Fischer & Daley, 2007; Morra et al., 2008). Neo-Piagetian theorists don't always agree about the exact nature of children's thinking at different age levels or about the exact mechanisms that promote cognitive development. Nevertheless, several ideas are central to their thinking:

- *Cognitive development is constrained by the maturation of information processing mechanisms in the brain.* Neo-Piagetian theorists have echoed Piaget's belief that cognitive development depends somewhat on brain maturation. Recall, for example, the concept of *working memory,* that limited-capacity component of the human memory system in which active, conscious mental processing occurs. Children certainly use their working memories more effectively as they get older, courtesy of such processes as myelination, chunking, maintenance rehearsal, and automaticity (see Chapters 2, 8, and 9). But the actual physical "space" of working memory may increase somewhat as well (see Chapter 8). Neo-Piagetian theorists propose that children's more limited working memory capacity at younger ages restricts their ability to acquire and use complex thinking and reasoning skills. Thus it probably places an upper limit on what children can accomplish at any particular age (Case & Mueller, 2001; Case & Okamoto, 1996; Fischer & Bidell, 1991; Morra et al., 2008).
- *Children acquire new knowledge through both unintentional and intentional learning processes.* Many contemporary psychologists agree that children learn some things with little or no conscious awareness or effort. For example, consider this question about household pets: "On average, which are larger, cats or dogs?" Even if you've never intentionally thought about this issue, you can easily answer "dogs" because of the many characteristics (including size) you've learned to associate with both species. Children unconsciously learn that many aspects of their world are characterized by consistent patterns and associations (see the discussion of concept learning in Chapter 10).

  Yet especially as children's brains mature in the first year or two of life, they increasingly think actively and consciously about their experiences, and they begin to devote considerable mental attention to constructing new understandings of the world and solving the little problems that come their way each day (Case & Okamoto, 1996; Morra et al., 2008; Pascual-Leone, 1970). As they do so, they draw on what they've learned (perhaps unconsciously) about common patterns in their environment, and they may simultaneously *strengthen* their knowledge of those patterns. Thus both the unintentional and intentional learning processes typically work hand in hand as children tackle day-to-day tasks and challenges and increasingly make sense of and adapt to their world (Case, 1985; Case & Okamoto, 1996).
- *Children acquire cognitive structures that affect their thinking in particular content domains.* As we've seen, children's ability to think logically depends on their specific knowledge, experiences, and instruction related to the task at hand, and so the sophistication of their reasoning may vary considerably from one situation to another. With this point in mind, neo-Piagetian theorists reject Piaget's notion that children develop increasingly integrated systems of mental processes (operations) that they can apply to a wide variety of tasks and content domains. Instead, neo-Piagetians suggest, children acquire more specific systems (**structures**) of concepts and thinking skills that influence thinking and reasoning capabilities relative to specific topics or content domains.
- *Development in specific content domains can sometimes be characterized as a series of stages.* Although neo-Piagetian theorists reject Piaget's notion that a single series of stages characterizes all of cognitive development, they speculate that cognitive development in specific content domains often has a stagelike nature (e.g., Case, 1985; Case & Okamoto, 1996; Fischer & Bidell,

1991; Fischer & Immordino-Yang, 2002; Morra et al., 2008). Children's entry into a particular stage is marked by the acquisition of new abilities, which children practice and gradually master over time. Eventually, they integrate these abilities into more complex structures that mark their entry into a subsequent stage. Thus, as is true in Piaget's theory, each stage constructively builds on the abilities acquired in any preceding stages.

Even in a particular subject area, however, cognitive development isn't necessarily a single series of stages through which children progress as if they were climbing rungs on a ladder. In some cases, development might be better characterized as progression along "multiple strands" of skills that occasionally interconnect, consolidate, or separate in a weblike fashion (Fischer & Daley, 2007; Fischer & Immordino-Yang, 2002; Fischer, Knight, & Van Parys, 1993). From this perspective, children may acquire more advanced levels of competence in a particular area through any one of several pathways. For instance, as they become increasingly proficient in reading, children may gradually develop their word decoding skills, their comprehension skills, and so on—and they may often combine these skills when performing a task—but the relative rates at which each skill is mastered will vary from child to child.

