 to 8 years) that children began to form a notion of mediate transmission.

The idea that an assumption of mechanism is lacking in the preschooler is contradicted by several lines of research. Bullock (1979) adapted her runway and jack-in-the-box apparatus to give children a choice between two events as possible causes. In one experiment, children saw a ball and a light source move down parallel runways and disappear at the same time into the jack box (the perception of light movement was due to an induced phi-phenomenon). In the experiment, 3-, 4- and 5-year-olds consistently chose the ball running down the runway as cause, presumably on the assumption that steel balls are more likely to hit something and release the jack-in-the-box. Support for the conclusion that 4- and 5-year-olds made such inferences follows from what happened in Bullock's next experiment.

In the second Bullock experiment, the runway portion of the apparatus was separated from the jack-in-the-box portion. Otherwise the experiment was exactly the same. (The jack-in-the-box was operated by remote control.) In this experiment, 4- and 5-year-olds did *not* choose the rolling ball. Instead, they attributed causality to the moving light. Put differently, children chose that event as cause that was most plausible. Balls do not produce impact at a distance; however, electrical devices often cause effects at a distance. Given their ability to take into account changes of conditions when making causal attributions, it is difficult to deny 4- and 5-year-olds an implicit concern for mechanism. A similar conclusion follows for even younger children, given work by Baillargeon, Gelman, and Meck (1981) and Shultz (1982).

In two separate experiments, Baillargeon et al. (1981) showed children the working of a three-part apparatus. The initial piece consisted of a long rod that could be pushed through a hole in a post; the intermediate piece was a set of five upright blocks; the end part was made up of a lever and a toy rabbit (Fred) sitting on a box next to a toy bed. Children in the experiment were first given a demonstration of the working apparatus: when the rod was pushed through the hole it hit the first block. The first block fell and created a domino effect. The last block landed on the lever that made Fred-the-rabbit fall into his bed. After the demonstration, the children were asked to predict whether Fred would fall into his bed given variations in the first, intermediate, and final parts of the apparatus. Modifications were of two types: *relevant* ones, those that disrupted the sequence, and *irrelevant* ones, those that did not disrupt it. For example, a short stick was used and, hence, could not reach the first block (a relevant change). In contrast, a long glass tube could reach the first block, and, thus, when used, constituted an irrelevant change. Similarly, the removal of one intermediate block versus the laying down of blocks was relevant as opposed to irrelevant. In the first experiment, prediction trials were run on a fully visible apparatus. In the second experiment, the block and lever portion of the apparatus was screened.

Baillargeon et al. (1981) reasoned as follows. If young children wrongly believe that the very occurrence of the first event in a causal sequence is sufficient to bring about the final event, they should treat all modifications of the first event as potentially disruptive and all modifications of the intermediary events as nondisruptive. On the other hand, if children do understand that the intermediary events in a causal sequence effectively connect the first and last events in the sequence, they should regard all and only the *relevant* modifications—whether of the initial or intermediary events—as likely to disrupt the sequence. In the first experiment all 20 children in the experiment were correct on at least 75% of their 23 predictions. Indeed, the average correct responses for the 3-year-olds was 85%; that for the 4-year-olds was 90.5%. In the second experiment, where the screen hid the intermediate mechanism, the children did almost as well: 19 met the 75%

correct criterion. Differential predictions at this level of accuracy could only have occurred if the children were using the intermediary events as such.

Shultz (1982) has concluded that even 2-year-olds assume that a cause produces its effects via a transmission of force, be it either direct (as in one ball hitting another) or through an intermediary. In Shultz's first experiment, after a brief initial demonstration of a cause-effect sequence, children were asked to assign causal attributions to one of two energy sources. As an example, children were shown that turning on a blower had the effect of putting out a candle. They were then shown two blowers (one white, the other green), each of which was surrounded on three sides by a Plexiglass shield. The critical difference between the two blowers was whether the open side was facing a lit candle—and, therefore, one could blow out the candle. If considerations of mechanism do not influence young children, they should choose randomly between blowers as cause. They did not; they systematically chose the blower whose opening faced the candle. Similar effects held for the transmission of a sound source from a tuning fork and the transmission of light from a battery. The consistent result was that children took note of barriers that would stop the transmission of light and sound when they made causal attributions. Interestingly, a similar result held in Shultz's (1982) study of Mali children in West Africa—whether or not they were in school environments.

