Psychology Editor: Stacey Purviance
Editorial Assistant: Amy Wood
Assistant Editor: Faith Stoddard
Project Editor: Trudy Brown
Print Buyer: Stacey Weinberger
Permissions Editor: Susan Walters
Publisher/Executive Editor: Vicki Knight
Production Service: Robin Gold / Forbes Mill Press

Copy Editor: Robin Gold
Cover Designer: Joan Greenfield
Cover Image: © TSM/Mug Shots; Tony Stone Images
Compositor: TBH Typecast

Printed in Canada

4 5 6 03 02

For permission to use material from this text, contact us by
Web: www.thomsonrights.com
Fax: 1-800-730-2215
Phone: 1-800-730-2214

Library of Congress Cataloging-in-Publication Data

Bjorklund, David F.
Children's thinking : developmental function and individual differences / David F. Bjorklund. — 3rd ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-534-35660-5
1. Cognition in children. 2. Individual differences in children.
I. Title.
BF723.C5B48 1999
1555.4'13—dc21 99-34362

This book is printed on acid-free recycled paper.

For more information, contact
Wadsworth/Thomson Learning
10 Davis Drive
Belmont, CA 94002-3098
USA
www.wadsworth.com

International Headquarters
Thomson Learning
290 Harbor Drive, 2nd Floor
Stamford, CT 06902-7477
USA

UK/Europe/Middle East
Thomson Learning
Berkshire House
168-173 High Holborn
London WC1V 7AA
United Kingdom

Asia
Thomson Learning
60 Albert Street #15-01
Albert Complex
Singapore 189969

Canada
Nelson/Thomson Learning
1120 Birchmount Road
Scarborough, Ontario M1K 5G4
Canada

Children's Thinking

Developmental Function and Individual Differences

Third Edition

David F. Bjorklund
Florida Atlantic University

Wadsworth
Thomson Learning™

Australia • Canada • Denmark • Japan • Mexico • New Zealand • Philippines • Puerto Rico
Singapore • South Africa • Spain • United Kingdom • United States

Life is full of problems that we seek to solve. Problems and their attempted solutions start early. Infants will strive to retrieve a fallen toy, overcoming obstacles along the way. The problems we face, and their solutions, become more complicated as we get older, but they all have certain things in common. We say that someone is solving a problem when there is a specific goal in mind that cannot be attained immediately because of the presence of one or more obstacles. We solve problems by learning rules or by using (sometimes discovering) one or more strategies. Sometimes a problem takes several attempts before it is solved, and we must be able to evaluate our progress toward the goal, if for no other reason, to know when the problem has been solved. Thus, the four basic requirements of problem solving are goals, obstacles, strategies for overcoming the obstacles, and an evaluation of the results (DeLoache, Miller, & Pierroutsakos, 1998).

Much of what we have covered in this book to this point can be considered to be in the realm of problem solving. The classic tasks of conservation and classification, for example, are problem-solving tasks. Arithmetic problems, which will be discussed in Chapter 12, are clearly problem-solving tasks. To some extent, many tasks assessing memory are problem-solving tasks, with the goal being to remember as much as one possibly can. In this chapter, I will describe children's general problem-solving abilities, beginning in infancy. This will be followed by a brief section on planning. The remaining part of the chapter will be devoted to a special type of problem solving, reasoning.

Problem Solving

The Development of Problem Solving

When do children first solve problems? Based on our definition of what constitutes **problem solving** (having a goal, obstacles to that goal, strategies, and evaluation of results), infants cannot be said to solve problems until they demonstrate some sense of **goal-directed behavior.** Recall from our discussion of Piaget's theory of sensorimotor development, goal-directed behavior requires that "need precede action." That is, infants do not discover an interesting outcome fortuitously (for example, hitting a mobile with their arm), but rather first seek to achieve a specific goal (move a mobile) and then act accordingly. This is also the beginning of cause and effect (means-end) thinking. Infants must realize that they must do something quite specific (make physical contact with the mobile) before the mobile will move.

Piaget proposed that not until about 8 months of age, during the substage of coordination of secondary circular reactions, are infants able to accomplish this. At this time, they can use one behavior *strategically* in the service of another (for example, push aside a cloth to retrieve a toy hidden underneath). Thus, following from Piaget's classic work, we can say that problem solving begins at least during the latter part of the first year of life.

But must infants wait that long to solve simple problems? Infants younger than 8-months can clearly learn to control aspects of their environments to make interesting things happen (Rovee-Collier & Gerhardstein, 1997; Lewis, Alessandri, & Sullivan, 1990). For example, infants 2 to 8 months of age learned to pull a lever to see a color picture of a baby's face and to hear an accompanying song (Lewis et al., 1990). Even the youngest infants learned to pull the lever to get the reinforcement and became angry when the lever pulls no longer produced the interesting outcome. But the study by Lewis et al., although it had a specific goal to be achieved, does not have all the classic aspects of problem solving. The only obstacle was infants learning the association between their behavior and the outcome, and there seems to be no explicit strategy involved. True problem solving, involving means-end action sequences, seems not to be found until about the time Piaget originally proposed (the latter half of the first year).

Peter Willatts (1990) has performed some interesting experiments demonstrating means-end problem solving in infants. In one study, 6-, 7-, and 8-month-old infants were placed on a table. In front of the infants was a long cloth with a toy placed on the cloth, out of the infants' reach. Here's a goal (get that toy) and an obstacle (it is out of reach). The solution is to strategically use one behavior (pull the cloth toward them) to achieve their goal (get the toy). How did the infants do? The 6-month-olds often retrieved the toy, but their behavior was not always intentional. Instead of pulling the cloth to them and fixing their attention on the toy, these youngest infants often simply played with the cloth, looked away from the toy, and, after a while, the toy finally was in their reach. By 8-months of age, infants were much less apt to play with the cloth. They grabbed the cloth and immediately began pulling it to bring the toy closer to them. They kept their fixation on the toy and quickly and efficiently brought the toy within their grasp, often holding out a hand in anticipation of the toy's arrival. The 7-month-olds fell between the 6- and 8-month-olds.

Although means-end problem-solving might be within the capacity of infants as young as 7- and 8-months of age, it does not mean that children will display such behavior on more complicated tasks. This is illustrated by an interesting study performed by Bullock and Lütkenhaus (1988). In their study, children between the ages of 15- and 35-months were asked to perform one of several tasks, for example, to stack blocks to copy a house built by an adult. The youngest children (average age, 17-months) showed little specific goal-directed behavior. They did play with the blocks and build "something," but there was little evidence that they kept the goal of building a house in mind during their activities. In contrast, most 2-year-olds were able to keep the goal in mind and build the house. These children also did a good job at monitoring their performance (evaluating the results of their behavior). Almost all these children made at least one correction, and 85% of the 2-year-olds stacked all the blocks correctly on at least one trial. The reactions of the children to their problem-solving attempts also reveals their evaluations of their behavior toward achieving their goal. Only about a third (36%) of the 17-month-olds showed some clear sign of emotion to their performance (smiling or frowning), whereas 90% of the older children (32-month-olds) did so.

The tasks children need to solve get more complicated as they get older, and so their problem-solving abilities must also improve. One factor that has been found to have a significant impact on problem solving is knowledge. The more one knows about a particular topic or the more familiar one is with the context, the more sophisticated problem solving will be.

Let me provide an example for learning the rules behind a computer game. Stephen Ceci (1996) has proposed that context influences how people approach and solve problems. Ceci defines context as the way in which a problem in represented in long-term memory; that is, it consists of what a person knows about a task, including the reason for performing it. Ceci (1996) reports an experiment in which 10-year-old children were asked to predict where, on a computer screen, an object would land by using a joystick to mark on the screen the next position of the object. The object varied in size (big or small), color (dark or light), and shape (square, circle, or triangle), producing 12 combinations of features (two sizes × two colors × three shapes). A simple algorithm was written so that (1) squares would move upward and circles downward, and triangles would stay on the horizontal; (2) dark figures would move to the right and light figures to the left; and (3) large objects would move diagonally from lower left to upper right, whereas small objects would move in the opposite direction. So, for example, a large, light square would move upward, leftward, and from the lower left to the upper right.

Figuring out how the object would move (that is, where it would be on the next trial) seems like it would be a difficult task for children (as well as for adults), and it was. The children were given 15 sessions with the task, with 50 trials per session. Some children were simply asked to predict where the object would move on each trial. Other children were told that this was a video game, the purpose of which was to capture flying animals. The three shapes were changed to a butterfly, a bee, and a bird. These children were told to use the joystick to place the "butterfly net" so that they could "capture the prey" on each trial. The algorithm (that is, the rule by which the target moved on each trial) was identical in both conditions.

