CHAPTER 15
The Development of Conceptual Structures

ROBBIE CASE

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Children’s early concepts differ in interesting ways from those of adults; even when they use the same word to describe a particular object (e.g., dog) the conceptual meaning that they attach to this word often differs substantially from the adult one (Anglin, 1993; Clark, 1983). It has also been claimed that the entire structure of children’s conceptual understanding is different from that of adults. When unpacked, this claim may normally be seen to involve one or more of the following propositions: (a) distinctive general patterns may be discerned in children’s conceptual understanding, ones which are present across a wide variety of local exemplars (e.g., mother, father, brother); (b) these patterns reflect a fundamental difference—not just in the content of children’s conceptual knowledge—but in the way that knowledge is organized; and (c) the reason children’s knowledge is organized differently from that of adults is not just because children have had less experience, but because the architecture of their cognitive systems is different in some fundamental way. The foregoing claims, or ones much like them, show up in the earliest writings on children’s cognitive development, and have inspired some of the most controversial work that has been done in the field throughout this century. In the present chapter I re-visit this work, with special attention to the age range for
which the largest body of empirical data has been gathered: namely, 4 to 10 years.

Most previous treatments of this topic have been organized in one of four ways: chronological, substantive, thematic, or theoretical. When adopting the chronological approach, the standard procedure is to review the conceptual structures that have been hypothesized for children at different ages, beginning in infancy and passing on to higher stages; then to evaluate the evidence that has been gathered and the conclusions that have been drawn for each. When adopting the substantive approach, the standard procedure is to lay out the major domains or types of concepts for which structural claims have been made (for example, those having to do with causality, time, and space); then to summarize the structural progression that has been hypothesized within each domain, the studies have been conducted, and the conclusions that have been drawn. The thematic approach is compatible with either of the foregoing forms of organization and is sometimes combined with them. Its distinctive feature is that a general set of issues or questions are presented at the outset: Do general conceptual structures exist at all? What sort of data would we need to gather to support or refute this claim? Are the conceptual structures at different stages of development qualitatively different? Is the transition from one form of structure to the next a gradual or a rapid one? Each of these questions has a long history in the field; accordingly, each can be treated in a separate section. Alternatively, the questions as a group can be used as a leitmotif to provide unity and coherence to the material that is reviewed throughout. The final form of organization is theoretical. Here the strategy is to devote a different section to each of the major theories that has been proposed in the field of cognitive development and to outline the position that each has taken on the structural question; then to attempt some sort of systematic comparison and/or integration of these positions at the chapter's end.

A modified form of this latter organization will be used in the present chapter. The basic thesis that underlies the present review, and that distinguishes it from other reviews on the same topic, is that many of the most enduring issues and controversies in this field are actually epistemological in nature; that is to say, they have to do with background assumptions that their authors make about the fundamental nature of human knowledge, and the process by which that knowledge is acquired. Although investigators have not always stated their background assumptions explicitly, these assumptions have nevertheless had a profound effect, both on the nature of the theories to which they have been attracted, and on the methodologies that they have regarded as most appropriate for investigating these theories. In order to highlight the role that background assumptions of this sort have played in the history of the field, the theories that are covered in the present chapter are organized into three broad epistemological categories. The history of the field is then described as a dialectic one, in which a succession of new and/or improved theories is seen as emerging within each of the three categories, in response to criticisms that were levelled at the previous theory by those subscribing to a rival epistemological position.

This chapter is organized in six sections. In the first, I provide a brief description of the major epistemological positions that have influenced the field, and the background assumptions that they entail about human knowledge. In subsequent sections, I describe (a) the view of children's conceptual structures that has been proposed in each tradition; (b) the dialogue that has taken place among the traditions, as the relative merits of the different positions have been debated and their points of disagreement clarified; (c) the work that has been done in each of the traditions in the last decade in response to the most recent round in this debate; and (d) several new lines of investigation: ones that suggest a way in which work in the three traditions may possibly be integrated. Finally, in the last two sections, I consider the question of how to conceptualize the process of structural change. After a brief review of the mechanisms that have been proposed in each of the three traditions, I conclude by suggesting a way in which these different proposals may be integrated.

For readers who are new to the topic of conceptual structures, my hope is that the present chapter will constitute a good introduction. All the classic positions on the topic are covered, as are the different substantive domains for which these positions have been developed, the data that have been gathered and the issues that have emerged. For readers who are already sophisticated students in this field, or active contributors to it, my hope is that my treatment of the history of the field will be of some interest as well. The assignment of theories to groups is somewhat different from the one that we have become accustomed to, as is the treatment of certain of the classic controversies. My hope is that the reader will find these differences to be productive, both in terms of the light that they cast on past work in the field, and the promise that they offer for the future.
THREE THEORETICAL TRADITIONS IN THE 
STUDY OF CONCEPTUAL GROWTH

Research on children’s conceptual structures has been conducted within several different epistemological frameworks. Although a number of schemes have been proposed for classifying these frameworks (Beilin, 1983; Overton, 1984, 1990, 1996), the scheme that will be used in this chapter is one that distinguishes three traditions: each with its own pioneers, its own methods, and its own tradition of progressive inquiry.

The Empiricist Tradition

The epistemological roots of the first tradition lie in British empiricism, as articulated by Locke and Hume (1955/1748). According to the empiricist position, knowledge of the world is acquired by a process in which the sensory organs first detect stimuli in the external world, and the mind then detects the customary patterns or “conjunctions” in these stimuli. Developmental psychologists who accept this view have tended to view the goals of psychology as being to describe (a) the process by which new stimuli are discriminated and encoded (perceptual learning); (b) the way in which correlations or associations among these stimuli are detected (cognitive learning); and (c) the process by which new knowledge is accessed, tested, and/or used in other contexts (transfer). The general method that has been favored includes the following three steps:

1. Make detailed empirical observations of children’s learning, in a fashion that can be replicated with reliability.
2. Generate explanations for these observations that are clear and testable.
3. Conduct carefully controlled experiments to test these hypotheses: ones that rule out any rival hypotheses.