If we acknowledge that young children's search for explanations of their world is governed by the implicit principles of priority and mechanism, we can account for the kinds of results reviewed here. But to grant these causal principles is not to say young children know they are using them. In the case of causal reasoning, we doubt whether most adults know they are using it. As before, we allow for the implicit use of principles, just as psycholinguists allow for the implicit use of rules that guide the use and comprehension of speech.

Again, to say the young child has some competence is not to say she has a complete, correct understanding of physical causality. As Baillargeon (1981) shows, the development of the ability to explain why a prediction is correct evolves very slowly. And as McCloskey, Caramazza, and Green (1980) show, even undergraduates at Johns Hopkins University make erroneous assumptions about the world. The kinds of predictions made are more consistent with Aristotle's writings on physics than anything Newton ever wrote! Wrong theories have abounded in the history of science. But, whatever the theory, assumptions must have been made about priority, mechanism, and weak determinism (Bullock et al., 1982), otherwise there could hardly be a history of science.

Like Carey (1980) we ascribe to the view that Piaget's (1974) recent experiments on causal reasoning should be viewed as experiments on the acquisition and change of explanation systems. Looking back to the Piaget (1974) experiment on the child's understanding of the transmission of force, we suspect many of our readers wanted to know what was wrong with the 6-year-olds' explanation of why the final marble moved. It certainly included an assumption of possible mechanism, albeit a naive one.

Our preceding point goes beyond a standard anti-Piagetian argument, that is, young children are bad explainers. We do not mean that causal understanding is simply a matter of being able to provide explanations per se. There is the separate issue of whether one understands the *correct* explanation. When viewed from this perspective, it is possible to allow that there are qualitatively different theories of physical reality as a function of development or even schooling—just as Aristotelean and Newtonian theory are. It is not, however, necessary to deny the young or uneducated a causal attitude that is governed by principles of causal reasoning.

There are further cases of earlier cognitive competence than once expected—either within a Piagetian framework or not. Many of these appear in other chapters (e.g., see *Brown, Bransford, Ferrara, & Campione, vol. III, chap. 2; Mandler, vol. III, chap. 7;* or *Shatz, vol. III, chap. 13*). We trust our main point is clear by now. Earlier competence? *Yes.* Full competence? *Certainly not.*

## SUMMING UP

### Structures of Thought?

When we began our review we simply announced our support of the Piagetian view that what we think, perceive, and remember is mediated by structures of thought. We did so without even justifying this position. That we did not is a sign of how heavily Piaget *has* influenced all of us. Piaget's ideas that cognitive structures set the limits of problem-solving abilities as well as influence both how we perceive the world "out there" and influence the contents of memory, were either ignored altogether or dismissed as unnecessary. As Flavell (1982) noted, the idea that structures determine our memories, perceptions, and problem-solving abilities is so pervasive in modern cognitive psychology that it is almost a puzzle as to what the fuss was once about. "Piaget, Newell and Simon, Chomsky and others have now convinced just about everyone that adult and child minds alike are inhabited by exceedingly rich structures of knowledge and cognitive processes'' (Flavell, 1982, p. 4). This volume is full of evidence in support of this view. However, given the subject of this review, we must point out that it is not true that everyone accepts Piaget's views.

First, there are still advocates of the learning theory view (e.g., Kendler, 1979). Second, we believe that Piaget still would hold that some of the current work in the information processing tradition tends to lose sight of the role of structure in cognitive development (see *Siegler, vol. I, chap. 4,* for a review of the work in this tradition). When we are told that a child fails task *x*, *y*, or *z* because of a memory problem or a limit in short-term memory or a failure to encode a crucial stimulus, the issue is, What exactly is being said? There could be the implicit assumption that the child has the requisite structures but we are not sure. The question is not confronted directly, and so we hesitate to put words in an author's mouth. In some cases it seems a legitimate inference (as in Trabasso's, 1975, work); in other cases the issue is more complex.

Consider Siegler's (1981) hypothesis that what changes in development is what is encoded. But why does what is encoded change? Piaget's answer is that the cognitive structures change. And because the structures determine what is assimilable, it follows that what is encoded will change. Siegler (1981) might very well accept this interpretation. But if he did, then we would ask for a description of the structure. Sure, we are asking for a lot, perhaps more than yet can be accomplished. (But see the recent publication by Siegler & Robinson, 1982.)