The results of this study are graphed in Figure 10-1. As can be seen, the two groups started out similarly, performing relatively poorly over the first five sessions. However, the children in the video-game

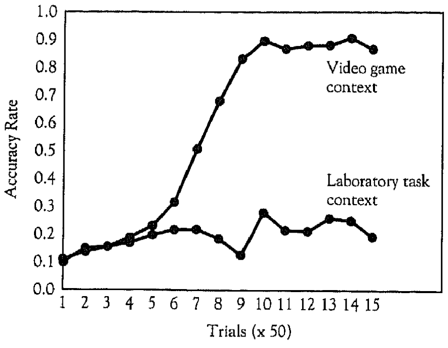

FIGURE 10-1 Children's mean proportion of accurate predictions of the position of a moving object in a video game versus laboratory context. SOURCE: From Stephen J. Ceci, *On intelligence . . . more or less: A bio-ecological treatise on intellectual development*, ©1990, p. 39. Reprinted by permission of Prentice-Hall, Englewood Cliffs, New Jersey.

context then took off, performing at levels approaching 90% by the ninth session. In comparison, the children given the laboratory context continued to perform poorly, never really improving on the task over the 15 sessions. Discovering the algorithm depended on the mental context in which the problem was presented. The rules were the same for all children, but the context, a form of knowledge, influenced greatly children's problem-solving performance (see also Oyen & Bebko, 1996 for a similar example of different memory strategy use when "instruction" is done via a computer game versus formal instruction).

Problem Solving as Inducing and Using Rules

One way of thinking about children's problem solving is considering their acquisition and use of *rules*. Rules specify relations between two or more variables, and are usually thought of in terms of "if . . . then" statements ("If condition A exists, make response X; if condition B exists, make response Y") (Zelazo & Jacques, 1997). One tradition in developmental psychology has focused on children's acquisition of the rules of formal logic ("If *p* then *q*," and so on), which will be discussed in a separate section later in this chapter. The second concerns children inducing, or discovering, a rule as a result of experience and using these rules to solve problems (DeLoache et al., 1998).

When Can Children Induce Rules?

When can children induce rules for solving a problem from experience? One simple task that requires the discovery of a rule is an *oddity problem*. This will be familiar to any readers who grew up watching *Sesame Street* and the game "One of these things is not like the other." In this game, and in oddity problems in general, people must figure out which object is different, or odd, relative to the others in the set. These problems can be very simple, based on perceptual similarity (for example, § § ¥), or more complex, based on conceptual similarity (for example, tiger, elephant, blue jay; or Brainerd, Gopnik, Karmiloff-Smith).

Oddity tasks can even be administered to preverbal children and animals. In these cases, subjects are shown a series of problems and receive a food reward when they select the correct (odd) item. William Overman and his colleagues (1996) used such an oddity task, showing toddlers from 16 months of age through adults series of three objects, two of which were the same (Experiment 1). When subjects selected the odd object they received a food reward. This was a difficult task for toddlers (16 to 31 months of age), even more difficult for the preschoolers (32 to 60 months of age), but relatively trivial for participants 6 years of age and older. Yet, most of the toddlers (16- to 31-month-olds) did eventually learn the task, although it took them several hundred trials, and most children of all ages quickly solved the problems when given verbal instructions (Experiment 2).

It is interesting that the lack of verbal instructions (that is, performing the task using nonverbal procedures as is done when testing animals) was particularly detrimental for children between the ages of about 2.5 and 5 years of age. Similar findings have been reported by other researchers (Inhelder & Piaget, 1964), and they have been interpreted as indicating that younger children approach oddity problems differently than older children (see Overman et al., 1996). Obviously, the approach the 2.5- to 5-year-old children used to solve the oddity problems was ineffective. It appears that these preschool children's reliance on language made inducing a rule based solely on behavior very difficult, whereas the problem was simple enough for older children and adults to figure out without being told explicitly what to do. But the fact that these children were able to solve the problem easily as soon as they were told the rule ("Pick the one that's different"), indicates that they can apply this rule across different problems, but just have a difficult time inducing a rule based on behavior alone.

Rule-Assessment Approach

Much of cognitive development can be viewed as a process of inducing rules to solve problems. Many problems can share many of the same underlying features, and thus require the application of very similar rule systems. For example, many of the problems developed by Piaget involved children learning about the physical world and, according to Piaget, require children to learn a set of logical rules for their solution. Although each problem would have something unique about it, a universal set of cognitive structures develops to handle these problems.

Robert Siegler (1976, 1981) developed a rule-based model of cognitive development to explain many of the concepts that children acquire over childhood initially described by Piaget and others. In his **rule-assessment approach,** cognitive development is characterized by the acquisition of increasingly powerful rules for solving problems. Let me provide a description of the rule-assessment approach for the balance-scale problem (Siegler, 1976, 1981). For this problem, children are shown a balance scale, similar to that shown in Figure 10-2. Weights are then placed on the two sides of the scale, and children must predict which side of the scale will fall (if either). Children must consider not only the number of weights on the two sides, but also their distance from the midpoint. Weights farther away from the midpoint will have a greater impact on the movement of the scale than weights closer to the midpoint. Siegler discerned four rules children used on this task. Children using Rule 1 consider only a single dimension: the amount (number) of weights on each side. Thus, children who use Rule 1 should say that the side with the most weights should fall, regardless of where those weights are placed. This will lead to some correct predictions, but also to some incorrect predictions. Children using Rule 2 similarly predict that the side with the most weights will drop, but when the number of weights is equal on both sides, they then consider the distance from the scale's midpoint. With Rule 3, children use both the weight and the distance dimensions; they predict that the side with either more weights or greater distance from the center will go down. If one side has more weights and the other side has greater distance, they muddle through the problem. Finally, children using Rule 4 make the appropriate computations of weight and distance, thus deriving the correct answer regardless of how the weights are distributed across the scale.

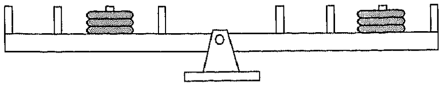

FIGURE 10-2 Example of a balance scale task. The scale would be locked and weights would be placed on the two sides and children were to predict which side, if either, would fall.

Siegler (1976) reported that 88% of children 5- to 17-years of age consistently applied one (or several) of these four rules in solving balance-scale problems. Most 5-year-olds used Rule 1, whereas 9-year-olds most often used Rules 2 or 3. Adolescents (13 to 17 years of age) usually used Rule 3, with very few children ever using the most sophisticated Rule 4. Perhaps somewhat surprisingly, most college students also rely on Rule 3, with only a minority of them using the most sophisticated Rule 4 (and the only one that will consistently produce a correct answer) (Siegler, 1981). This use of systematic rules breaks down on the balance-scale problem when younger children are tested. Siegler (1981) reported that none of the 3-year-olds he tested, and about half of the 4-year-olds, used any discernible rule. The problem was apparently beyond their comprehension, and they were unable to generate even the simplest rule (more weights win) to solve these problems. Other studies have confirmed this sequence (Amsel et al., 1996; McFadden, Dufresne, & Kobasigawa, 1986), and Siegler (1981) reports similar sequences following similar rules for a variety of tasks (for example, probability judgment, conservation, judging the projection of shadows).

Siegler (1996) has since modified his view of children's problem solving, proposing that, instead of a stage-like progression, children have a variety of strategies available to them to solve problems at any one time, and that these strategies "compete" for use. Siegler's *adaptive strategy-choice model* was discussed in some detail in Chapter 5. There is much evidence in the recent problem-solving literature to suggest that Siegler is right. Rather than presenting that evidence here, however, I will postpone a discussion of the adaptive strategy-choice model in greater detail for the development of arithmetic strategies in Chapter 12.

Learning to Follow Rules

Philip Zelazo and his colleagues have focused on preschool children's ability to follow simple sets of rules and propose that following relatively arbitrary sets of rules is a reflection of consciousness and cognitive self-control (Zelazo & Jacques, 1997; Zelazo et al., 1997). In an early experiment, Zelazo and Reznick (1991) gave children between the ages of 31 and 36 months of age a sorting task to complete. Children were shown sets of pictures and given two rules to follow: "If it's something found *inside* the house, then it goes in this box. If it's something found *outside* the house, then it goes in that box." Pictures included a variety of objects, some of which were obviously "inside" things (bed, TV), and others that were obviously "outside" things (snowman, plane). Children were also given a "knowledge" task. Now, instead of having to sort each object into one of two boxes, they were shown each card and simply asked "Is this something found inside the house or is it found outside?" All children performed well on the knowledge task (that is, they answered correctly when asked if an object belonged "inside" or "outside"). However, only the oldest children (36-months) could put this knowledge into action, sorting the cards correctly into boxes. The younger groups of children (31- and 33.5-month-olds) did not sort items correctly, despite "knowing" to which category each item belonged. Later research indicated that 32-month-old children similarly failed the sorting task (and passed the knowledge task) despite having each item labeled ("This is a bed, where does it go?"), being reminded of the rules ("Remember, if it goes inside, then you put it here, and if it goes outside you put it here"), and receiving feedback and rewards for correct responding (Zelazo, Reznick, & Piñon, 1995).