In the field of child development, early attempts to apply this perspective led to two main kinds of investigation. The first was directed toward clarifying the nature of the perceptual stimuli that infants could detect at birth, and documenting the forms of learning that were possible (Lipsitt, 1967). The second was directed to clarifying the sort of higher order learning that children could engage in at older ages, once they could make the required perceptual discriminations. Of particular interest was the learning of verbal concepts. To study this latter type of learning, children were presented with pairs of sensory stimuli that varied along a number of dimensions (e.g., form, color, pattern), and then asked to play a game where they had to figure out which stimulus feature was associated with receipt of a small reward (e.g., square stimulus on top of container = raisin inside container; circular stimulus on top = nothing inside). On each trial children were allowed one guess as to which stimulus would be rewarded. When they had succeeded in picking the correct stimulus on some predetermined number of trials (typically 9 out of 10), they were said to have acquired the concept. At that point, a different attribute was selected, and a fresh sequence of experimental trials was initiated.

The results that were obtained from these studies were as follows. Although preschool children could learn to select a stimulus on the basis of its shape, color, or pattern by the age of 3 to 4 years, and could also learn to change the basis for their selection when the criterion was changed, they did so in a rather slow and laborious manner, with the result that their learning curves looked much more like those exhibited by lower primates (Kendler, Kendler, & Wells, 1960). By the age of 5 to 6 years, children’s original learning became much more rapid. They also became capable of relearning much more rapidly, typically within one or two trials (Kendler & Kendler, 1962). However, this was true only if the new criterion was one that required attention to the same general stimulus dimension (e.g., shape). If they were required to shift to a different dimension, particularly one that was perceptually less salient than the first dimension, the capability for rapid relearning did not emerge until the age of 7 to 10 years of age (Mumbauer & Odom, 1967; Osler & Kofsky, 1966).

When these phenomena were first observed, the change in children’s learning on such tasks was hypothesized to be part of a larger pattern, which White (1967) referred to as the “5 to 7 shift.” In keeping with the learning theories of the time, Kendler and Kendler (1962) proposed that the pattern was caused by a shift from unmediated to verbally mediated learning. The notion was that children under the age of 5, like lower primates, can learn to differentiate objects that are associated with reward from other objects. However, since they do not covertly label each object using dimensional terms (e.g., square), they have to learn about each object in a rather local fashion. By contrast, since older children and adults do engage in this sort of covert verbal labelling, they are capable of much more rapid initial learning; they are also capable of much more rapid re-learning, since all they have to do is substitute one
dimensional term for another, not learn a whole new set of associations. This same change, that is, the change from unmediated to verbally mediated learning, was believed to have a wide variety of other consequences for children’s cognition, especially the sort that is required in school (Kendler & Kendler, 1967; Rohwer, 1970).

In interpreting the data in this fashion, investigators in this tradition were subscribing to the first two classical hypotheses that were stated at the outset, namely (a) that a distinctive pattern may be discerned in young children’s conceptual understanding, which is present across a wide variety of different local exemplars and (b) that this pattern reflects a fundamental difference, not just in the content of children’s conceptual knowledge, but in the way that knowledge is organized. The third hypothesis that was mentioned — namely, that this difference does not derive from experience, but from a fundamental difference in the architecture of children’s cognitive systems — was not necessarily subscribed to. Indeed, a good deal of work was devoted to showing that children could encode the relationship to be learned in the required fashion with a little instruction, but did not do so spontaneously (Kendler & Kendler, 1967). This latter datum was interpreted as indicating a “performance” rather than a “structural” deficiency in children’s verbal mediation.

In retrospect, what can be said about the early work on children’s concept formation in this tradition? From a theoretical point of view, the harvest was relatively meager. Although the notion of verbal mediation continued to play some role in other epistemological traditions (see below), it was by and large abandoned in the empiricist tradition, because it did not fit the overall pattern that emerged, as further training and transfer studies were conducted. (See Stevenson, 1972; Ch. 9 for a review.) From a methodological point of view, the harvest was not as rich as it might have been, either. For a variety of reasons that will be described below, subsequent investigators decided that this sort of perceptually-based learning paradigm was not the best one to use during this age range, in order to reveal the full conceptual understanding of which children are capable.

To say that the harvest from these early studies was relatively meager is not to say that there was no harvest at all, however. First, the data that were gathered were extremely reliable and formed a lasting part of the general corpus that subsequent investigators felt obliged to explain, in building a model of the change that takes place in children’s cognition in this age range (Case, 1985; Gholson, 1985). Second, the general paradigm embodied a number of methodological canons that proved enduring. Of particular importance were:

1. There is much to be learned, in studying any complex conceptual structure, by examining the manner in which children encode its constituent elements.
2. There is also much to be gained by selecting a carefully circumscribed task, and varying its parameters.
3. Finally, there is much to be learned by examining the performance of different age groups, in a multiple-trial task where learning can be observed directly.

All three of these features have been preserved (or rather reintroduced) by subsequent investigators in this tradition (Siegler, 1978, 1996).

The Rationalist Tradition

The second theoretical tradition in which children’s conceptual structures have been studied drew its inspiration from Continental rationalism rather than British Empiricism. In reaction to British empiricists, philosophers such as Kant (1961/1796) suggested that knowledge is acquired by a process in which order is imposed by the human mind on the data that the senses provide, not merely detected in these data. Examples of concepts that played this foundational role in Kant’s system were space, time, causality, and number. Without some pre-existing concept in each of these categories, Kant argued that it would be impossible to make any sense of the data of sensory experience: to see events as taking place in space, for example, as unfolding through time, or as exerting a causal influence on each other. For this reason he believed that these categories must exist in some a priori form rather than being induced from experience.