Our point simply is that we cannot be satisfied with a zeitgeist that accepts the notion of structure. What is needed are descriptions of these structures—all the more now that the evidence goes against Piaget's particular descriptions. Further, we need to determine the interaction between structural and information processing constraints as they influence cognitive development. Such thoughts are more than in the air. A variety of investigators and theoreticians are trying to accomplish this (e.g., Case, 1978; Fischer, 1980; Halford & Wilson, 1980; Pascual-Leone, 1970). The Halford and Wilson paper is interesting because it offers an a priori definition of a unit of information processing. To do this they work with category theory.[6] We reserve judgment on the descriptive adequacy of this theory. As Halford and Wilson (1980) point out, it needs further empirical support. Still, we see here an effort to use a known mathematical structure to define a unit and then to make predictions about information processing demands. Newport (1980) makes a similar attempt in the domain of language acquisition by using linguistic theory to define structural units. We suspect this is just the beginning of such theorizing.

In any case, we trust that Flavell (1982) is right and that the notion of structure is here to stay. Piaget's influence on this outcome in cognitive developmental circles has been, and will continue to be, enormous. We obviously believe that the ultimate characterizations of these structures will be different than those offered by Piaget. In particular, we anticipate that the structures underlying arithmetic thought will not be the same ones underlying the tendency to form cause-and-effect explanations. No matter what, the fact remains that there is a need for a structural account—be it logic or a set of reasoning principles—about those domains of knowledge to which Piaget turned our attention.

### Stages of Cognitive Development?

In our opinion there is little evidence to support the idea of major stages in cognitive development of the type described by Piaget. Over and over again, the evidence is that the preoperational child has more competence than expected. Further, the evidence is that the concrete-operational child works out concepts in separate domains without using the kind of integrative structures that would be required by a general stage theory. In addition, there is evidence in some cases that the structure underlying the way a preschooler reasons about a problem is much like that used by older children and even adults, for example, the principles of causal reasoning. In other cases, the evidence is that there is structural change reflected in the development of a concept. The case of number concepts is one clear example of the latter.

None of the foregoing points eliminates the possibility of there being within-domain stages of development. It could even turn out that there are some cognitive developmental domains wherein there is evidence of stages and others wherein there is no evidence. Flavell's (in press) recent work on visual perspective-taking abilities is perhaps one such candidate. And the domain of number concepts may be yet another, although Gelman and Gallistel's (1978) version of the stages needs modification.

Recall Gelman and Gallistel's hypothesis. The preschooler could only reason about specific numerical values. In contrast, the elementary school-aged child could reason about nonspecified numbers. The proposed stages were that Stage 1, reflected arithmetic competence with countables; Stage 2 reflected an advance to algebraic reasoning about numbers. Unfortunately, the data contradict the hypothesis. Under certain conditions, preschoolers can and do use a principle of one-to-one correspondence to reason about number. And they do this with set sizes they cannot count accurately. Evans (1982) further finds no correlation between the development of the concepts of zero, infinity, and negative numbers in elementary school-aged children. Indeed the seemingly related concepts of forever and infinity fail to show a within-subject correlation. So even in the case of number concepts, the evidence for a transtask stage development is weak at best.

There is one possible way to retrieve the stage argument for within-cognitive-domain developments. This involves representing a given level of competence in terms of hierarchies of related concepts and then characterizing each stage in terms of the dominant tendencies at a given time. A similar strategy has been used by Kohlberg (1969). We hesitate to guess whether this or other efforts to characterize cognitive development in terms of stages (e.g., Case, 1978; Feldman & Toulmin, 1975; Halford & Wilson, 1980; Pascual-Leone, 1970) will prove more successful.

One of Piaget's better known positions is that the course of cognitive development must be paced, that is, there is little that can be done to engineer a truly accelerated rate of development (Piaget, 1966). Although the many successful training studies serve as evidence against this position, notions of readiness still abound—and we suspect they always will. Siegler (1978) reports that a 5-year-old who uses the same rule as does an older child does not benefit as much from the same training as does the older child. This is in part due to a weaker tendency on the part of the younger child to encode the relevant information; the latter fact raises the question of whether time itself must pass before the training is effective or whether differences involving encoding strategies, processing space, knowledge, and so on, need to be modified during this time. More generally, the question is what happens during a given time period to enable learning to go forward (see Siegler & Klahr, 1981, for an extended discussion).

#### How Does Development Happen?

Up to this point we have focused almost exclusively on matters of structure. We now turn to matters of function. How do an individual's cognitive structures operate (i.e., How do they respond to inputs from the environment?)? The central notions in Piaget's (e.g., 1970) account are assimilation, accommodation, and equilibration. And which functional mechanisms are responsible for the emergence of each stage of development? The crucial notions here are those of abstraction réfléchissante and équilibration majorante (Piaget, 1975b).