These findings indicate that 36-month-old children can follow an arbitrary rule system, whereas younger children have a difficult time doing so, despite *knowing* the rules. However, 3-year-old children's ability to follow and coordinate rules is far from fully developed. This is indicated by experiments using the *dimensional card sorting task*, discussed briefly in Chapter 5 (Zelazo, Frye, & Rapus, 1996). In this task, children are shown sets of cards that vary on two dimensions. Figure 10-3 provides an example of the cards used in these experiments. Children are shown two target cards, a yellow car and a green flower, for instance. When playing the color game, they are told that all the yellow cards go here (with the yellow car) and all the green cards go there (with the green flower). Children then are given a series of test cards (for instance, yellow flowers and green cars), and are asked to sort them by color. This most children do easily. Then children are told they are going to play a new game, the shape game. (For half the children the shape game is played first, and for the other half, the color game is played first.) In the shape game, children are to place cars in this box (with the yellow car) and flowers in that box (with the green flower). These are called *switch trials*, because the rules have been switched (from sorting on the basis of color to shape, or vice versa). Now, most 3-year-old children fail, continuing to sort the cards according to the original dimension. Yet, when asked what the new rule is, most can easily and correctly tell the experimenter. That is, like the 32-month-olds for the simpler task (Zelazo & Reznick, 1991), 3-year-olds can verbalize the rule but cannot execute the problem. By 4 years of age, most children do fine on both tasks.

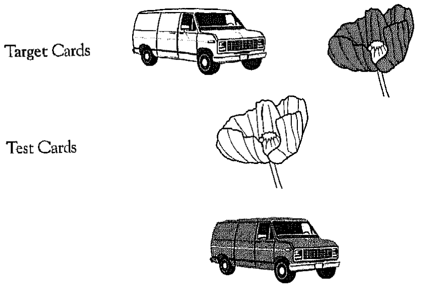

FIGURE 10-3 Dimensional card-sorting task. Children are to sort cards initially by one dimension (color) and later by a second dimension (shape). SOURCE: Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development*, *11*, 37–63.

Why do children have difficulties on these tasks, and what develops so that by 4 and 5 years of age most children can follow simple rule systems relatively easily? One thing to look at on these tasks is the type of errors children make. Children tend to persist making responses they had learned earlier, termed *perseverative errors* (Zelazo, Reznick, & Piñon, 1995; Zelazo et al., 1996), and this suggests that one source of their problem is poor inhibitory control (Harnishfeger & Bjorklund, 1993). That is, children have learned a response in this context and have a difficult time not making that response (sort by color) when the rules change (now sort by shape). Although I'm convinced that children's developing inhibitory abilities play a role in their use of rules, it cannot be the entire answer. For example, Zelazo and his colleagues (1996, Experiment 2) reported that 3-year-olds made perseverative errors on the dimensional card sorting task after only one trial on the original dimension. That is, it was not necessary for children to acquire a well-learned response for them to make errors on the switch trials.

What, then, accounts for the development of rule use over the preschool years? According to Zelazo and his colleagues, children gain increasing conscious control over their problem solving, and this is captured by the **cognitive complexity and control (CCC)** theory (Zelazo & Frye, 1997). Much like the distinction between implicit and different levels of explicit representation in Karmiloff-Smith's (1992) theory (see Chapter 4), Zelazo and Frye propose that there are age-related changes in the complexity of rule systems that children can represent. According to Zelazo et al., (1997), developmental differences in *reflection* give children increased control over their behavior and cognition. "Reflection is defined as a recursive process whereby the contents of consciousness become an object of consciousness so that they can be operated on and modified . . . [H]igher order rules mediate reflective awareness of lower order rules and make possible the deliberate selection of lower order rules for use. In the absence of a higher order rule, children will perseverate on whichever lower order rules are most compelling" (p. 21). In other words, children acquire rules early on and can follow them in certain situations. But coordinating rules requires greater conscious reflection, and this develops over the preschool years. It is interesting to see the parallel in development between rule use reported by Zelazo and his colleagues and theory of mind research discussed in Chapter 7. Although speculative, it appears that a single representational system might be underlying cognition in these seemingly different areas.

Planning

An important part of problem solving is *planning*. In many complicated problems, several steps must be executed in order before a goal can be reached. There is little planning involved for an 8-month-old, whose goal is to get a toy by pulling on a cloth. But as the problems get more complicated, so does the need for planning. For example, in the study by Bullock and Lütkenhaus (1988) discussed earlier, children had to plan ahead as to which blocks they would select first and which needed to be used only later. There were several aspects to the problem, and, although a trial-and-error procedure might have eventually produced a correct answer, it rarely did for the youngest children in the Bullock and Lütkenhaus study.

Planning is difficult for young children, and they rarely do it, or at least rarely do it well. There are many reasons for this, associated with children's limited cognitive abilities. Ellis and Siegler (1997) have listed several reasons for young children's generally poor planning abilities:

1. Planning often requires inhibition of currently active behavior. As you may recall from our discussion of the development of inhibition/resistance from interference in Chapter 5, these abilities increase with age, with preschool children often having difficulty inhibiting an ongoing activity (Harnishfeger & Bjorklund, 1993).
2. Planning takes time, and children often prefer to do a task quickly than to do it accurately. This, in part, might be facilitated by adults' reactions to children's problem-solving attempts. Adults often praise children for the attempt, telling them that they have performed better than they actually have. Related to this, children's goals in solving a problem might not be identical to that of an adult, and they might not have the metacognitive ability to evaluate how successfully they achieved their goal, tending to overestimate their performance (Bjorklund, 1997a).
3. Planning is often viewed as difficult, time-consuming, and subjectively unpleasant. This is true not only for children but also for adults. Planning is a special type of strategy (or meta-strategy), and strategies are used when people cannot solve a problem using less effortful procedures. If you have reason to believe that the solution to a problem will "just come to you" as you fiddle with the components (such as putting your new barbecue grill together without reading the instructions), then why spend the time planning? A plan (as many strategies) should be used only when solving the problem can't be done without one.
4. When children do generate a plan, they are not always successful. Why spend the time and effort when the outcome is uncertain?
5. It might be more fun to "wing it." Problem solving can present novel activities for children, and the implementation of a plan might make the process less enjoyable.

Such a description makes it seem as if young children approach problems in a willy-nilly fashion, and if they're lucky, eventually bump into the right solution. There is a bit of trial-and-error learning in most problem solving, but rarely are children's approaches to a problem totally random. They tend to select problem-solving strategies that are appropriate (if not always optimal) for the task at hand, and often modify their strategies as they progress through the problem (Siegler, 1996). However, young children rarely demonstrate the forward-looking approach that older children and adults often do when solving a complicated problem.

Preschool children do show signs of some planning in some situations, of course. For example, several studies have asked preschoolers to "plan" a trip to a grocery store (Gauvain & Rogoff, 1989; Hudson, Shapiro, & Sosa, 1995). In one study, children were asked to get several items from a model grocery store (Gauvain & Rogoff, 1989). Most 5-year-olds did an efficient item-by-item search, but older children were more likely to display signs of explicit planning by looking through the entire store and then searching for specific objects based on where they believed they would be located. The result was a more effective search. In other research, Judith Hudson and her colleagues (1995) asked 3-, 4-, and 5-year-olds to plan a trip to a grocery store (or to the beach). Children were also told of potential mishaps that could occur (you forgot to bring your shopping list) and asked how they might remedy or prevent the situation. They reported that recognizable plans were relatively rare for the 3- and 4-year-olds, but quite common for the 5-year-old children. Age differences were also found both in children's responses to remedy and prevent a mishap. Children of all ages were able to suggest some remedy to a potential problem (although the number of plans to remedy mishaps did increase with age), but very few 3- and 4-year-old children suggested plans to prevent a mishap. Only the 5-year-old children made a substantial number of prevention plans.

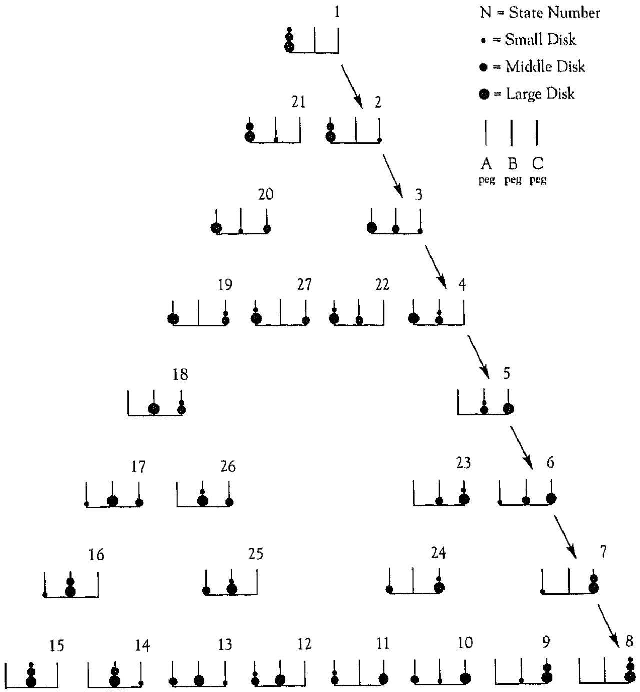

FIGURE 10-4 Possible legal moves on a three-disk Tower of Hanoi problem. The most efficient solution path is shown by the arrows on the far right. SOURCE: Fireman, G. (1996). Developing a plan for solving a problem: A representational shift. *Cognitive Development, 11,* 107–122.