- *Formal schooling has a greater influence on cognitive development than Piaget believed.* Whereas Piaget emphasized the importance of children's informal interactions with their environment, neo-Piagetians argue that within the confines of children's neurological maturation and working memory capacity, formal instruction can definitely impact cognitive development (Case & Okamoto, 1996; Case et al., 1993; Fischer & Immordino-Yang, 2002; S. A. Griffin, Case, & Capodilupo, 1995). One prominent neo-Piagetian, Robbie Case, has been particularly adamant about the value of formal education for cognitive advancements. A closer look at his theory can give you a [illegible] the neo-Piagetian approach.

Case's Theory

Robbie Case was a highly productive neo-Piagetian researcher at the University of Toronto until his untimely death in 2000. Central to Case's theory is the notion of **central conceptual structures**, integrated networks of concepts and cognitive processes that form the basis for much of children's thinking, reasoning, and learning in particular areas (Case, 1991; Case & Okamoto, 1996; Case, Okamoto, Henderson, & McKeough, 1993). Over time, these structures undergo several major transformations, each of which marks a child's entry into the next higher stage of development.

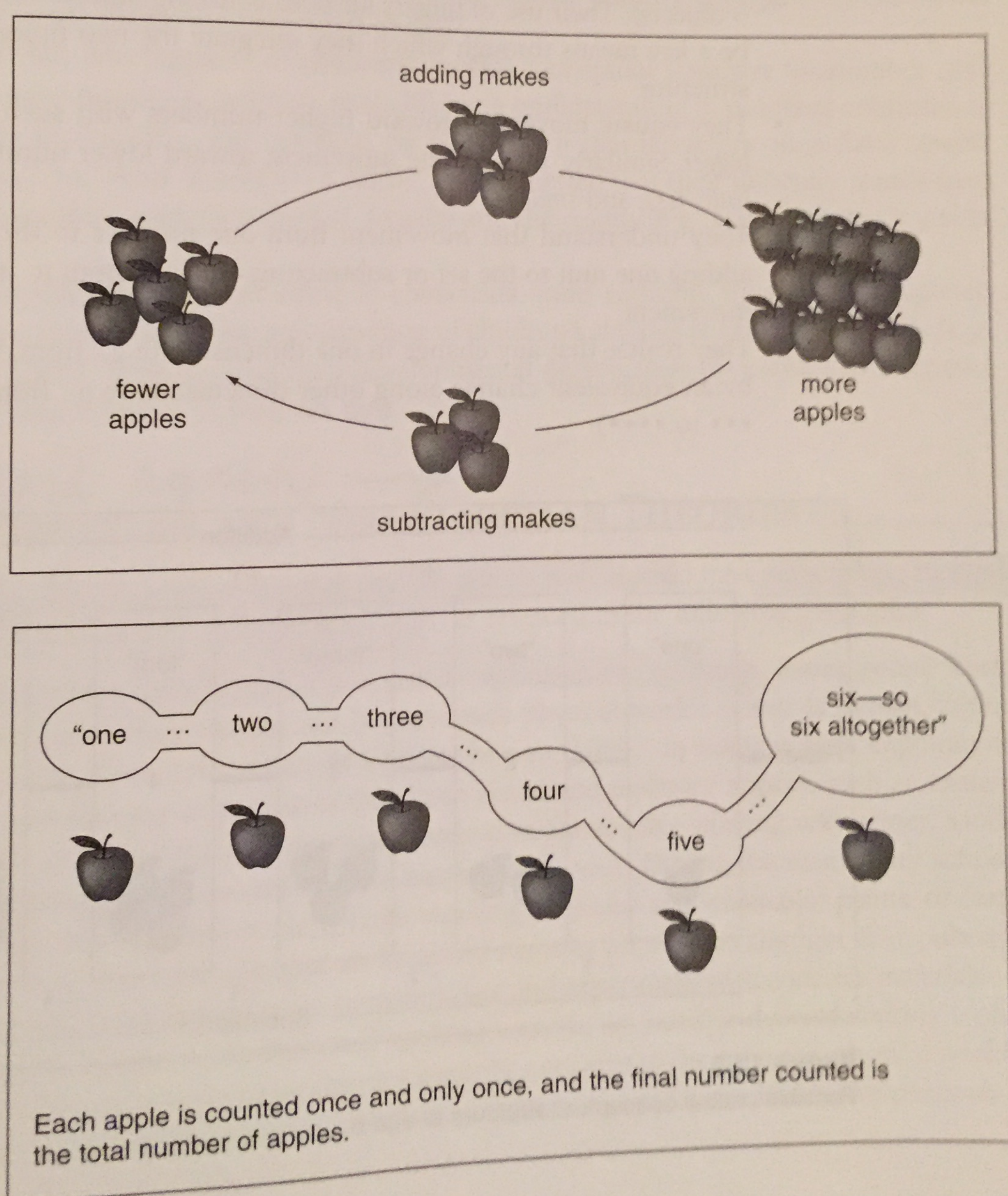
Case speculated about the nature of children's central conceptual structures with respect to several domains, including number, spatial relationships, and social thought (Case, 1991; Case & Okamoto, 1996). A central conceptual structure related to *number* underlies children's ability to reason about and manipulate mathematical quantities. This structure reflects an integrated understanding of how such mathematical concepts and operations as numbers, counting, addition, and subtraction are interconnected. A central conceptual structure related to *spatial relationships* underlies children's performance in such areas as drawing, construction and use of maps, replication of geometric patterns, and psychomotor activities (e.g., writing in cursive, hitting a ball with a racket). This structure enables children to align objects in space according to one or more reference points (e.g., the x- and y-axes used in graphing). And a central conceptual structure related to *social thought* underlies