For Piaget, all cognitive functioning involves the two fundamental, complementary processes of assimilation and accommodation. Piaget defines assimilation as the incorporation of external elements (objects or events) into sensorimotor or conceptual schemes. Thus, for example, thumb sucking in the infant is described as the assimilation of a novel element, the infant's thumb, into the existing sucking scheme. Similarly, the concrete-operational child who orders a set of rods is said to have assimilated the rods into a seriation scheme.

In his book, *L'équilibration des structures cognitives*, Piaget (1975b) postulates that every scheme tends to feed itself, that is, to incorporate into itself external elements that are compatible with its nature. The child's schemes are, thus, seen as constituting the motivational source, or the motor of development. Schemes do not merely constrain the nature and range of exchanges the child has with her environment, but they actively bring about such exchanges in their effort to feed or actualize themselves. The child's activity is, thus, necessary, in that it alone provides inputs to the child's assimilation schemes.

Many consider the foregoing notions vague. Yet, as indicated in our opening remarks, we said we accepted the idea that development proceeds as a function of assimilation and accommodation. To show why, we apply these notions to some of our work.

An example of the way in which schemes guide as well as motivate behavior comes from Gelman and Gallistel (1978). These authors found that even very young children obey the how-to-count principles that underlie counting behavior in older children and adults. Consider, for instance, the case of a 2½-year-old child who said, "2, 6, 10, 16" when engaging in what appeared to be counting. When shown one object and asked how many there were, the child answered "2." When shown two objects and asked how many there were, the child said, "2, 6, *6*" (emphasis on the last digit). Finally, when shown three objects and asked to count them, the child counted "2, 6, 10," and when asked how many there were, simply replied "10." This child can be said to have applied all of the how-to-count principles because he assigned one unique tag to each object, he used the same list over trials, and he repeated the last tag in a count when asked the cardinal-number question.

According to Gelman and Gallistel, the child's adherence to the how-to-count principles reveals the availability of a counting scheme, which embodies these (and possibly other) counting principles. The counting scheme guides and motivates the child's behavior. It must be clear from the foregoing how the counting scheme structures the child's counting performance. Evidence that the counting scheme serves a motivating role as well comes from at least two separate sources. The first is the existence of nonconventional or idiosyncratic count lists, such as the one cited above (children have also been found to count with letters as well as numbers). The children who use such lists do not do so because they have been taught them or heard them. They must have created them themselves using elements from the two lists they have had most occasion to hear, that is, the alphabet and the counting numbers. Gelman and Gallistel argue that the creation of these nonconventional lists points to the presence of a scheme that requires the count list to be stably ordered, but leaves unspecified the nature of the items that will constitute the list. What we have, then, is a scheme in search of a list. The scheme assimilates items that can then be stably ordered to create an acceptable count list, that is, a list that is compatible with the scheme itself.

The second source of evidence that counting schemes serve a motivating function is the frequency with which spontaneous counting is observed in the young child. Young children appear to have a compulsion to count, be it cows they pass while in a car, toys, candies, leaves on a tree, and so on. How else to explain this, Gelman and Gallistel argue, if not in terms of a scheme that presses children to search for items that can be readily assimilated? Because young children are not instructed to practice counting, a theory that required extrinsic (as opposed to intrinsic) motivation would be on difficult grounds. In their theory, the motivation would come from the schemes themselves, that is, the schemes would continually have to assimilate external elements to subsist and develop, and, hence, would press children to engage in activities whose results will be compatible with the schemes themselves.

In an assimilation, external elements are structured by, or adjusted to, the individual's schemes. In an accommodation, by contrast, the individual's schemes must adjust themselves to the demands of the environment. A scheme must always accommodate itself to the particular characteristics of the element (object or event) it is trying to assimilate. Thus, for example, the infant's grasping scheme will be applied differently when dealing with small as applied to large objects. In the very act of assimilating, or grasping the object, the infant must accommodate her action to the specific contour, weight, size, and so on, of the object she is attempting to grasp. The young child who uses an idiosyncratic count list eventually will accommodate to the conventional one. Otherwise communications involving counting and numbers will be exceedingly difficult.

Another example of schemes accommodating themselves comes from Saxe's (1980) work with the Papuans in Papua New Guinea. The Papuans use a 53-item count list that has no base rules embodied in it. With recent exposure of some men to money has come the shift to a base-20 system—presumably to make it possible to deal with large numbers.