In other research, 4- and 5-year-old children were asked to plan a route through a large space to retrieve a set of objects as quickly as possible (Fabricius, 1988). Children were familiarized with the space and then asked to retrieve the objects "the quick way." Fabricius concluded that the 5-year-old children engaged in *forward search*, in which a person envisions a series of moves that will achieve a partial solution. In other words, 5-year-olds had a plan that permitted them to foresee the consequences of their moves and thus made relatively few "backtracking" moves during their search. The 4-year-olds were less apt to do this, and when they did engage in forward search, they did so inconsistently.

One example of a problem where planning is important is the Tower of Hanoi problem. The three-disk version of this problem is illustrated in Figure 10-4. Children are shown a structure with three pegs, with three different sized disks on one peg (the one to the far left, for instance). The task is to get all the disks to the peg on the opposite side by moving only one peg at a time and obeying the rule that a larger peg cannot be placed on a smaller peg. This task can be solved in seven moves, which are indicated by the arrows in Figure 10-4. It would seem that planning is important in solving this problem. Having an idea in mind ahead of time (or figuring one out soon after the task begins) would seem to be associated with the likelihood of finding the right solution quickly.

Several researchers have emphasized that the first move children make on the Tower of Hanoi task is important and reflects and influences their planning on the task (Klahr & Robinson, 1981). However, a study by Gary Fireman (1996) with first- and second-grade children on the three-disk problem failed to find any relation between making the optimal first move (move number 2 in Figure 10-4) and later success on the problem. Children who never solved the problem were just as likely to make a correct first move as were children who eventually solved the problem within the 3-minute time limit. Does this mean that planning is actually *not* important in the Tower of Hanoi problem? Not at all. This is a difficult task for children of this age, and most of the planning on this task seems to come after a few moves are made as children become familiar with the problem and the range of strategies they have available to them to solve the problem. Before planning could occur, children needed to learn, in a hands-on way, the constraints associated with the problem. According to Fireman (1996), at the start of the task "children were not concerned with the strategy of reducing the problem depth or attaining a subgoal. Instead, children's initial actions explored the range of legal and illegal moves. Apparently, the children had to experience the instructions in action, despite their initial, spontaneous declaration that they understood the goal of the problem" (p. 120). Planning for these children came only after getting acquainted with the problem.

Rudiments of planning may be found in early childhood, but even older children and adults are often reluctant to engage in planning (Chalmers & Lawrence, 1993). In general, planning is a late developing ability and many of us, adults as well as children, approach many problems with as little planning as possible.

Reasoning

Reasoning is a special type of problem solving. Reasoning usually requires that one make an *inference*. That is, to reason, one must go beyond the information given. It is not enough to figure out the rules associated with some game. That's problem solving, but not necessarily reasoning. In reasoning, one must take the evidence presented and arrive at a new conclusion based on that evidence. The result is often new knowledge (DeLoache et al., 1998).

We use some forms of reasoning in our everyday lives, and we are so accustomed to thinking this way that we are often unaware of it. Other types of reasoning are highly formalized (in fact, termed formal reasoning), which most of us do not engage in regularly, and when we do we are certainly conscious of it. In the following sections, I will discuss three types of reasoning: analogical reasoning, formal reasoning, and scientific reasoning, and conclude with a discussion of the relation between reasoning and memory.

Analogical Reasoning

Perhaps the type of reasoning that most people are familiar with is **analogical reasoning.** Analogical reasoning involves using something you already know to help you understand something you don't know yet. Analogical reasoning involves **relational mapping**—the application of what one knows about one set of elements (the relation of A to B) to relations about different elements (the relation of C to D). Classic analogical reasoning problems are stated A:B :: C: ? For example, *dog* is to *puppy* as *cat* is to ?. The answer here, of course, is *kitten*. By knowing the relation between the first two elements in the problem (a *puppy* is a baby *dog*), one can use that knowledge to complete the analogy for a new item (*cat*). Analogies are thus based on *similarity relations*. One must understand the similarity between dogs and cats and puppies and kittens if one is to solve the above analogy.

How basic is analogical reasoning to cognitive development? Is it an early or late developing ability? How well adults are able to solve analogies is related to general intelligence as measured by IQ tests (Sternberg, 1985), and one advantage gifted children have over nongifted children is in their ability to solve analogies (Muir-Broaddus, 1995). Individual differences in analogical reasoning are found over the life span and are predictive of intelligence. This suggests that it is a complex skill that is influenced by a variety of other cognitive abilities and does not peak early in life. According to Piagetian theory (Inhelder & Piaget, 1958), analogical reasoning is a sophisticated ability that is not seen until adolescence. Others, however, have proposed that analogical thinking serves as the basis for other reasoning and problem-solving tasks (Halford, 1993), and might be present at birth (Goswami, 1996).

How can there be such divergence of opinion about when analogical reasoning is first seen in development? Part of the problem lies in the nature of the problems children are asked to solve. In cases when successful problem solving is not seen until late childhood or adolescence, the problems often involve objects or concepts with which children are unfamiliar. Perhaps more than any other factor, knowledge for the objects and relations among objects in analogical reasoning problems is paramount in determining whether a child will solve or fail to solve a problem. Other factors also contribute to a child's success on analogical-reasoning problems, including memory for the premises, availability of mental resources, representation of the relations, and metacognitive knowledge (see DeLoache et al., 1998; Gentner, 1989). In the following section, I will review children's ability to solve analogical-reasoning problems and look at some of the factors that contribute to this developmental progression.

Analogical Reasoning in Young Children

Counter to the traditional Piagetian account of analogical reasoning, several theorists have proposed that very young children are capable of such reasoning, and in fact use analogical reasoning to solve a host of problems (Goswami, 1996; Halford, 1993). Children can use what they know about solving one problem to solve a related problem. One would expect this ability to increase with age, as knowledge, mental capacity, memory, and other factors increase with age, but there is no a priori reason that this ability should not be present in infancy. In fact, Usha Goswami (1996) has proposed the **relational primacy hypothesis,** proposing that analogical reasoning is available early in infancy.

In one of the few experiments to assess analogical reasoning in infants, Chen, Sanchez, and Campbell (1997) tested 1-year-old infants (Experiment 1). The basic task involved placing a desirable toy out of reach of the infant, with a barrier between the baby and the toy. Two strings, one attached to the toy and one not, were also out of the infant's reach, but each string was on a cloth that *was* within reach. To get the toy, the infants had to pull the cloth toward them and then pull the string attached to the toy. (This is similar to the task described earlier by Willatts, [1990]). There were three similar tasks, although the toy, the barrier, and the color of the cloth varied among the three tasks. These are illustrated in Figure 10-5. If infants did not solve the problem after 100 seconds, their parents modeled the correct solution for them. The primary research question concerned whether, after solving an initial problem, either with or without parental modeling, would the infants see the similarity with the later problems and be more apt to solve them? That is, would infants use analogical reasoning to solve the subsequent problems?

Few children solved the first problem spontaneously (most required help from a parent). However, the percentage of infants solving the problems increased from 29% for the first problem, to 43% for the second, and 67% for the third (Experiment 1). Infants' problem solving was also rated for "efficiency," with higher scores reflecting a greater goal-directed approach, as opposed to a trial-and-error approach to the problem. As can be seen in Figure 10-6, efficiency increased steadily over the three problems.

The research by Chen and her colleagues (1997) reveals that 1-year-olds are able to use the similarity between tasks analogically to solve problems. However, this is very different from the classic problems used in research. The first study to demonstrate analogical reasoning in young children using a more traditional task was performed by Holyoak, Junn, and Billman (1984). In their study, preschool and kindergarten children had to move some gumballs in

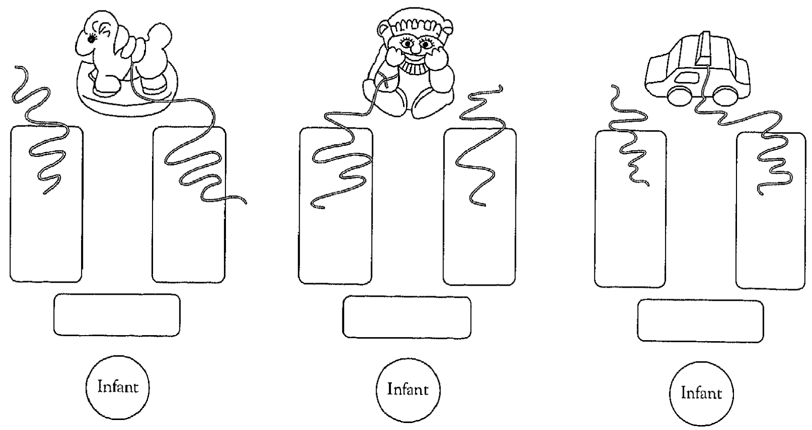

FIGURE 10-5 The configuration of the three problems 1-year-old infants solved. SOURCE: Chen, Z., Sanchez, R. P., & Campbell, T. (1997). From beyond to within their grasp: The rudiments of analogical problem solving in 10- and 13-month-olds. *Developmental Psychology, 33*, 790–801. Copyright © 1997 by the American Psychological Association. Reprinted with permission.