Developmental psychologists who were influenced by Kant’s view tended to see the study of children’s cognitive development in a different fashion from those who were influenced by empiricists. They thought that one should begin by exploring the foundational concepts with which children come equipped at birth; then go on to document any change that may take place in these concepts with age. The first developmental theorist to apply this approach was Baldwin (1968/1894). According to Baldwin, children’s conceptual schemata progress through a sequence of four universal stages, which he termed the stages of “sensori-motor,” “quasi-logical,” “logical,” and “hyper-logical”
thought, respectively. In any given stage, Baldwin believed that new experience is “assimilated” to the existing set of schemata, much in the manner that the body assimilates food. He saw transition from one form of thought to the next as driven by “accommodation,” a process by which existing schemata are broken down and then reorganized into new and more adaptive patterns. Finally—and in this he was attempting to go beyond Kant—he saw children’s conceptual understanding in each of Kant’s categories as something that they construct, not something that is inborn. The only primitive elements with which he saw children being endowed at birth were entities that he called “circular reactions.” He called for subsequent generations to explore these reactions, and to chart the process by which they are assembled into higher order schemata.

Although Baldwin was the first to articulate a general theory of conceptual development, it was Piaget’s (1960, 1970) acceptance of Baldwin’s challenge, and his reworking of Baldwin’s theory, that had the greatest impact on the field. The most important feature that Piaget added to Baldwin’s theory was the notion of a “logical structure,” that is, a coherent set of logical operations that can be applied to any domain of human activity, and to which any cognitive task in the domain must ultimately be assimilated. Piaget hypothesized that the form of children’s structures is different at different stages of their development, and that it is this difference that gives the thought of young children its unique character. To highlight the importance of these structures, he re-labelled Baldwin’s second and third stages of development, calling them the stages of “pre-operational” and “operational” thought, respectively. He also divided the stage of operational thought into the “concrete” and “formal” periods.

Together with his collaborators at the University of Geneva, Piaget conducted a vast number of studies that were designed to reveal the details of children’s conceptual understanding in each of Kant’s categories, and the process by which this understanding is arrived at. The basic procedure was to present children with a wide variety of simple problems or tasks, in order to see how they would respond to them; then to interview them in order to determine the reasoning on which these responses were based. A final step was to look for a common pattern in children’s reasoning at different ages, and to treat this pattern as a clue regarding the underlying logical structure that was present.

The conservation task is perhaps the most famous of Piaget’s problems (Piaget, 1952). A precursor to this task had actually been studied by Binet (1900), who asked children to judge which of two objects was bigger under a variety of illusory conditions. Binet and his colleagues had shown that preschool children could not perform successfully on such tasks, that is to say, they could not overcome the perceptual illusion that the stimulus situation presents. By contrast, school-aged children were able to overcome the illusion, and to make an accurate judgment of quantity (Binet & Simon, 1905). Piaget modified this task so that children of all ages would have a more certain, logical basis for making a judgment about relative quantity. First, he presented children with a pair of objects whose quantity was equal, under perceptual conditions that were not illusory, and asked them if they thought the two objects were equal in quantity (typically children decided that they were). Next, he transformed one of the two objects, in full view, so that it looked bigger or smaller than the other object. If dealing with two lumps of plasticene, for example, he might pull one of the two lumps into a long, loglike shape. After the transformation was complete, Piaget’s final step was to ask the children if they still thought the quantities were equal, or if one was now bigger (or contained more) than the other. Once they had answered, he asked them to explain why they thought this was the case.

The results are by now well-known. Notwithstanding the fact that “logic” argued that the two quantities must still be equal, preschool children were misled by the evidence of their senses into concluding that one of the two arrays contained more than the other. By contrast, older children concluded that the amount in each array must still be the same. At the age of 7 to 8, the most frequent explanation was that nothing had been added to, or taken away from, the original array. Justifications that were sometimes added at a later age included the argument that—while one array does look bigger now along one dimension (e.g., length)—it looks smaller along another (e.g., width).

Piaget’s explanation for the change in children’s justifications was that they had acquired a new logical structure: one in which the illusions of the sensory world can be compensated for by a set of internal, logico-mathematical operations. He further asserted that these operations were system-wide in their applicability, and signalled a major change in the architecture of their cognitive systems. Note that—while Piaget’s interpretation included all three of the components that were mentioned at the outset of the chapter—it was quite different from the interpretation that had been advanced by empiricists, in order to explain the change that they had observed during the same time period. Rather than seeing children as learning to recognize and
label the basic dimensions of the empirical world, as a result of experience with it. Piaget saw them as constructing a powerful new form of logic, one which enabled them to overcome the illusions to which empirical experience would otherwise subject them.

In this particular case, the logical structure that Piaget presumed children had to assemble was one in which compensation plays a vital role, and that can be symbolized by the following formula:

\[ A_1 \times B_1 = A_2 \times B_2 \]

where \( A_1 \) stands for the value of the first dimension at time 1, \( B_1 \) stands for the value of the second dimension at time 1, \( A_2 \) stands for the value of the first dimension at time 2, and \( B_2 \) stands for the value of the second dimension at time 2.

As Piaget became interested in logical structures of this sort, he devised a number of tasks that he hoped would document their existence more directly (Inhelder & Piaget, 1958, 1964). Included among these was another task that became a classic: namely, the task of class inclusion. In this problem, children are shown an array of shapes (say, a set of square and round shapes). They are then asked to compare the set comprised of all the shapes with the larger of the two subordinate sets, and say which set is bigger. Once again, the result is by now well known. Prior to the age of 7, most children assert that the subordinate set (e.g., square shapes) is larger than the superordinate set (all shapes). They then justify their response by comparing the two subordinate sets. By the age of 7 to 10, most children reverse their earlier decision and conclude that the superordinate set is larger. Moreover, they appear to experience this fact as a "logical necessity." For Piaget, the switch to the correct response, coupled with the feeling of logical necessity, provided further evidence that children were acquiring a new set of algoico-mathematical structures.