To summarize, for Piaget, the child's schemes are the motivational source of development because they actively assimilate and accommodate. But the process of assimilation does more than constrain the nature and range of exchanges that a child will have with his environment. The process of assimilation also involves the seeking out of stimuli that are assimilable to a given scheme. As such, the scheme obtains the necessary inputs that feed the scheme. Because accommodation is always part of the assimilation process, it guides the eventual change in structures. We have illustrated how the processes of assimilation and accommodation might work in the development of counting skill and knowledge. By postulating that the counting principles form a scheme that assimilates and accommodates, we can account for the appearance of unusual count lists, the child's seeming compulsion to practice counting without a request, the tendency to self-correct and the further development of counting. We know of no other way to do so and, hence, accept Piaget's view that assimilation and accommodation are fundamental developmental processes. Indeed, because the characteristics of young children's counting behaviors are ubiquitous in other domains of development (e.g., language aquisition), it seems plausible that assimilation and accommodation are likewise ubiquitous during the course of development and later knowledge acquisition.

If every cognitive act involves schemes that assimilate and accommodate, how can there ever be stability of cognitive structures, or at least enough stability for one to recognize a stage? Piaget dealt with this issue by distinguishing between different kinds of assimilation-accommodation functions and the consequent different kinds of equilibration (Piaget, 1975b). In cases were accommodation is readily effected either by repetition of a previous accommodation or by relatively insignificant alterations of the individual's schemes, Piaget talks of simple, limited equilibrations that do no more than preserve or restore the existing state of equilibrium. In cases where accommodation is unsuccessful, however, and assimilation of a given element proves impossible without significant modifications of the individual's schemes or cognitive systems, Piaget talks of equilibrations majorantes or major improvements that generate qualitatively distinct, superior states of cognitive equilibrium.

Obviously the latter situations—those unsuccessful accommodations that call for an improved (majorante) equilibration—are the most important ones from a developmental point of view. Exactly how does the major equilibration happen? It is hard to find a clear account in Piaget's writings. One thing is clear, this is that Piaget thought that qualitatively new concepts could emerge from the process of reflective abstraction.[7]

We admit to having been less than successful in our efforts to understand fully the notion of reflective abstraction. Again, we resort to an example from Evans' (1982) work on the acquisition of the concept of infinity. Evans suggests that some children acquire, on their own, the notion that there is no largest number on the basis of their self-initiated counting trials. The idea is that some children set themselves the task of counting up to the largest number and eventually come to recognize that they will never get there because there is no largest number. Piaget would say the child who reaches this conclusion does so via the process of a reflective abstraction from the set of count trials that were self-generated. Parenthetically, the self-generated count trials are examples of what Piaget means by logical as opposed to physical abstraction (Piaget, 1975b).

We suspect that part of the resistance to accepting the idea that schemes assimilate and accommodate is due to the absence of detailed accounts of how the assimilation and accommodation processes yield development. Piaget (1975b) tried to do this in his more recent treatments of the processes of equilibration and reflective abstraction. We see this work as part of Piaget's continuing efforts to detail the nature of assimilation and accommodation. However, we confess that we still are far from a full understanding of the various processes postulated in Piaget's treatment of reflective abstraction and equilibration. Yet, we do not think it necessary to throw up our hands in despair. Perhaps work by Rumelhart and Norman (1978) on schema development or Siegler and Klahr (1981) on developmental transition processes will serve this end. And Rozin's (1976) notion of accessing has much in common with Piaget's (1975b) notion of reflective abstraction. Further, to repeat, there can be no denying something like assimilation and accommodation as being involved in learning and development. Those familiar with the theoretical work of Rumelhart and his colleagues (e.g., Rumelhart and Norman, 1978; Rumelhart & Ortony, 1977) will recognize the use of similarly active processes in their account of how schemata are formed and developed. Whether Piaget's particular version of how schemes develop will stand the test of time, we do not know. But we are sure that notions akin to assimilation and accommodation will. And by now, they are no more mysterious to us than are the processes of association and selective attention.

### Whence Come Structures?

The issue of whence concepts was taken up in the Piaget-Chomsky debate held in France in 1975 and published in English with Piatelli-Palmarini (1980) serving as editor and commentator. Not only were Piaget and Chomsky present, so were Bateson, Fodor, Inhelder, Jacob, Mehler, Monod, Papert, and Premack—to list but some of the distinguished participants. The debate was supposed to focus on the Piagetian and Chomskian accounts of language acquisition but was, in fact, a broader debate about Piaget's constructivism versus Chomsky's and Fodor's innatism. Piaget defended his view that structures are constructed and not inherited. He maintained that cognitive functions, but not cognitive structures, were innate. Fodor and Chomsky were on the side of innate ideas.