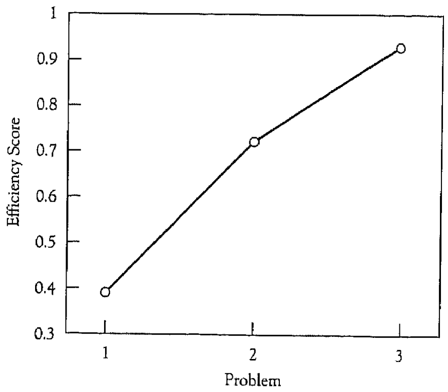

FIGURE 10-6 Infants' problem-solving efficiency scores. SOURCE: Chen, Z., Sanchez, R. P., & Campbell, T. (1997). From beyond to within their grasp: The rudiments of analogical problem solving in 10- and 13-month-olds. *Developmental Psychology, 33*, 790–801. Copyright © 1997 by the American Psychological Association. Reprinted with permission.

one bowl on a table to another, out-of-reach bowl, without leaving their chair. They had various objects available to them that they could use to solve the problem, including scissors, an aluminum cane, tape, string, and a sheet of paper. Before solving the problem, children heard a story about a genie who had a similar problem. The genie's problem was to move some jewels from one bottle within his reach to another bottle, out of his reach. One way in which he solved this problem was to roll his magic carpet into a tube and pass the jewels down the tube into the second bottle. Another solution that other children heard was to use his magic staff to pull the second bottle closer to him. After hearing the stories, children were told to think of as many ways that they could to solve *their* problem—to get the gumballs from one bowl to another. About half of the preschool and kindergarten children solved the "magic staff" problem, and the remainder did so after a hint. That is, these 4.5- to 6-year-old children were able to reason by analogy. However, they were less successful with the "magic carpet" analogy, suggesting that young children's performance on analogical reasoning tasks is highly dependent on the similarity between objects. The "magic staff" and the aluminum cane were more perceptually similar to one another, Holyoak and his colleagues argued, than were the "magic carpet" and the sheet of paper, making the former analogy easier to use for these young children than the latter. But the basic finding that preschool children could use the similarity in one story to solve a similar (analogous) problem, suggests that such reasoning is well within the capability of these children, counter to the traditional Piagetian position.

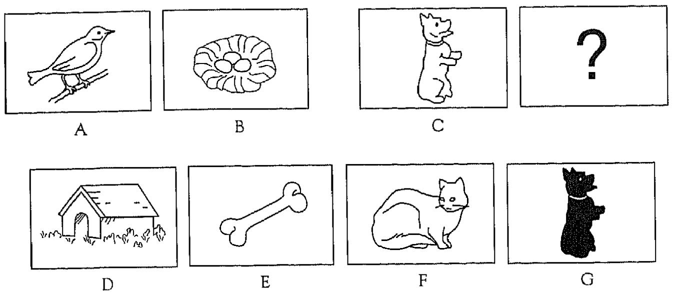

FIGURE 10-7 Example of problem used in Goswami & Brown. Children must select from set of pictures in bottom row (pictures D through G) the one that best completes the visual analogy on the top row. (The correct answer is D). SOURCE: Goswami, U., & Brown, A. L. (1990). Higher-order structure and relational reasoning: Contrasting analogical and thematic relations. *Cognition 36*, 207–226. Reprinted with permission of Elsevier Science.

Not all similarity is perceptual, however. Sometimes the similarity between objects is *relational*. This is illustrated in a study by Goswami and Brown (1990), who showed 4-, 5-, and 9-year-old children sets of pictures of the A:B :: C: ? type. Children were given four alternatives and had to choose which of the four best completed the analogy. An example of a problem used in this study is shown in Figure 10-7. In this problem, children must discover the relation between bird and nest (a bird lives in a nest) and find the proper match for dog (here, dog house). Chance performance on this task would be 25%, and children of all ages performed greater than expected by chance (59%, 66%, and 94% correct for the 4-, 5-, and 9-year-olds, respectively). Note that children are not solving the problem based on *perceptual similarity*. The bird and dog look nothing alike, nor do the nest and the dog house. To solve this problem, they must do so on the basis of *relational similarity*—the relation between the A and B terms (bird and nest) is used to find the best match for the C term (dog). This is clearly a more advanced form of analogical reason than that demonstrated by the 1-year-old infants in the Chen et al. (1997) study.

However, children might have not been using analogical reasoning to solve this problem. Maybe they were simply selecting the item that "went best with" the dog. This apparently was not the case, however. Children in a control group were asked exactly this question: pick the one that "goes best" with the C term (in this case, dog). When asked to do this, children were no more likely to select the analogical choice (here, dog house) as they were a high associate (here, bone). Thus, children's performance on the analogical-reasoning task cannot be attributed to responding on the basis of strictly associative or thematic relations, but rather reflects the use of true analogical reasoning.

The fact that at least some young children were solving these problems using true analogical reasoning was reflected by the type of errors they made. For example, Goswami (1996) reports a 4-year-old child, Lucas, who, after seeing the *bird* : *nest* :: *dog* : ? problem, figured out what the answer should be without seeing the alternatives. However, what he figured was wrong. "Lucas first told us that the correct solution was *puppy*. He argued, quite logically, 'Bird lays eggs in her nest . . . dog—dogs lay babies, and the babies are—umm—and the name of the babies is puppy'" (p. 102). Lucas quickly changed his mind when he saw that a puppy was not among the alternatives, rethought the problem and identified the "lives in" relation. However, his first idea was also relational. He had simply identified a type of relation (*type of offspring*) different than that identified by the experimenters. Successful analogical reasoning requires identifying the "right" relation, but there can be many different relations existing between sets of items, and, outside of the laboratory or classroom, there might not be clear-cut "right" and "wrong" answers.

Factors Affecting Children's Analogical Reasoning

According to Goswami's (1996) analogical primacy view, the ability to reason by analogy is present in infancy. Even if we accept such a position, however, many factors influence children's success on any given analogical-reasoning task. For example, Graeme Halford (1993) has proposed that analogical reasoning develops in a stage-like fashion reminiscent of Piaget, based on the availability of mental resources. A child's ability to symbolically represent concepts and relations will also affect whether and how a child will use analogical reasoning (see DeLoache et al., 1998).

Analogical reasoning and relational shift. Related to how a child represents a problem are the types of relations children identify and base their reasoning on. For example, although the research of Goswami and Brown (1990) indicates that young children *can* use analogies based on relational similarity, it does not mean that they do so easily, especially when they can form analogies based on perceptual similarity. Dedre Gentner (1989) has argued that a **relational shift** occurs in the development of analogical reasoning, in which young children are more likely to focus on perceptual similarity, whereas older children and adults focus more on relational similarity in solving problems. (Compare this with the "shift" between perceptual and conceptual basis of classification discussed in Chapter 7.) For example, infants and young children are more influenced by the surface similarity of objects, such as an object's shape. Older children, on the other hand, are more tuned to the underlying relation between sets of objects. For example, the better performance of the preschool children in the Holyoak (1984) study for the "magic staff" than the "magic carpet" analogy was attributed to the greater perceptual similarity between the magic staff and the aluminum cane available to solve the "gumball" problem, than between the magic carpet and the sheet of paper (for other examples, see Daehler & Chen, 1993; Pierce & Gholson, 1994). When there is a conflict between object similarity and relational similarity, young children's ability to use relational similarity is hindered (see Goswami, 1996).

Knowledge. One factor that affects whether children will use relational similarity to solve an analogical-reasoning problem is knowledge, or familiarity. How familiar are children with the underlying relations used to make the analogy? Remember, the function of analogical reasoning is to use something you know to help you understand something you don't know. From this perspective, analogical reasoning can only make sense if a child is familiar with the base relation. You might get a better understanding of the human nervous system, for example, if you see it as analogous to electrical circuits. But if you know nothing about electrical circuits, it won't help you understand the nervous system at all, no matter how well developed your analogical reasoning abilities are. I think it is fair to say that all major theorists acknowledge the importance of knowledge and familiarity on the development of analogical reasoning, although they might disagree on the exact role that knowledge plays in such development (see DeLoache et al., 1998; Goswami, 1996).

The role of familiarity is illustrated in a study by Goswami (1995) that used a familiar children's story, *Goldilocks and the Three Bears*, as the basis for analogical reasoning. Goswami (1995) used the familiar story of the three bears ("The Daddy Bear has all the big things, the Mummy Bear has all the medium-sized things, and the Baby Bear has all the tiny things") to help children make *transitive mappings*. A transitive relation involves at least three objects, such as the length of objects. If object A is longer than object B, and object B is longer than object C, then object A must be longer than object C (that is, A → B → C). Can young children use the transitive relation on one dimension as a basis for mapping transitive relations on another dimension? Or, stated somewhat differently, can children map the transitive relation from one dimension (the Daddy, Mummy, and Baby bear) to another (size, for instance)?