As it happens, the class inclusion task is rather similar to the concept learning task in certain respects. Both tasks present children with a simple set of shapes that can be classified in a number of different ways (by shape, color, etc.). Both tasks require children to overcome their "natural" or "habitual" way of classifying a set of stimuli. Both tasks require children to sustain a focus on subordinate stimulus values, without losing sight of a superordinate classification. Finally, both tasks are passed for the first time during the same general age range: 7 to 10 years. The form of interpretation that the two groups of theorists developed to explain the developmental change, however, was quite different. For learning theorists, the switch to a new form of response was seen as the result of applying a learned set of labels to stimuli, and forming associations among them; in short, it was seen as the result of a verbally mediated learning process. For Piaget and those who followed him, the switch was seen as the result of acquiring a new logical structure: one in which superordinate and subordinate categories were differentiated and integrated. This structure, in turn, was seen as emerging from an internal process of reflection, not from a process in which exposure to empirical experience played the major role.

The difference between the two groups in their view of children's developing cognitive competencies was paralleled by a difference in their view of the methods that were most appropriate for studying these processes. The approach favored by empiricists was to focus on a single task that involved some form of empirical learning, then to systematically vary its parameters. By contrast, the approach favored by Piaget and his colleagues was to focus on children's understanding across a broad range of tasks, in which the results of empirical learning had to be overcome in some fashion. The form of response that the two groups analyzed was also different. Empiricists offered children a choice between two clear cut alternatives, then examined their success rate and the strategies that led to it. By contrast, Piaget and his colleagues gave a much higher weight to children's explanations, probing the reasoning that lay behind these explanations in a clinical manner. Like the differences in their theories, these differences in methodology were a function of differences in epistemology.

The Sociohistoric Tradition

A third epistemological tradition within which children's conceptual understanding has been studied has its roots in the sociohistoric epistemology of Hegel, Marx, and the modern continental philosophers (Kaufmann, 1980). According to the sociohistoric view, conceptual knowledge does not have its primary origin in the structure of the objective world (as empiricist philosophers suggested). Nor does it have its origin in the structure of the subject and his spontaneous cogitation (as rationalist philosophers suggested). It does not even have its primary origin in the interaction of between the structure of the subject and the structure of the objective world (as Baldwin and Piaget maintained). Rather, it has its primary origin in the social and material history of the culture of which the subject is a member, and the tools,
concepts, and symbol systems that the culture has developed for interacting with its environment.

Developmental psychologists who adopted the sociohistoric perspective viewed the study of children's conceptual understanding in a different fashion from empiricists or rationalists. They believed that one should begin one's study of children's thought by analyzing the social, cultural, and physical contexts in which human cultures find themselves, and the social, linguistic, and material tools that they have developed over the years for coping with these contexts. One should then proceed to examine the way in which these intellectual and physical tools are passed on from one generation to the next, in different cultures and at different time periods.

The best known of the early sociohistoric theories was Vygotsky's (1962). According to Vygotsky, children's thought must be seen in a context that includes both its biological and its cultural evolution. Three of the most important features of human beings as a species are: (a) that they have developed language; (b) that they fashion their own tools; and (c) that they transmit the discoveries and inventions of one generation to the next. From the perspective of Vygotsky's theory, the most important milestone in children's early development is the acquisition of language, not the construction of some logical structure, or exposure to a set of universal stimuli and labels. Children first master language for social (interpersonal) purposes. Next, they internalize this language and use it for intra-personal (self-regulatory) purposes. Finally, as this change takes place, their culture recognizes their new capabilities, and begins an initiation process that includes an introduction to the forms of social practice in which they will have to engage as adults. In modern literate societies this initiation process normally includes the teaching of skills such as reading, writing, and enumeration in primary school, followed by such subjects as science and formal mathematics in secondary school. Followers of Vygotsky often saw the acquisition of the first set of skills as being causally related to the appearance of the concrete logical competencies that children develop in middle childhood, and the second set as being causally linked to the emergence of the more formal competencies that appear in adolescence.

Early research in the sociohistoric tradition led to a number of interesting new findings. One of the most provocative was that adults in a traditional agricultural culture, especially ones who have not attended school, tend to score at a much lower level than adults who have attended school, on tests of mnemonic and formal logical capabilities such as syllogisms (Luria, 1976; Vygotsky, 1962). To Vygotsky, this finding indicated that modern schooling, not some universal process of reflexive abstraction, is the major instrument of cognitive growth. This inference has not gone unchallenged in recent years. Nevertheless, the datum was an important one, and one that has led to many further studies. In most of the early studies, strong schooling effects were found, not just on the sort of tasks that Luria and Vygotsky had used, but on tasks that had been used in the other two traditions as well. (Cole, Gay, Glick, & Sharp, 1971; Goodnow, 1962; Greenfield, Reich, & Oliver, 1966).

Although the results differed somewhat from study to study, the general pattern was that children moved through the 5 to 7 shift at a considerably later age if they did not attend school; very often, too, they failed to show the teenage shift to a more abstract or "formal" type of response. Instead, the shift that they showed was one that could only be understood by studying their culture, its beliefs, and its socialization practices (Bruner, 1964; Greenfield, 1966).

As this tradition developed, ethnocentric and historical methods were utilized with increasing frequency in order to place children's reasoning in context. Use of these methods further differentiated the sociohistoric tradition from the empiricist and rationalist traditions.