The nub of the disagreement between Chomsky and Piaget concerns the origin of mental structure. Chomsky and Fodor maintain that structure begets structure and that this is logically necessary. Fodor's argument is that learning involves hypothesis testing; hypotheses are either rejected or accepted. For one to induce the correct hypotheses, one must be able to formulate those hypotheses. Therefore, the hypotheses must already be available to the organism.

> To let such a device [a learning device] do what it is supposed to do, you have to presuppose the field of hypotheses, the field of concepts on which the inductive logic operates. In other words, to let this theory do what it is supposed to do you have to be in effect a nativist. You have to be a nativist about the conceptual resources of the organism because the inductive theory of learning, simply doesn't tell you anything about that. (Fodor in Piatelli-Palmarini, 1980, pp. 146–147)

As noted by the biologists at the debate, the nativist position (outlined here) does not, of course, mean that the adult's mental structures are present from the outset any more than it means—to translate the argument to a purely biological example—that adult sexual organs are present in the newly fertilized ovum. Work in ethology provides ample evidence that constructivist and nativist positions need not be contradictory. The acquisition of bird song provides a lovely example. The adult white-crowned sparrow has a characteristic song. By varying the kind of environment available to the young white-crowned sparrow, Marler (1970) has been able to show that experience plays a central role in the development of the song that is characteristic of the region in which the bird lives. For, if a baby sparrow is raised in isolation, it will sing a distinctly odd song as an adult. Experts agree that this odd song is the basic form of the adult song. It is odd because it is never heard in nature and lacks those characteristics that give it the status of one dialect or another. If the young bird is exposed to the adult song during its first 10 to 50 days of life, but never again, the bird will sing the adult characteristic song. This is true, even if the young bird is deafened after the exposure. What matters is not the opportunity to sing the song—the young cannot—but the opportunity to hear the song of the region. There is a critical period during which the bird must hear the adult model. If the isolated bird hears the song for the first time at 100 days, the experience will have no effect. Likewise, if the acoustic input is provided during the first days of life, it does not take. Subsequent deafening does inhibit acquisition. Marler argues from such findings that the white-crowned sparrow is born with template for the basic song. Experience serves to tune that template to allow the young bird to learn its particular dialect. The bird brings to the interaction with the environment a structural advantage that helps it focus attention on, that is, assimilate one set of songs as opposed to another. In interacting with the environment, the bird develops the particular song of its locale, that is, the basic template is accommodated. The idea is *not* that development involves a bit of innate structure and a bit of learning but *that development is a function of the organism's interaction with its environment*. The potential for structural change is not reached unless there is development, that is, an interaction between structure and environment. Nevertheless, the potential is innately given.

For Chomsky and Fodor, the complexity and power of the final structure is preordained by the complexity of the initial structure. This is precisely where Piaget disagrees. Piaget insists that each successive structure in the stagelike course of development is not only different from, but more complex and powerful than, the preceding structure. Piaget fosters a notion of developmental process as divorced from structure. He grants that the processes or developmental functions are innate, but he does not grant that complex processes presuppose a complex structure for their realization. Piaget argues that cognitive functions foster the emergence of structures more complex than prior ones. Carrying this argument back to the very beginning of development, he maintains there is only process or function and no structure: "I have my doubts . . . [that the point of departure is innate], because I am satisfied with just a functioning that is innate" (Piaget in Piatelli-Palmarini, 1980, p. 157). The tendency of the subject to assimilate and accommodate is enough to bring him into interaction with his environment and this interaction yields cognitive structures.

Piaget's distinctly Lamarkian hypothesis was criticized by the biologists at the debate. For example, Jacob pointed out:

> In the case of the small animals from the bottom of Lake Geneva, the observed variations are always those allowed by their genotype. One always remains within the working margin authorized by the genes. . . . *There is regulation only on structures and with structures that exist and that are there to regulate*. . . . They adjust, of course, the allowed working margin, but it is, once more, the genotype that prescribes the limits. (Jacob in Piatelli-Palmarini, p. 62)

Despite persistent efforts by the biologists, Piaget stood by his view that structures are not determined innately. Rather than granting Fodor's view that successive structures must be represented in prior structures, he maintained that a prior structure can contain the subsequent structure *only as possibilities*, possibilities that do not get formed until they are constructed or created in the course of an interaction with the environment. The interaction itself alters the prior structures and, thus, more complex structures develop.