In Goswami's (1995) study, 3- and 4-year-old children were asked to use the relation in the Goldilocks story (Daddy Bear → Mummy Bear → Baby Bear) to classify objects that differed in quantity (a lot versus a medium amount versus a little pizza, candy, or lemonade), or to rank order (three levels) certain phenomena on the basis of loudness (footsteps), pitch (of voices), temperature (of porridge), saltiness (of porridge), width (of beds), or height (of mirrors). Four-year-olds generally performed well on all these tasks, using the Three Bears analogy to map onto other dimensions. Three-year-olds did less well, although they performed above chance levels on most tasks, indicating that they, too, could use the familiar (perhaps less familiar to them than to the 4-year-olds) story as a basis for making analogical relations.

Metacognition. To what extent is explicit awareness of the relations between entities on analogical reasoning tasks important in solving problems? Can children think analogically but be unable to articulate what they are doing? Might such knowledge be *implicit*, and unavailable to consciousness? It certainly appears that the knowledge that the infants in the Chen et al. (1997) study had was implicit. These preverbal children's metacognitive understanding of the problem and their solutions to them was likely nonexistent. How important is metacognitive knowledge for analogical reasoning during childhood?

That analogical relations can be explicit to young children was illustrated by the example of 4-year-old Lucas discussed earlier, who generated an analogical relation (albeit an incorrect one) for the bird:nest :: dog: ? problem before seeing the alternatives. Successful training of analogical reasoning is often best accomplished when children receive explicit instruction about the rationale behind the training (Brown & Kane, 1988; Chen & Daehler, 1993), much as has been found in the training of memory strategies (see Chapter 8). This suggests, not at all surprisingly, that knowing what one is doing (that is, having metacognitive knowledge) facilitates analogical reasoning.

One set of studies relevant to metacognitive knowledge was done by Brown, Kane, and their colleagues (Brown & Kane, 1988; Brown, Kane, & Long, 1989), who assessed children's **learning to learn** on a series of analogical reasoning tasks. Learning to learn refers to improvements in performance on new tasks as a result of performance on earlier tasks, during which time children learn a general rule or approach to problems. That is, participants learn a general set of rules that they can apply to new tasks, so that performance on later tasks is enhanced relative to performance on earlier tasks.

In Brown and Kane's studies, preschool children were given a series of problems similar to the "magic carpet" story used by Holyoak and his colleagues (1984). For example, some children were first given the genie problem. If they did not solve it, they were told about how rolling the "carpet" could be used to transport the jewels. They were then given a similar problem (the Easter Bunny needing to transport eggs by using a rolled up blanket), and then a third (a farmer transporting cherries using a rolled-up rug). Children receiving this series of problems, and who were given the solution to a problem when they failed, showed a large learning-to-learn effect. For the "rolling" solution, 46% of the children used analogical reasoning to solve the second problem, and 98% of the children did so for the third task.

This compares with a control group, who received the three sets of "rolling" problems but who did not receive the hints. They showed only 20% transfer after the first problem and 39% after the second.

Does a learning-to-learn effect have to involve metacognition? Not necessarily. But some of the children's comments suggested that their improved performance on the later problems was the result of their awareness of analogical reasoning strategies. For example, one 4-year-old child in the Brown and Kane (1988) study, after solving two "rolling" problems, commented at the beginning of the third problem: "And all you need to do is get this thing rolled up? I betcha!" (p. 517). Brown and Kane (1988) commented that children had developed a mind-set to look for analogies, expecting to extract some general rule to solve problems and to be able to use knowledge they acquired in one context elsewhere.

Formal Reasoning

To this point, we have examined children's informal reasoning, or the type of reasoning children might use in their everyday lives (even if the problems are invented by a psychologist). Informal reasoning is contrasted with formal reasoning. According to DeLoache, Miller, and Pierroutsakos (1998), "In **formal reasoning,** the *form* of an argument, not its semantic content, is crucial. Logical, not empirical, truth matter: The internal consistency of a set of premises and the conclusion drawn from them is all that counts, not whether or how they map onto the real world" (p. 804). Why should such decontextualized reasoning be of interest to developmental psychologists, who are ostensibly concerned about children's intellectual development in the real world? The answer is that formal-reasoning ability has long been viewed as a hallmark of adult, and especially scientific, thinking. This is seen clearly in Piaget's account of adolescent thinking (Inhelder & Piaget, 1958). It is no accident that Piaget called this final stage of cognitive development formal operations (see Moshman, 1998).

Piaget proposed that not until 11 or 12 years of age is formal reasoning first seen and that the thinking of adults (and older adolescents) corresponds to a certain type of logical operation—specifically, **propositional logic.** Propositional logic is a form of symbolic logic that involves two or more factors (conventionally, P and Q), with each factor having two possible values (for instance, true or false). Take, for example, two coins, a penny and a dime. Each coin has two and only two possible values, heads and tails. In flipping these coins we have four possible combinations: both the penny and the dime are heads (P and Q); the penny is heads and the dime is tails (P and not Q); the penny is tails and the dime is heads (not P and Q); and both the penny and the dime are tails (not P and not Q).

These four alternatives can themselves be combined, resulting in 16 outcomes that are referred to as the 16 binary operations.[1] Piaget proposed that these 16 binary operations correspond to mental operations characteristic of formal operational thought. One of these operations, implication, is found frequently in human discourse and is expressed as "P implies Q." This means that Q is true if P is true, or P implies Q "if and only if no interpretation makes [P] true and [Q] false" (Quine, 1972, p. 40). In everyday language, implication is expressed in "if . . . then" statements. Tests of implication usually take the following form:

1. If there is a P, then there is a Q.
2. There is a P.
3. There is a Q.

Subjects are to determine the validity of the third statement, which in this example is true. Conversely, there is the invalid form of implication, and tests of this are usually expressed as follows:

1. If there is a P, then there is a Q.
2. There is no P.
3. There is no Q.

In this case, the third statement is not necessarily true, for although P implies Q, the initial premise does not require that "not P implies not Q." For example, "If John passes calculus, then he will take his girlfriend out to dinner." Given this statement, the girlfriend can expect dinner if John passes calculus. Should John fail, however, dinner is not necessarily out of the question.

Based on observations from a variety of experimental tasks and the verbal reports of their participants, Inhelder and Piaget concluded that concrete operational children are unable to use the 16 binary operations to solve problems, whereas formal operational thinkers can use each of the 16 operations as the tasks demand.

A substantial amount of research has generally supported Piaget's view that formal, logical reasoning is not observed for most preadolescent children (Markovits & Vachon, 1989; Overton et al., 1987). But what about adults? Do *we* really think this way? Apparently not, at least not most of the time. For example, Paris (1973) assessed the ability of children and adults to comprehend statements of propositional logic, including "if . . . then" implication statements. Paris reported that even 7-year-olds could answer correctly valid implications, for instance, "If there is a P, then there is a Q. There is a P. There is a Q" (true or false?). However, both 7-year-olds and adults performed poorly on the invalid implications, for example, "If there is a P, then there is a Q. There is no P. There is no Q" (true or false?). That is, not only can concrete operational children not solve invalid forms of implication, but neither can college students. Rather, like children, adults tend to interpret the reasonableness of the problem ("John didn't say anything about taking his girlfriend out to dinner if he fails.)

Yet, as Paris (1973) demonstrated, even young children can reason logically for some problems in some situations. An interesting example of this is provided in a study by Hawkins, Pea, Glick, and Scribner (1984), who presented verbal syllogisms to 4- and 5-year-old children. Syllogisms are problems that require deductive reasoning (a characteristic of formal reasoning) and are of the form:

1. Socrates was a man.
2. All men are mortal.
3. Socrates was mortal.

On such problems, participants are to discern the truth of the third statement given the first two. Note that the truth value of the third statement is based solely on the content of the first two, not on the basis of what one knows to be true of the real world. Piaget proposed that to solve syllogisms, the conclusions drawn from the premises "must be held to be true only by reason of the premises and quite independently of the empirical truth of these premises" (Piaget, 1969b, p. 32). Hawkins and his colleagues presented preschool children with syllogisms of three types: (1) *fantasy*, involving imaginary characters of which the children had no knowledge (for example, "Every banga is purple"); (2) *congruent*, in which the premises were consistent with children's world knowledge (for example, "Bears have big teeth"); and (3) *incongruent*, in which the premises were in contradiction to the children's knowledge (for example, "Glasses bounce when they fall"). Here are examples of a fantasy, congruent, and incongruent syllogism:

Fantasy Syllogism
Every banga is purple.
Purple animals sneeze at people.
Do bangas sneeze at people?

Congruent Syllogism
Bears have big teeth.
Animals with big teeth can't read books.
Can bears read books?

Incongruent Syllogism
Glasses bounce when they fall.
Everything that bounces is made of rubber.
Are glasses made of rubber?

The children were given eight problems of each type, with some children being presented the set of fantasy problems first and others being presented the fantasy problems second or third.