children's reasoning about interpersonal relationships, their knowledge of common scripts related to human interactions, and their comprehension of short stories and other works of fiction. This structure includes children's general beliefs about human beings' thoughts, desires, and behaviors. Case found evidence indicating that these three conceptual structures probably develop in a wide variety of cultural and educational contexts (Case & Okamoto, 1996).

From ages 4 to 10, Case suggested, parallel changes occur in children's central conceptual structures in each of the three areas, with such changes reflecting increasing integration and multidimensional reasoning over time. We'll take the development of children's understanding of number as an example.

A Possible Central Conceptual Structure for Number

From Case's perspective, 4-year-old children understand the difference between *a little* and *a lot* and recognize that adding objects leads to more of them and subtracting objects leads to fewer of them. Applying such knowledge to apples might take the form depicted in the top half of Figure 12.4. Furthermore, many 4-year-olds can accurately count a small set of objects and conclude that the last number they count equals the total number of objects in the set. This process,

Figure 12.4
Possible number structures at age 4



In essence, the more comprehensive conceptual structure at age 6 forms a mental number line that children can use to facilitate their understanding and execution of such processes as addition, subtraction, and comparisons of quantities (e.g., see Figure 12.5).

At age 8, Case proposed, children have sufficiently mastered this central conceptual structure that they can begin to use two number lines simultaneously to solve mathematical problems. For example, they can now answer such questions as, "Which number is bigger, 32 or 28?" and "Which number is closer to 25, 21 or 18?" Such questions require them to compare digits in both the "ones" column and "tens" column, with each comparison taking place along a separate mental number line. In addition, 8-year-olds presumably have a better understanding of operations that require transformations across columns, such as "carrying a 1" to the tens column during addition or "borrowing a 1" from the tens column during subtraction.