Comparing the Three Traditions and Clarifying Their Differences

Before proceeding, it is worthwhile to review the differences among the three traditions, and the challenge that these differences posed to subsequent investigators. The first difference was in the data that were collected on children's conceptual growth. Studies in the empiricist tradition demonstrated that, during the early years of schooling, children show a change in the strategies that they employ on tests where some novel association must be learned (e.g., square = correct; circle = wrong). They also showed that these strategies can be manipulated by instruction, at least to some extent. Studies in the rationalist tradition demonstrated that, during the same age range, a change takes place children's understanding of fundamental properties of the world: properties such as quantity, time, and space. They also showed that a change was present in children's tendency to base their response on the structure of the perceptual world, rather than the structure suggested by reasoning or "logic." Finally, studies in the sociohistoric tradition demonstrated that the emergence of a "logical" (and supposedly universal) pattern of responding during
this age range is affected by variables such as culture and schooling. Indeed, for certain formal tasks (e.g., syllogistic reasoning) the pattern that emerges does not appear to be a universal one at all.

The first challenge that these three groups of data posed to subsequent investigators was to fashion a theory that provides a unified account of all three sets of findings. A second challenge had to do with the most appropriate methods to use in exploring such accounts, or trying to decide among them. As indicated above, each group had a natural affinity with a particular set of methods, because it was motivated by a distinctive set of epistemological questions. For this reason, it was not clear how to combine the results of the different methods, or how to weigh the different evidence that each one generated. This task was further complicated by the fact that the different traditions did not just hold different views of children's conceptual development. As indicated in Table 15.1, they also held different views about such basic constructs as learning, intelligence, and experience. Finally, and perhaps most problematically, the three groups held different views about what constituted "good science."

Although the activities of scientists are different in a great many respects from those of children, they are similar in that they often share a common goal: namely, the acquisition of knowledge. Because knowledge and its acquisition were viewed so differently in the three traditions, subtle disagreements arose on what constituted good science. From the empiricist perspective, good science was science that focused on a clearly identified empirical phenomenon, that developed explicit and testable causal hypotheses regarding this phenomenon, and that tested these hypotheses in a rigorous fashion. General theories were valued, but the best method for arriving at them was presumed to be a bottom-up one, in which theoretical constructs were induced from specific phenomena,

<table>
<thead>
<tr>
<th>Psychological Constructs</th>
<th>Empiricist</th>
<th>Rationalist</th>
<th>Sociohistorical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Repertoire of patterns or problems that one has learned to detect and operations that one can execute on them.</td>
<td>Structure created by human mind and evaluated according to rational criteria such as coherence, consistency and parsimony.</td>
<td>Creation of a social group, as it engages in its daily interaction and praxis, and both adapts to and transforms the environment around it.</td>
</tr>
<tr>
<td>Learning</td>
<td>Process that generates knowledge; begins when one is exposed to a new problem, continues as one learns to respond to that problem and generalize one's response to other contexts.</td>
<td>Process that takes place when the mind applies an existing structure to new experience, in order to understand it.</td>
<td>Process of being initiated into the life of a group, so that one can assume a role in its daily praxis.</td>
</tr>
<tr>
<td>Development</td>
<td>Cumulative learning.</td>
<td>Long-term, transformational change that takes place in the structures to which new experience is assimilated.</td>
<td>The emergence and training of the symbolic and tool-using capacities that make social initiation possible.</td>
</tr>
<tr>
<td>Intelligence</td>
<td>Individual trait that sets limit on the maximum rate at which cumulative learning takes place.</td>
<td>Adaptive capability that all children possess, to apply and modify their existing cognitive structures; this capability grows with age (and is transformed).</td>
<td>Distributed across a group, and intimately tied to the tools, artifacts and symbolic systems that the group develops.</td>
</tr>
<tr>
<td>Motivation</td>
<td>Internal state that is subject to external influence, and that affects the deployment of attention.</td>
<td>Set of natural tendencies that draw human beings of all ages toward epistemic activity.</td>
<td>Identification: i.e., the natural tendency of the young to see themselves as being like their elders and to look forward to the day when they will assume their elders' role.</td>
</tr>
<tr>
<td>Education</td>
<td>Process by which the external conditions that affect children's learning and motivation are carefully arranged and sequenced so that socially desirable goals may be achieved.</td>
<td>Child-centered process: one that involves the provision of an environment that will stimulate children's natural curiosity and constructive activity, and promote active reflection on the results of that activity.</td>
<td>Process by which a community takes charge of its young, and moves them from a peripheral to a central role in its daily practices.</td>
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and retained a close linkage to them. This meant that the
general structure of empiricist theories often resembled a
list of "factors," together with a set of operational proce-
dures for measuring the factors in a particular situation,
and predicting their combined effect.

From the rationalist perspective, such theories often
appeared to be oversimplified, pedestrian, and/or trivial.
In the rationalist tradition, good science was seen as in-
volving the articulation of a sophisticated intellectual sys-
tem, and the exploration of its implications across a wide
range of circumstances. Although a theory's power to ac-
commodate new data was acknowledged to be important,
theoretical change was seen as equally likely to result from
the discussion, clarification, and rationalization of the ele-
ments of the system itself. Thus, the theories that emerged
in this tradition were more likely to resemble a complex
system of interwoven arguments, assertions, and con-
structs than they were a list of factors, principles, or even
general laws. By the same token, the development of new
methods of observation, the gathering of more detailed
data, and the use of new statistical techniques was not seen
as having much scientific import in and of itself. What was
seen as being of importance was the extent to which any
given method flowed from, or could contribute to, an ad-
advance in general theoretical understanding.

Finally, from the third perspective, science was seen
first and foremost as a social activity. Like any other social
activity, it was viewed as having evolved in a particular cul-
tural and historical context, and as depending on a particu-
lar set of intellectual tools and representations. It was also
viewed as being practiced by individuals who acquired a
particular status because of their practice, and who shared
a particular set of biases and beliefs. From this perspec-
tive, cross-cultural investigation was seen as a vital tool in
building up a general model of any social phenomenon, not
just something one could conduct after the fact, in order to
explore the possibility of "social influences." At the same
time, scientific results of this sort were also seen as being
open to distortion, due to the tendency of the members of
any one cultural group to take their own views and prac-
tices as the standard, against which the practices of all
other cultural groups should be measured. In this tradition,
then, good science was seen as science that was critically
aware of its own social origins, modest in the generality of
its claims, and neutral in its evaluation of ultimate develop-
mental outcomes.