In keeping with Piaget's observations, children consistently failed the incongruent problems (13% correct). They were not able to ignore what they know about the world in answering these questions. In other words, they were not able to think "formally," using only the *form* of the problem to generate an answer. Children's performance was excellent, however, for the congruent problems (94%). But such performance does not require any reasoning at all. Children could have used their world knowledge to answer the question ("Do bears read books? Of course not!"). In fact, when children's justifications of their answers to the congruent problems were examined, most of them (81%) were described as *empirical*, with reference being made to their practical world knowledge. Very few of their justifications were classified as *theoretical* (10%), in which reference was made only to the information presented in the problem.

But what about the fantasy questions? Here, performance is independent of children's past knowledge. They posed questions about hypothetical characters, requiring, it would seem, formal reasoning. Children's performance on the fantasy problems was very high, particularly when these problems were presented first (94% correct). The percentage of correct answers was lower on these problems when the congruent or incongruent problems preceded them (66% correct). Furthermore, children's justifications on the fantasy problems were likely to be classified as theoretical when the fantasy problems were presented first (58%), although nontheoretical explanations predominated when the fantasy problems were presented later in the session (92% nontheoretical explanations).

One interpretation of these findings is that 4- and 5-year-old children possess rudiments for formal reasoning. However, this study also reveals the tenuous nature of such reasoning in young children. They consistently failed the incongruous problems. When their real-world knowledge conflicted with the *form* of the problem, they almost always went with what they know (generally not a bad strategy to follow). Yet when imaginary characters were used, young children's responses and their justifications were indicative of formal reasoning (see also Markovits & Vachon, 1989). Nevertheless, children were easily biased away from such deductions when the fantasy problems were preceded by the congruent or incongruent problems. Obviously, formal reasoning is not well-established in young children and is displayed only under optimal conditions (compare with Fischer's skill theory, discussed in Chapter 4).

Scientific Reasoning

Not all logical reasoning is decontextualized. Logic comes in handy frequently in everyday life, especially if you happen to make your living being a scientist. I discussed scientific reasoning briefly in Piaget's model of formal operations (Chapter 4). **Scientific reasoning** involves generating hypotheses about how something in the world works and then systematically testing those hypotheses. Basically, one uses scientific reasoning by identifying the factors that can affect a particular phenomenon (the rate at which a pendulum oscillates, as in the example provided in the Piaget chapter, for instance), and exhaustively varying one factor at a time while holding the other factors constant. As you will recall, Piaget proposed that scientific reasoning is not found until adolescence (Inhelder & Piaget, 1958). Subsequent research has not always supported Piaget's theories, but it is generally agreed that scientific reasoning is a late-developing ability that is not easily demonstrated by many adults (Kuhn, Amsel, & O'Loughlin, 1988). (Recall, however, that "theory theory" accounts of development propose that something akin to theory testing, and thus scientific reasoning, characterizes even infants and young children [Gopnik & Meltzoff, 1997].)

Let me provide an example from research by Kuhn and her colleagues. Deanna Kuhn and her colleagues (1988) presented hypothetical information about the relation between certain foods and the likelihood of catching colds to sixth- and ninth-grade students and to adults of varying educational backgrounds. Participants were first interviewed to determine which foods they thought might be associated with colds. Then, over several trials, they were given a series of foods (for example, oranges, baked potatoes, cereal, Coca-Cola), each associated with an outcome (cold or no cold). Some foods were always associated with getting a cold (baked potatoes, for instance), some were always associated with not getting colds (cereal, for instance), and others were independent of getting colds (that is, sometimes they were associated with getting colds, and sometimes not). At least one outcome was consistent with a participant's initial opinion about the "healthiness" of a food, and one inconsistent with it.

Scientific reasoning involves hypotheses, but what is most crucial about the scientific method is that it involves *evidence*. Maybe you have grown up believing that eating chicken soup will make you healthy, but science requires that *evidence*, when available, be used to provide an answer. Initial responses on these questions were usually based on prior beliefs, but as more evidence accumulated, most adults increased their decisions based on that evidence. The adolescents, however, were much less apt to consider evidence in their decisions, but instead relied more frequently on extra-experimental beliefs (for example, "The juice makes a difference because my mother says orange juice is better for you"). In fact, 30% of the sixth graders never made a single spontaneous evidenced-based response. Yet, when asked how they knew one food did or didn't have an effect, most participants of all ages were able to provide an evidenced-based answer, although children were still less likely to do so than adults. This indicates that reasoning from evidence is something that sixth graders can do, but that they choose not to do spontaneously. It's also worth noting that the adults did not fare perfectly on these problems either. Only the most highly educated adults (philosophy graduate students) consistently solved these problems using the evidence that was presented.

Scientific reasoning can improve with practice. Several researchers have given participants of varying ages sets of scientific problems to solve over repeated testing sessions (Kuhn et al., 1995; Schauble, 1996). In these studies, participants' performance improved over sessions and generalized to different scientific problems (for example, from determining what factors affect the speed of a car to determine what factors influence school achievement). However, although participants of all ages showed improvements over sessions, preadolescent children showed fewer gains than adults. Elementary school children can be trained to use scientific reasoning with explicit instruction, but transfer of such trained strategies is limited to older preadolescent children only (Chen & Klahr, in press).

Why do children, adolescents, and many adults perform so poorly on scientific reasoning problems? Kuhn and her colleagues (1988) argued that scientific reasoning involves thinking *about* theories rather than just working with them. In other words, scientific reasoning requires a high level of metacognition. Scientific reasoning requires integrating theories (or hypotheses) with data (or evidence). When the two agree, there is little problem. Problems occur when hypotheses and evidence are in conflict. Kuhn (1989) has speculated that children (and many adults) take one of two extreme approaches to theory-data conflicts: *Theory-bound children* distort the data to fit the theory, whereas *data-bound children* focus not on the global theory to explain their results but, rather, on isolated patterns of results (to avoid conflict with the theory).

Although poor metacognition might be the overarching reason for peoples' difficulties with scientific reasoning, it is not the only one. Children and adolescents often do not conduct effective experiments; they frequently fail to vary one factor systematically, or they come to a decision before all possible factors have been tested. Children, and to a lesser extent adults, have a positive-results bias. They put more weight on results that produce good outcomes (for example, good academic performance, good health) than on results that yield negative outcomes (see DeLoache et al., 1998). Adolescents' preexisting beliefs also strongly influence their scientific reasoning. Outcomes that are consistent with their prior beliefs are quickly and uncritically accepted, whereas evidence counter to their beliefs are regarded more critically (Klaczynski, 1997; Klaczynski & Narasimham, 1998).

In general, the "big" picture of scientific reasoning painted by Inhelder and Piaget (1958) more than 40 years ago has not been drastically changed. Scientific reasoning is rarely found in children. What the new research indicates, however, is that scientific reasoning is only occasionally found in adolescents and adults without specific training. Given these findings, it makes good sense for university-level psychology students to have a course in research methods, where the logic of experimental design is made explicit. College students are clearly capable of such thinking, but we should not be surprised that it does not come spontaneously or easily to them.

Reasoning-Remembering Relationships

Most reasoning tasks are examples of "higher-order" cognition, in that they involve more than the basic-level processes of encoding, categorizing, and short-term memory. Yet, these basic-level processes clearly influence a child's ability to perform reasoning problems. That is, like other forms of complex thinking, reasoning is supported by a host of lower-level forms of cognition.

One basic-level process that has been proposed to be involved in most, if not all forms of reasoning is memory. Children need to remember the premises of a problem to solve it. One popular explanation for young children's poor reasoning abilities is that they forget the premises on which their reasoning is based. This has been illustrated for *transitive-inference* problems. Transitive inference is the process of inferring the relation between two concepts or objects from a knowledge of their relation to other concepts or objects. For instance, in a series of sticks arranged in increasing length (for example, A, B, C, D, and E), there is an implicit knowledge that any given stick is both larger than the one immediately preceding it (for example, C → B) and smaller than the one immediately following it (for example, C ← D). However, children do not necessarily know the relation between two items that have not been specifically compared. For example, if D is longer than C, and C is longer than B, what is the relation between B and D? Although it is obvious to adults, it is not always apparent to children.

Tom Trabasso and his colleagues argued that it is not young children's lack of reasoning ability, per se that prevents them from solving transitive inference problems but, rather, their poor memories. They forget the premises (C → B; C ← D; and so on.), making it difficult if not impossible for them to come up with the right answer. To support their position, Bryant and Trabasso (1971) showed that young children can solve transitive-inference problems when given extensive training on all the premises. Sticks of different colors were used, and children were presented with successive pairs of sticks and asked to judge which was the longer (for example, A or B; B or C; C or D; D or E). The children were later tested for their retention of the premises (for example, their memory that the red stick A was longer than the yellow stick B). The children were then asked to make judgments concerning pairs of sticks that had not been presented together before (in our example, they might be asked which is longer: the yellow stick B or the blue stick D). Counter to the findings of Piaget and others, children as young as 4 years in these experiments were able to answer the critical transitive-inference question correctly, indicating that young children have the competence to solve such problems but that limitations of memory prevent them from displaying this competence under some circumstances.