Finally, at about age 10, children become capable of generalizing the relationships of two number lines to the entire number system. They now understand how the various columns (ones, tens, hundreds, etc.) relate to one another and can expertly move back and forth among the columns. They can also treat the answers to mathematical problems as mental entities in and of themselves and so can answer such questions as "Which number is bigger, the difference between 6 and 9 or the difference between 8 and 3?"

Case tracked the development of children's central conceptual structure for number only until age 10. He acknowledged, however, that children's understanding of numbers continues to develop well into adolescence. For instance, he pointed out that teenagers often have trouble with questions such as "What is a half of a third?" and suggested that their difficulty results from an incomplete conceptual understanding of division and the results (e.g., fractions) that it yields.

Neo-Piagetian theorists haven't come to consensus—and certainly they don't completely agree with Piaget—about the nature and structure of children's abilities at various age levels (e.g., see Morra et al., 2008). Even so, cognitive-developmental perspectives have much to offer educators and other practitioners, as we'll se

MPLICATIONS OF PIAGETIAN AND NEO-PIAGETIAN THEORIES

Piaget's theory and the subsequent research and theories it has inspired have numerous practical implications for educators and other professionals, as revealed in the following principles:

- *Children and adolescents can learn a great deal through hands-on experiences*. Young people learn many things by exploring their natural and human-made physical worlds (Flum & Kaplan, 2006; Ginsburg et al., 2006; Hutt, Tyler, Hutt, & Christopherson, 1989). In infancy, such exploration might involve experimenting with objects that have visual and auditory appeal, such as rattles, stacking cups, and pull toys. At the preschool level, it might involve playing with water, sand, wooden or plastic blocks, and age-appropriate manipulative toys. During the elementary school years, it might entail throwing and catching balls, working with clay and watercolor paints, or constructing Popsicle-stick structures. Despite an increased capacity for abstract thought after puberty, adolescents also benefit from opportunities to manipulate and experiment with concrete materials—perhaps equipment in a science lab, food and cooking utensils, or wood and woodworking tools. Such opportunities allow teenagers to tie abstract scientific concepts to the concrete, physical world.

Figure 12.5 captures some of this structure's elements, again using applies for illustrative purposes.

In educational settings, learning through exploration is sometimes called **discovery learning**. Piaget suggested that effective discovery learning should be largely a child-initiated and child-directed effort. By and large, however, researchers are finding that students benefit more from carefully planned and structured activities that help them construct appropriate interpretations (M. C. Brown, McNeil, & Glenberg, 2009; Hardy, Jonen, Möller, & Stern, 2006; Mayer, 2004; McNeil & Jarvin, 2007; J. Sherman & Bisanz, 2009).

A variation of discovery learning, **inquiry learning**, typically has the goal of helping students acquire more effective *reasoning processes* either instead of or in addition to acquiring new information. For example, kindergarten teachers can teach students how to ask questions about phenomena in their physical world and then (1) make predictions, (2) gather and record data related to their predictions, and (3) draw conclusions (Patrick, Mantzicopoulos, & Samarapungavan, 2009). And middle school science teachers can give students practice in separating and controlling variables by guiding them as they design and conduct experiments related to, say, factors affecting how fast a pendulum swings or how far a ball travels after rolling down an incline (e.g., Lorch et al., 2010).

Effective discovery and inquiry learning sessions don't necessarily have to involve actual physical objects; they can instead involve experimentation in computer-based simulations. For example, children can learn a great deal about fractions with virtual "manipulatives" on a computer screen, and adolescents can systematically test various hypotheses that might affect earthquakes or avalanches in a virtual world (D. Kuhn & Pease, 2010; Moreno, 2006; Sarama & Clements, 2009; Zohar & Aharon-Kraversky, 2005).