This third perspective is worthwhile to keep in mind,
in evaluating the strengths and weaknesses of the three
traditions. The empiricist tradition was born in England,
and had its greatest impact on the conduct of social science
in that country, and its former colonies. The rationalist po-

tition was born in continental Europe, and had its greatest
impact in this sphere of influence. Finally, the sociohis-
toric tradition was born in postrevolutionary Russia, and
had its main impact, at least in its early years, in the coun-
tries of the Soviet bloc. Thus, it should be realized that—to
some extent, at least—the early discussion and debate that
took place among the three traditions involved a confronta-
tion between different cultures and world views, not
just different views of knowledge, of children, or of social
science.

DIALOGUE BETWEEN THE EMPIRICIST AND
RATIONALIST TRADITIONS

Early Empiricist Critiques of Piaget's Theory

Up until the late 1950s, North American psychology was
dominated by empiricism of a rather extreme form: namely, the school of "logical positivism." Although the
influence of this school was rather short lived in philoso-
phy, its hold on North American psychology lasted much
longer, and served to justify the radical Behaviorism that
developed on that continent. During the late 1950s and
early 1960s, however, North American behaviorism began
to come under fire from within North America as well as
outside it. The most common criticism was that behavior-
ism failed to do justice to the organization of human
behavior, and the complex inner processes that are respon-
sible for generating it (Bruner, Goodnow, & Austin, 1956;
Chomsky, 1957; Miller, Gallenten, & Pribram, 1960;
Newell, Shaw, & Simon, 1958). At the same time as this
criticism was being voiced, computers were emerging as a
new economic force, and a new discipline was being cre-
ated whose province was the design of software for them.
Eventually, investigators from the newly formed discipline
of computer science joined hands with psychologists, lin-
guists, and other social scientists, in an effort to describe
the cognitive processes that are necessary to generate and
control complex human behavior. This event became known
as the "cognitive revolution" and the new discipline became
known as "cognitive science" (Gardner, 1985).

Although theories of learning underwent a profound
transformation during this time period, the underlying
epistemology on which they were based changed relatively
little. By and large, North American investigators still presumed that the ultimate locus of knowledge was the empirical world, and that the acquisition of knowledge by psychologists should follow the traditional canons of empiricist methodology. In the field of cognitive development, the result was an interesting ambivalence. On the one hand, there was a great surge of interest in the sort of work that Piaget had pioneered. When Flavell’s (1963) English language summary of Piaget’s work became available, it was widely read and discussed. Although reactions were varied, by and large Piaget’s theory was seen as offering a far deeper understanding of children’s conceptual understanding than had been possible from the perspective of learning theory, and a wealth of new data. On the other hand, Piaget’s theory was often read with empiricist glasses. Thus, many investigators found the manner in which his theory was formulated to be excessively abstract, vague, and difficult to operationalize. They also found it too impregnated with general philosophical arguments and hence difficult to verify or falsify. They had problems with the substance of the theory, as well: in particular, they thought that the general logical structures Piaget hypothesized probably did not exist, and that such cognitive structures as did exist were more likely to be the result of empirical learning than “reflexive abstraction.” Finally, they viewed Piaget’s method of interviewing children as too clinical and subjective, and his methods of sampling and data-analysis as too unsystematic.

The continuing split between the two epistemological traditions, and the ambivalent way in which Piaget’s theory was received in North America as a result, was well reflected in the way in which children’s conceptual development was characterized in the 1970 edition of the present handbook. Four chapters were devoted to this topic. The first was Stevenson’s (1970) description of research on children’s learning, which covered work that had been done in the empiricist tradition. The second was Piaget’s chapter, which described his own theory and research (Piaget, 1970). The third was White’s (1970) look at research in both traditions, and its dependence on epistemological priors. Finally, the fourth was a chapter by Flavell (1970), which was devoted almost exclusively to an evaluation of Piaget’s work, from a perspective that Piaget classified as friendly but foreign, due to its strong empiricist emphasis (Piaget, in Flavell, 1963, p. vii).

For the purpose of the present review, the most interesting of these four chapters is the one written by Flavell, since it provides such a clear view of the different perspectives that the two traditions bring to bear on the task of studying children’s conceptual development, and the difficulties confronting any attempt to build a bridge between them. The first task that Flavell undertook was simply to describe Piaget’s theory in terms that would render it more comprehensible to an audience grounded in detailed empirical research and precise, operational definitions. The second task was to describe, in simple terms, the more specific conceptual changes that Piaget hypothesized in each of Kant’s major conceptual categories. The third task was to describe the measurement instruments that Piaget had devised, and the data he had gathered, to support his model of children’s conceptual growth in each of these areas. The fourth task was to review the empirical data that had been gathered using these instruments. Included in this category were: (a) original data gathered by Piaget; (b) new data gathered by investigators elsewhere, to see if Piaget’s findings could be replicated (by and large the answer to this question was affirmative); (c) data gathered on instruments that had been modified in various ways (here the general pattern was that modifications produced differences in the passing age of tasks, but not the general sequence); and (d) instructional studies that had been done, in an attempt to determine whether the overall sequence could be accelerated (here the answer appeared to be that the effects of the interventions were positive but modest).