Such results seem clear-cut and appear to reflect a significant relationship between reasoning and remembering. However, research by Brainerd and Kingma (1984) demonstrated that the relationship is more apparent than real. They modified the standard transitive-inference paradigm, inserting occasional memory probes for adjacent relations (for example, "Which is longer, A or B?"). In a series of experiments, they found that memory for the premises was independent of reasoning performance. In other words, one was not able to predict reasoning performance based on memory for the premises.

Reyna and Brainerd have investigated more thoroughly the relation between reasoning and memory and have interpreted these relations in terms of **fuzzy-trace theory** (Reyna, 1992; Reyna & Brainerd, 1995; see Chapter 5). As you may recall from our earlier discussion of fuzzy-trace theory, people of all ages have a bias toward reasoning using the more readily available and inexact fuzzy (gist) traces. Thus, when a reasoning task can be accomplished with fuzzy traces, performance can progress without the child's remembering the specifics of the background information (that is, without using verbatim information). Verbatim information deteriorates more rapidly than gist information, so that it should not be surprising that children forget the details (that is, the specific premises) but still retain enough of the fuzzy traces from the representation to solve the problem. Younger children will fail the transitive-inference task (and others) not because they forget the premise, but because of faulty reasoning. In addition, young children's greater tendency to encode and reason with verbatim traces provides them with another handicap. Such traces are more prone to being forgotten and are more difficult (mentally effortful) to use in solving many reasoning

problems. Older children will solve the transitive-inference problem because of their efficient processing of fuzzy traces (that is, proper reasoning with gistlike traces), independent of whether they remember the verbatim information or not.

In other situations, fuzzy-trace theory predicts that there will be a significant relationship between memory for background facts and reasoning. For example, in mental arithmetic problems, correct answers can only be obtained by processing verbatim information. If children forget the premise (for example, 8 + 9 = ?), they cannot rely on fuzzy traces to arrive at the correct answer. In these cases, dependencies between memory and reasoning are indeed found (Brainerd & Reyna, 1988).

Although different reasoning requires different types of information, Reyna and Brainerd propose that most everyday reasoning involves primarily gist traces, often supported by verbatim sources, such as dictionaries, reference books, and lists (Reyna, 1992). For example, as I write this section, I rely on my gistlike understanding of fuzzy-trace theory, frequently checking one of Brainerd and Reyna's many papers on the topic to confirm my interpretation and to obtain the details of experiments. Thus, although I could not write this section on fuzzy-trace theory without substantial verbatim information, my decisions about how to organize the section, what, in general, to include, and what to emphasize are based on the gistlike traces I have established from reading papers on fuzzy-trace theory and discussions I've had with colleagues and students on the topic over the last several years.

Summary

Problem solving involves having a goal, obstacles to that goal, strategies for overcoming the obstacles, and an evaluation of the results. Infants have shown signs of true *goal-directed behavior* and problem solving in the latter part of the first year. Problem solving improves over the preschool years and is influenced by how much knowledge the problem solver has about the task to be solved or the context in which the task is embedded.

Some forms of problem solving involve the discovery or induction of rules. Rules for simple oddity problems can be learned by preverbal toddlers, especially when accompanied by language instructions. In the *rule-assessment approach*, cognitive development is characterized by the acquisition of increasingly powerful rules for solving problems. Although the rule-assessment approach describes reasonably well the development of many tasks (for example, balance-scale problem, conservation), children typically use a variety of strategies for any particular problem, as exemplified by Siegler's adaptive strategy-choice model. Zelazo and his colleagues have focused on children's developing ability to follow rules and report that young children often fail to use a rule even though they can demonstrate knowledge of the rule. This is especially apparent when the rules governing a task change (for example, from sorting cards by color to sorting cards by shape). *Cognitive complexity and control* (CCC) *theory* proposes that there are age-related changes in the complexity of rule systems that children can represent and that developmental differences in conscious awareness give children increased control over their behavior and cognition.

Planning is an important aspect of problem solving, but is a relatively late-developing phenomenon. Some reasons for young children's frequent failure to plan include poor inhibition abilities, a bias toward speed over accuracy, planning is difficult and time consuming and does not always improve task performance, and that it may be more fun to solve novel problems without planning. Planning improves over the preschool years, and most 5-year-olds display planning for simple tasks.

Reasoning is a special type of problem solving that requires that one make an inference. *Analogical reasoning* involves *relational mapping*—the application of what one knows about one set of elements to relations about different elements. The *relational primacy hypothesis* proposes that analogical reasoning is available early in infancy. Although there is some evidence for this, preschool children have difficulty with more traditional analogy problems, although they are able to solve them in some situations. Similarity (perceptual and relational) between different aspects of a problem plays an important role in solving analogies. There appears to be a *relational shift* in the development of analogical reasoning, in which young children are more likely to focus on perceptual similarity, whereas older children and adults focus more on relational similarity in solving problems. Other factors that influence children's success at analogical reasoning are knowledge for the relations on which the analogy is based, and metacognition, or a conscious awareness of the basis on which one is solving a problem.

In *formal reasoning* the *form* of an argument, not its semantic content, is crucial. Piaget proposed that formal reasoning is the hallmark of adult cognition and was reflected by adolescents' and adults' use of *propositional logic,* a form of symbolic logic that involves two or more factors (conventionally, P and Q), with each factor having two possible values (for instance, true or false). Counter to Piaget's theory, propositional logic is frequently not shown by adults. Other forms of formal reasoning, such as syllogisms, can be demonstrated by preschool children under certain situations when statements in a problem do not contradict their world knowledge.

Scientific reasoning involves generating hypotheses about how something in the world works and then systematically testing those hypotheses. Scientific reasoning is also a late-developing ability, in part because of the metacognitive difficulty involved in reasoning *about* theories.

Reasoning and memory for the premises of a problem have been proposed to be related. However, in many cases, depending on the nature of the problem, they are not. Reyna and Brainerd applied *fuzzy-trace theory* to reasoning-remembering relations to account for the inconsistent pattern found in the research literature.

Note

1. The sixteen binary operations of propositional logic following Inhelder and Piaget (1958) are: (1) Affirmation: All combinations are possible, for example, P and Q, P and not Q, not P and Q, and not P and not Q are all possible; (2) Negation: No combinations are possible; (3) Conjunction: P is true and Q is true; (4) Incompatibility: P is never true if Q is true, and vice versa; (5) Disjunction: P is true or Q is true (or both are true); (6) Conjunctive Negation: P is false and Q is false; (7) Implication: P implies Q; (8) Nonimplication: P does not imply Q; (9) Reciprocal Implication: Q implies P; (10) Negation of Reciprocal Implication: Q does not imply P; (11) Equivalence: The effect of P is equal to the effect of Q; (12) Reciprocal Equivalence: The effect of P is not equal to the effect of Q; (13) Affirmation of P: P is true independent of Q; (14) Negation of P: P is false independent of Q; (15) Affirmation of Q: Q is true independent of P; (16) Negation of Q: Q is false independent of P.

Key Terms and Concepts

problem solving
goal-directed behavior
cognitive complexity and control (CCC) theory
rule-assessment approach
reasoning
analogical reasoning
relational mapping
relational primacy hypothesis
relational shift
learning to learn
formal reasoning
propositional logic
scientific reasoning
fuzzy-trace theory

Suggested Readings

DeLoache, J. S., Miller, K. F., & Pierroutsakos, S. L. (1998). Reasoning and problem solving. In D. Kuhn & R. S. Siegler (Vol. Eds.), *Cognitive, language, and perceptual development,* Vol. 2 (pp. 801–850). In B. Damon (General Editor), *Handbook of child psychology.* New York: Wiley. This chapter presents an up-to-date, comprehensive review of the developmental literature of problem solving and reasoning, extending beyond the topics covered in this textbook.

Goswami, U. (1996). Analogical reasoning and cognitive development. In H. W. Reese (Ed.), *Advances in child development and behavior* (Vol. 26) (pp. 92–138). San Diego: Academic Press. This chapter provides an excellent review of research examining analogical reasoning in children. Much of the review focuses on Goswami's own research, which is substantial, influential, and interesting.

Zelazo, P. D., & Jacques, S. (1997). Children's rule use: Representation, reflection and cognitive control. *Annals of Child Development, 12* (pp. 119–176). London: Jessica Kingsley Press. This chapter provides a review of children's rule-following, beginning with classic Soviet work by Luria and his colleagues, and concluding with the contemporary research of Zelazo and his colleagues.

Kuhn, D., Amsel, E., & O'Loughlin, M. (1988). *The development of scientific thinking skills.* San Diego: Academic. This book provides an excellent overview of research on the development of scientific reasoning, as well as presenting the authors' own innovative work.

Reyna, V. F. (1992). Reasoning, remembering, and their relationship: Social, cognitive, and developmental issues (pp. 103–132). In M. L. Howe, C. J. Brainerd, & V. F. Reyna (Eds.), *Development of long-term retention.* New York: Springer-Verlag. This chapter provides a clear presentation of fuzzy-trace theory as it relates to reasoning-remembering relations.