We agree with Chomsky and Fodor regarding the ultimate origin of the structures mediating the kinds of concept Piaget describes as being present during the early school years. First, we cannot make sense of the notion of a functioning divorced from a structure. If structures do not guide functioning, then we fail to see how the developmental process gets started on the *same* developmental course for *all* normal children. But, if we allow innate structural constraints on the course of development, then we can begin to make sense of the fact that children all over the world seem to develop the same concepts in about the same sequence up to around the beginning of the concrete-operational period. Further, the evidence points to innate structural dispositions in infants (e.g., Haith, 1980; Spelke, 1980). Likewise, much of the recent evidence regarding the cognitive capacities of preschoolers points to the early availability of rich and complex reasoning structures. As more evidence like this comes in, it becomes harder and harder to escape the argument that there are innate structural constraints on the course and nature of cognitive development. Osherson (1978) and Keil (1981) have made some progress in characterizing these constraints.

To say that young children's reasoning structures are rich is not to say that they are the same as the adult structures. Indeed, we noted the many conceptual domains where (despite the presence of early capacities) young children's reasoning structures are nowhere near those of older children, which, in turn, seem impoverished compared to adult's capacities. As far as we are concerned, to say there are rich cognitive structures to start is just the beginning. There remain the questions of what those structures are and how they determine the emergence of advanced structures, given an appropriate range of experience. And, of course, the account of what the appropriate range of experiences are has to be related to the nature of the structures that set the range. Finally, the obvious fact that humans have considerable conceptual plasticity, has to be reconciled with the idea that there are innate structural constraints on the course of cognitive development. For an example of how this might be accomplished we turn to Rozin's Accessing theory of intellectual development.

Rozin (1976) has attempted to deal with the facts that (1) highly "intelligent" behavioral mechanisms are available to species low down on the phylogenetic scale and (2) even though more "intelligent" organisms have genetically specified behavior programs, they are less constrained by these programs or are more open to environmental variations.

Rozin begins by calling attention to the highly "intelligent" nature of many special-purpose behavioral mechanisms in animals. Foraging bees, for example, record the location of food sources in polar coordinates, with the home nest as the origin of the coordinate system and the sun as the point of angular reference. It is now known that almost all of such "intelligent" behavior is founded on genetically specified computational machinery that prepares the bees to learn the location of a food source. The learning here does not reflect some general-purpose faculty of association. Instead, the learning ability appears within genetically constrained behavioral circumstances and the bees' "knowledge" of celestial mechanics, which is implicit in the bees' behavior and is unavailable for use in other aspects of the bees' behavior.

According to Rozin, the genetically determined behavioral machinery in lowly creatures is unaccessible for use in contexts other than the specific context that shape the evolution of the requisite neural machinery in the first place. Rozin's thesis is that the evolution of general-purpose intelligence in higher mammals has involved the evolution of more general access to computational processes that originally served specialized behavioral purposes. Still, he stresses the fact that even in humans, there are many computational routines whose outputs are not generally accessible. For example, our visual system makes extensive computations that draw on a great deal of implicit knowledge of trigonometry and optics. The end result, our perception of the world around us, is generally accessible. But the intermediate computations are not. Likewise, humans appear to possess genetically specified neural machinery for computing phonetic representations of the speech they hear (Eimas, 1974). This phonetic representation is an intermediate stage in the computation of a semantic representation of what humans hear. The evidence indicates that the phonetic representation is not *consciously* available to preschool-aged children (Gleitman & Rozin, 1977; Liberman, Shankweiler, Liberman, Fowler, & Fischer, 1977; Rozin & Gleitman, 1977).

Rozin and Gleitman (1977) hypothesize that the ability to read rests heavily on the ability of humans eventually to gain conscious access to the phonetic representation of what they hear. Spelling rules relate written English to a phonetic representation of spoken English. Every fluent reader can give decidedly nonarbitrary pronunciations of words she has never seen (Baron, 1977). Thus, it seems hard to deny that an important aspect of learning to read is learning to compute a phonetic representation of written material by using the lawful relations between spelling and pronunciation. Learning to compute such phonetic representations of visual inputs must be very difficult if one does not have conscious access to the phonetic representation of what one hears. But it is known (see above) that the young child has limited access to the phonetic representation. Hence, the Rozin and Gleitman (1977) argument that reading ability requires the development of conscious access to the phonetic representation.