The mere fact of undertaking these four tasks already represented a major effort at bridging the gap between the two traditions. The final task that Flavell set himself, however, was perhaps the most challenging. This was to tackle the question of how Piaget’s most general theoretical claims could be tested empirically. In particular, how could one test the claims having to do with the existence of general logical structures, the process by which they are formed, and their supposedly stage-like development? One view at the time was that—if Piaget’s stage theory was valid—children should be found to acquire a wide range of logical competencies relatively rapidly, that is, within a relatively tight age range (Brainerd, 1976). Flavell spent a good deal of effort documenting the difficulties that were involved in testing this assertion. Since it is difficult to establish an indisputable operational criterion for determining when, exactly, any logical competence is fully in place to begin with, it is doubly difficult to determine whether two or more such competencies emerge in the same age range, in a synchronous fashion.

In retrospect, Flavell’s most prescient comment was perhaps the one in which he raised the question of whether these were the most appropriate criteria to be using in the first place, in order to document the existence of general conceptual structures. As he put the matter:
I assume that my knowledge of developmental psychology is in some sense a cognitive structure rather than a collection of independent pieces of information. However, it would be factually wrong to argue that this structure emerged at a given point in my adult development—elements, relations, and all—and logically absurd to claim that, since it did not, it could not now be a genuine structure. (Flavell, 1970, p. 1039)

Note that, in making this comment, Flavell was separating the question of whether or not conceptual structures exist from several other questions, including (a) whether or not these structures emerge in a saltatory as opposed to continuous fashion, (b) whether or not they are age- or stage-specific, and (c) whether or not they depend on the presence of an underlying logico-mathematical competence. In subsequent years, these distinctions turned out to be crucial.

Subsequent Developments of the Empiricist Critique

During the decade that followed Flavell’s chapter, work on Piaget’s theory in the empiricist tradition continued, and dissatisfaction mounted concerning the theory’s assumptions about the role of logico-mathematical structures in children’s thought. Thus, when Gelman and Baillargeon (1983) reviewed the theory 13 years later, they were able to cite at least five different strands of empirical research—all of which were by now well developed—which called Piaget’s general view of these structures into question. The relevant data were: (a) data on intertask correlations, which were often substantial but which did not assume a pattern that bore any obvious relation to the structures Piaget had hypothesized; (b) data on the sequence of cognitive development, which rarely showed logico-mathematical structures emerging before the conceptual competencies they were supposed to generate; (c) data on preschool cognition, which often demonstrated the presence of logical competencies years before many Piagetians would have predicted; (d) data on the training of concrete operational concepts, which likewise indicated that they could often be acquired during the pre-operational period; and (e) data on logical competencies in adolescence and adulthood, which often demonstrated the absence of logical competencies at an age when they would have been long since been expected.

In suggesting which aspects of Piaget’s theory were likely to prove lasting, Gelman and Baillargeon cited his emphasis on the active nature of children’s cognitive processes, his suggestion that these processes were organized into coherent (though not necessarily logical) structures, and his elucidation of concepts such as assimilation and accommodation. Elsewhere, Gelman (1979) also mentioned the many tasks that Piaget’s group had created, and the provocative data that they had generated, as significant and enduring contributions. The aspects of Piaget’s theory that were seen as having received no support, however, and being unlikely to last, were (a) his view of the role played by children’s logico-mathematical structures in their cognitive development; and (b) his view of the stagelike nature of children’s cognitive growth.

This general evaluation was a pervasive one among empiricists in the late 1970s and early 1980s. (For a dissenting view, see Chapman, 1988.) The dilemma with which it left investigators, however, was a perplexing one. How could one create an account of children’s development that would eliminate the weaknesses of Piaget’s theory, without also eliminating its strengths? How could one characterize the development of children’s conceptual understanding in a fashion that captured its specificity, without also eliminating any ability to capture its overall shape? How could one create a weaker and less logic-bound characterization of children’s conceptual structures, which would not also weaken the powerful heuristic utility that Piaget’s account had shown?

NEW MODELS OF CHILDREN’S CONCEPTUAL UNDERSTANDING

Several different lines of inquiry have been pursued since the publication of the last Handbook, in response to this dilemma. In the present section I consider four of these. The first (often referred to as neo-Piagetian theory) had its origins in an attempt to integrate the core assumptions of the empiricist and rationalist traditions. The other three had their origins in attempts to re-think the core assumptions of one of the three classic traditions, in the light of the criticisms that had been levelled at it from other quarters, or new developments that had taken place within the tradition itself.

Conceptual Development as a Local Process, Limited by General Constraints

The first line of theoretical inquiry to emerge was one that became known as “neo-Piagetian” theory. This theoretical enterprise involved a direct attempt to build a bridge between the assumptions and methods that had underpinned
Piaget's research program and the assumptions and methods of empiricism. Neo-Piagetians accepted Piaget's position that children construct their own understanding of the world, and that reflexive abstraction plays an important role in this process. They also accepted Piaget's contention that development is a very general process, in which changes that cannot be tied to any form of specific external stimulation play an important role. Finally, they accepted the implicit methodological canons underlying Piaget's research: including (a) the notion that misleading tasks provide a particularly important window on children's conceptual understanding, and (b) the notion that the best way to develop a balanced view of children's intellectual capabilities is to examine their cognition on a broad spectrum of tasks, which span all the major categories of human understanding.

At the same time, however, neo-Piagetians also agreed with empiricists that much of children's knowledge of the world is acquired in a more piecemeal fashion than Piaget had indicated, and that local task factors, specific experience, and associative processes play a crucial role in this process. They also accepted the notion that one must examine and explain children's performance in specific contexts in great detail, and model the process of learning. Finally, they accepted the necessity of defining their constructs and task situations in operational terms. The notion of a scheme, for example, was defined in the first neo-Piagetian system as an ordered pair of responses, s-r (Pascual-Leone, 1970).