The extent to which discovery and inquiry activities need to be structured depends somewhat on students' current knowledge and reasoning skills. For instance, advanced high school science students may profit from their own, self-directed experiments if they can test various hypotheses systematically through careful separation and control of variables and if they have appropriate concepts (*force, momentum,* etc.) with which to interpret their findings. Younger and less knowledgeable students are apt to need more guidance about how to design conclusive experiments and interpret their findings (de Jong & van Joolingen, 1998; D. Kuhn & Pease, 2010; B. Y. White & Frederiksen, 2005; Zohar & Aharon-Kraversky, 2005).

Teachers should keep in mind that discovery and inquiry learning activities have a downside—one related to the *confirmation bias* phenomenon I mentioned in Chapter 10. In particular, students may misinterpret what they observe, either learning the wrong thing or confirming their existing misconceptions about the world (de Jong & van Joolingen, 1998; Hammer, 1997; Schauble, 1990). Consider the case of Barry, an eleventh grader whose physics class was studying the idea that an object's mass and weight do *not,* in and of themselves, affect the speed at which the object falls. Students were asked to design and build an egg container that would keep an egg from breaking when dropped from a third-floor window. They were told that on the day of the egg drop, they would record the time it took for the eggs to reach the ground. Convinced that heavier objects fall faster, Barry added several nails to his egg's container. Yet when he dropped it, classmates timed its fall at 1.49 seconds, a time very similar to that for other students' lighter containers. He and his teacher had the following discussion about the result:

Teacher: So what was your time?
Barry: 1.49. I think it should be faster.
Teacher: Why?
Barry: Because it weighed more than anybody else's and it dropped slower.
Teacher: Oh really? And what do you attribute that to?
Barry: That the people weren't timing real good. (Hynd, 1998a, p. 34)