Note that Rozin does not contend that the ability to read per se is coded in the genes but that related abilities as well as a general accessing ability (reflective abstraction?) are. The notion of accessing by itself does not constitute a solution to the developmental problem, that is, how to account for new concepts within a nativist frame of reference. Instead, it points to the form such a solution might take. If the notion is to be taken seriously, one must raise *and* answer the following questions: What is it about the early representation of a given set of experiences that prevents their being worked on by a given piece of computational machinery? How must this representation be altered for the machinery to operate on it? What are the processes that produce such alterations and what experiences bring these processes into play?

We introduce Rozin's theory because it has the form of the theory that is needed to deal with the facts about the concepts that Piaget has studied. Their development is more domain specific than not. Very young children have considerable cognitive abilities. Still, some, if not most, are exceedingly hard to demonstrate, and the range of application of these abilities is oftentimes remarkably restricted compared to that in older children. Hence, their ubiquitous tendency to fail may related tasks. Eventually, what are rigid, undergeneralized capacities become fluid, generalized capacities.

#### A Concluding Remark

There are at least three important ways in which Piaget's work has influenced the field of child cognitive psychology. First, Piaget was among the first modern psychologists to insist on the active role the child plays as a learner. Traditional learning theory tended to characterize development in terms of the passive registering and gradual accumulation of environmental contiguities. In marked contrast, Piaget portrayed the young child as one who continually engages in the selection and interpretation, as well as the storage, of information. Second, Piaget was also among the first modern psychologists to underscore the role cognitive structures play in young children's reasoning. Again and again Piaget demonstrated that young children's cognitive structures determine their perception and understanding of the world and delimit the nature and range of knowledge they acquire at each point in their development. Third, Piaget is undoubtedly the psychologist who has most contributed to our knowledge of the facts of cognitive development. His work covers the development of a remarkably wide and varied set of concepts: object permanence, number conservation, class-inclusion, length, distance, and so on. As we repeatedly pointed out in the chapter, investigators may not always agree with Piaget's interpretation of the developmental phenomena he reported—but they do not deny their reliability or interest.

On the debit side, we would argue that Piaget's work presents two major drawbacks. Throughout his career, Piaget maintained that all cognition develops through four successive stages, with each stage characterized by the emergence of qualitatively distinct structures. It seems to us that Piaget's strong commitment to this view, though praiseworthy in some respects, also had some unfortunate consequences. In particular, it appears to have led him to disregard—and even at times summarily dismiss—alternative accounts of his findings that were at least as plausible as those he proposed himself. The second drawback is analogous to the first. Having commited himself to the view that cognitive structures are actively constructed by the child, Piaget seems never to have seriously considered alternative views of the development of these structures. True, Piaget's treatment of developmental issues almost invariably includes a discussion of the rationalist and empiricist standpoints. However, his presentations of these views are usually so simplistic as to border on the charicatural. One lesson of modern research in child psychology is that accounts of how development proceeds can no longer ignore the possibility that at least some of the structures that underlie our systems of knowledge are innate. Another lesson is that in order to do justice to the richness and complexity of the learning processes involved in the acquisition of cognitive structures, far more sophisticated investigative and descriptive tools than were hitherto available must be developed. Piaget's account of the manner in which cognitive structures emerge appears extremely limited. But then, it is always easy to examine the past in terms of the present. What is more difficult is to create the future. It will be hard, very hard, to do as well as Piaget.

### NOTES

1. Osherson (1974) provides a proof that the groupings themselves are either inconsistent or tautological.

2. Gold provided the information about subjects' ages upon request from the authors. These are not in his text.

3. Shultz et al. (1979) make as good a case as

anyone for treating separately issues of a belief in logical necessity and the understanding of many conservations.

4. For a complete list of the properties of classificatory systems see Inhelder & Piaget, 1964, p. 48.

5. Our comments about causal reasoning are restricted to the domain of physical causality. See Gelman & Spelke (1981) for a discussion of possible differences in reasoning about physical causality and social causality.

6. An example of the difficulty in defining a unit of *M*-space is taken up in Trabasso and Foellinger (1978). Pascual-Leone (1978) considers the critique unjustified on many counts. However, there still remains the question of how to define a unit on a priori grounds.

7. This is but one of Piaget's uses of the concept of reflective abstraction. See Vyuk (1981) for an excellent coverage of this and related concepts.

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