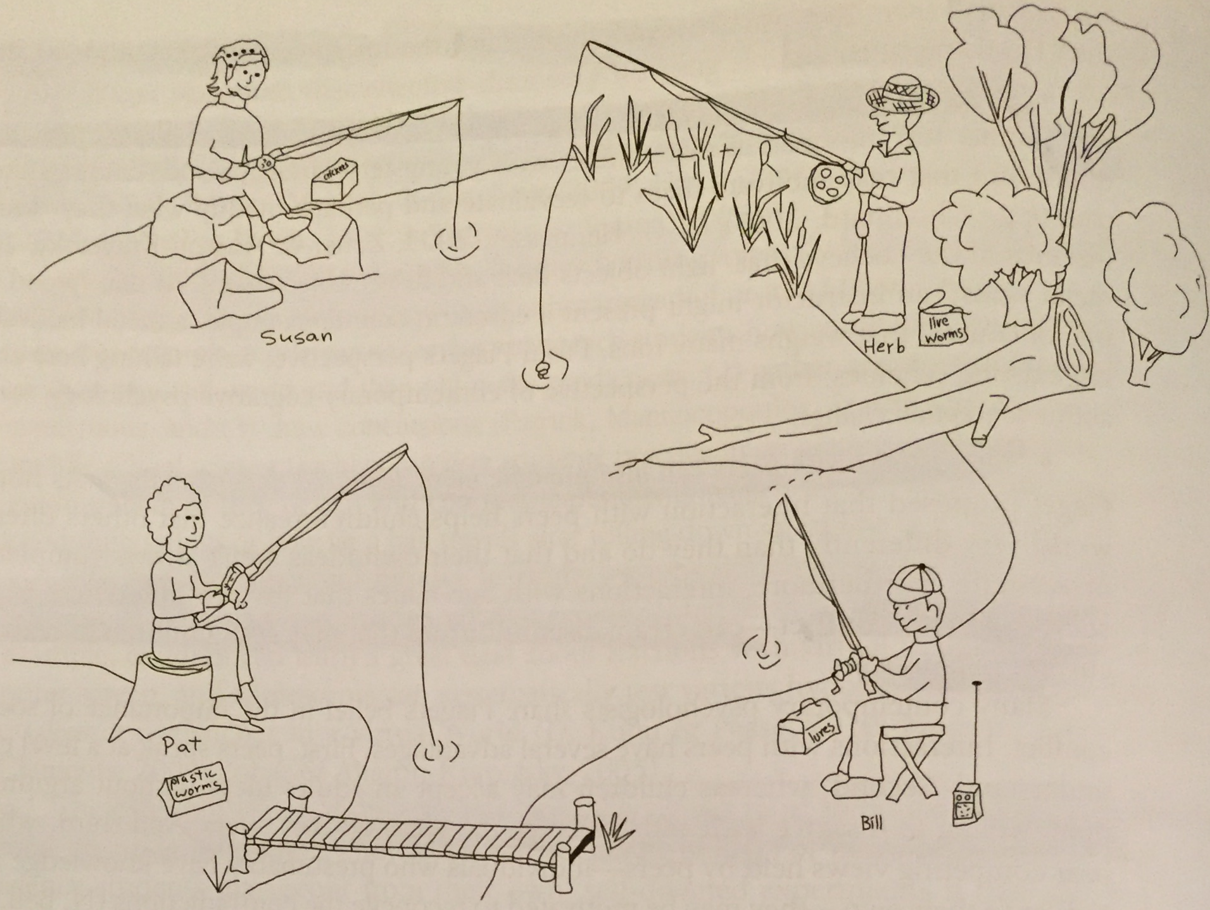


Figure 12.6
Fishing picture used in Pulos and Linn (1981)
Picture used with permission of Steven Pulos.

For instance, they might think that roads depicted in red are *actually* red. They might also have difficulty with the scale of a map, perhaps thinking that a line can't be a road because it's "not fat enough for two cars to go on" or that a mountain depicted by a bump on a relief map isn't really a mountain because "it's not high enough" (Liben & Myers, 2007, p. 202). Understanding the concept of *scale* of a map requires proportional reasoning—an ability that doesn't fully emerge until adolescence—and so it's hardly surprising that young children would be confused by it.

- *Piaget's stages can provide some guidance about when certain abilities are likely to emerge, but they shouldn't be taken too literally.* As we've seen, Piaget's four stages of cognitive development aren't always accurate descriptions of children's and adolescents' thinking capabilities. Nevertheless, they do provide a rough idea about the reasoning skills youngsters are likely to have at various ages (D. Kuhn, 1997; Metz, 1997). For example, preschool teachers shouldn't be surprised to hear young children arguing that the three pieces of a broken candy bar constitute more candy than a similar, unbroken bar—a belief that reflects lack of conservation. Elementary school teachers should recognize that their students are apt to have trouble with proportions (e.g., fractions, decimals) and with such abstract concepts as *historical time* in history and *pi* (π) in mathematics (Barton & Levstik, 1996; Byrnes, 1996; Tourniaire & Pulos, 1985). And educators and other professionals who work with adolescents should expect to hear passionate arguments that reflect idealistic yet unrealistic notions about how society should operate.

Piaget's stages also provide guidance about strategies that are likely to be effective in teaching children at different age levels. For instance, given the abstract nature of historical time, elementary school teachers planning history lessons should probably minimize the extent to which they talk about specific dates before the recent past (Barton & Levstik, 1996). Also, especially in the elementary grades—and to a lesser degree in middle and high school—instructors should find ways to make abstract ideas more concrete for students.

Yet teachers must remember that most reasoning skills probably emerge far more gradually than Piaget's stages suggest. For instance, students have some ability to think abstractly in elementary school but continue to have trouble with certain abstractions in high school, especially about topics they don't know much about. And they may be able to deal with simple proportions (e.g., $\frac{1}{2}$, $\frac{1}{3}$) in the elementary grades and yet struggle with problems involving complex proportions (e.g., $^{15}/_{27} \div {}^{19}/_{33}$) in the middle and secondary school years.

- *Children can succeed in a particular domain only if they have mastered basic concepts and skills central to that domain.* Some basic forms of knowledge provide the foundation on which a great deal of subsequent learning depends. Examples include knowledge and skills related to counting (recall our discussion of a central conceptual structure for number) and locating objects accurately in two-dimensional space (recall the central conceptual structure for spatial relationships). If children come to school without such knowledge and skills, they may be on a path to long-term academic failure unless educators actively intervene.

For example, as noted earlier, a central conceptual structure for number seems to emerge in a wide variety of cultures. Yet Robbie Case and his colleagues have found that some children—perhaps because they've had little or no prior experience with numbers and counting—begin school without a sufficiently developed conceptual structure for number to enable normal progress in a typical mathematics curriculum. Explicit instruction in such activities as counting, connecting specific number words (e.g., "three," "five") with specific quantities of objects, and making judgments about relative number (e.g., "Since this set [•••] has more than this set [••], we can say that 'three' has more than 'two'") leads to improved performance not only in these tasks but in other quantitative tasks as well (Case & Okamoto, 1996; S. A. Griffin et al., 1995).

Another early and highly influential developmental psychologist, Lev Vygotsky, was quite vocal about the importance of explicit formal instruction for promoting children's learning and cognitive development. We turn to Vygotsky's ideas in the next chapter.

Summary

Cognitive-developmental theories focus on how thinking processes change, qualitatively, with age and experience. A classic cognitive-developmental theory is that of Swiss psychologist Jean Piaget, who conducted innumerable research studies beginning in 1920s and continuing through the 1970s. Piaget portrayed children as active and motivated learners who interact with and increasingly adapt to their physical and social worlds through two processes: *assimilation* (responding to and possibly interpreting an object or event in a way that's consistent with an existing scheme) and *accommodation* (either modifying an existing scheme or forming a new one in order to deal with a new object or event). Piaget proposed that children's cognitive development is to some degree propelled by the process of *equilibration:* Children encounter situations for which their current knowledge and skills are inadequate (such situations create *disequilibrium*) and may be spurred to acquire new knowledge and skills that help return them to a state of *equilibrium*.

Piaget characterized cognitive development as proceeding through four stages: (1) the sensorimotor stage (when cognitive functioning is based primarily on behaviors and perceptions); (2) the preoperational stage (when symbolic thought and language become prevalent but reasoning is illogical by adult standards); (3) the concrete operations stage (when logical reasoning capabilities emerge but are limited to concrete objects and events); and (4) the formal operations stage (when thinking about abstract, hypothetical, and contrary-to-fact ideas becomes possible).

Developmental researchers have found that Piaget probably underestimated the capabilities of infants, preschoolers, and elementary school children and overestimated the capabilities of adolescents. Researchers have found, too, that children's reasoning on particular tasks depends somewhat on their prior knowledge, background experiences, and formal schooling relative to those tasks. The great majority of developmentalists now doubt that cognitive development can accurately be characterized as a series of general stages that pervade children's thinking in diverse content domains. A few theorists, known as neo-Piagetians, propose that children acquire more specific systems of concepts and thinking skills relevant to particular domains and that these systems may change in a stagelike manner. Many others suggest that, instead, children exhibit gradual trends in a variety of abilities. However, virtually all contemporary theorists acknowledge the value of Piaget's research methods and his views about motivation, the construction of knowledge, and the appearance of qualitative changes in cognitive development.

Piaget's influence is seen in a number of contemporary educational practices. For example, the use of discovery learning and inquiry learning activities is consistent with the importance Piaget placed on hands-on activities for cognitive development. Classroom demonstrations of puzzling physical phenomena and discussions with peers about controversial issues can provoke disequilibrium, motivating children to acquire more advanced understandings. And Piaget's clinical method can yield numerous insights into children's reasoning processes.