Different neo-Piagetian theorists proposed somewhat different views of the general architecture of the cognitive system, and the way in which that system develops. Nevertheless, there was a core set of propositions to which they all subscribed which included the following: Children's cognitive development does show a general pattern of growth across many different domains. However, this is not because of the existence of systemwide logico-mathematical structures. Rather, it is because the local structures that children construct are all subject to a common, systemwide constraint in information processing capacity, and this constraint gradually lifts with age. Different theorists focused on different aspects of children's information processing capacity, such as their short-term memory, their working memory, and/or their information processing speed (Biggs & Collis, 1982; Case, 1985; Fischer, 1980; Halford, 1982; Pascual-Leone, 1970). They also used different metrics for calibrating the load that any given task places on children's information processing capacity. Regardless of the specifics, however, there was general agreement that a far more detailed analysis of specific task requirements was necessary than Piaget had attempted, and that these specific requirements had to be related to children's more general information-processing capacities—not just to their logical competencies.

In order to get a sense of the changed view of children's conceptual structures that neo-Piagetian analyses generated, it is worthwhile to consider a specific example. Consider, therefore, an early analysis of conservation. According to Piaget's analysis, it will be remembered, what children need in order to pass this task is a general logico-mathematical structure. By contrast, what neo-Piagetians claimed was necessary was a set of specific schemes of the following sort (Case, 1972a; Pascual-Leone, 1969):

E An executive scheme representing the task instructions ("Do the two arrays still contain the same amount?") and directing an appropriate scan of the stimulus array.

F₁ A figurative scheme representing the fact that the two arrays originally had the same quantity.

F₂ A figurative scheme representing the rule (constructed from prior experience) that—if nothing is added or taken away—then the quantity should remain the same. (Note: If 4-year-olds do not actually witness the result of the transformation, this is their prediction.)

The thing that made the conservation task so problematic, according to this analysis, was that 4-year-old children also have another scheme, constructed on the basis of previous experience, namely:

Fₘ A misleading figurative scheme representing the rule that arrays of objects which look larger normally contain more substance.

Since the conservation task was deliberately designed in order to insure that Fₘ would be activated, children were believed to need three general things in order to pass it. First, they need a learned repertoire of schemes such as those indicated. Such a repertoire, it was hypothesized, can only be acquired through experience. Second, they need an information processing capacity of at least e + 2 units, in order to activate E, F₁, and F₂. According to the theory (see Table 15.2), an information processing capacity of e + 2 units is not available until the age of about 5 to 6 years. Even with appropriate experience, therefore, it is unlikely
that children will pass the task before this age, and for variants of the problem where a second dimension needs to be focused on in order to arrive at a judgment, they will be unlikely to pass it before 7 to 8 years (Case, 1977). Third, children need a cognitive style of field independence: that is, a style that will allow them to integrate the first three schemes, \(E, \ F_1, \) and \(F_2\) and reach a logical conclusion, even in the face of the misleading schema \(F_m\). If they do not have such a style, their acquisition of conservation will be considerably delayed.

In support of this analysis and others like it, neo-Piagetian theorists gathered several new kinds of data. Among the most important were the following:

1. Tests of children’s information processing capacity do reveal an increase with age which follows the scale in Table 15.2 (Case, 1972b, 1995a; Pascual-Leone, 1970).
2. Subjects whose information processing capacity develops in an unusually rapid or slow manner show a corresponding acceleration or delay in acquiring new conceptual understandings of the sort studied by Piaget (Case, 1985; Crammond, 1992).
3. Subjects whose information processing capacity is normal, but who have a field dependent cognitive style, do not pass the most misleading of Piaget’s tasks until 1 to 2 years after other children (Globerson, 1985; Pascual-Leone, 1969, 1974, 1989).

Finally, the age at which conceptual tasks are passed can be reduced by two years, by training studies that chunk two schemes together (Case, 1972a). Conversely, it can be increased by two years by task modifications that increase the number of schemes that must be coordinated, in order to arrive at a successful task solution (Case, 1972b; Pascual-Leone & Smith, 1969).

In keeping with the general rationalist tradition, such demonstrations were not just attempted for logical tests such as conservation or classification. They were also attempted for high level logical tasks (DeRibaupierre & Pascual-Leone, 1979) and for a very broad range of other tasks, including those involving language (Johnson, Fabian, & Pascual-Leone, 1989; Johnson & Pascual-Leone, 1994), art (Bleiker, 1995; Dennis, 1992; Morra, Moizo, & Sospes, 1988), classical learning tasks (Halford, 1982), social interaction (Fischer, Hand, Watson, Van Parys, & Tucker, 1984), motor skill (Todor, 1979) and even attachment (Case, 1995b). Finally, an attempt was also made to analyze the data from the concept learning studies cited earlier in order to show that they, too, showed a similar pattern. In this case, the suggestion was that in order to focus on a single dimension, children had to abstract its relevance by focusing on at least two lower order schemes. For this reason, it was argued, initial learning does not become rapid until children have an information processing capacity of \(e + 2\) units. By the same token, if children are to decenter from this dimension, and focus on some other, less salient dimension, then they need an information processing capacity of \(e + 3\) units (Case, 1985, p. 200). For this reason it was argued, relearning does not become rapid until 7 to 8 years of age, unless the second dimension happens to be more salient than the first one.

As work in this tradition progressed, neo-Piagetian analyses of individual tasks became much more detailed. They also became a good deal broader, and expanded to include an analysis of skills, (Fischer, 1980) executive control structures (Case, 1985), and mental models (Case, 1992a; Halford, 1993). Finally, an attempt was made to account for the growth of information processing capacity itself, on the basis of neurological change on the one hand (Case, 1985, 1995a; Pascual-Leone et al., 1990), and automaticity and improved speed of processing on the other (Case, 1985). The basic postulates described above, however, remained at the core of the endeavor.

**Conceptual Development as a Sequence of Theoretical Revolutions**

In contrast to the first line of work, which attempted to integrate the assumptions of the empiricist and rationalist traditions, the second line of work stayed more squarely
within the rationalist tradition itself. Rather than turning to information processing theory for inspiration, theorists who took this second direction turned to two other sources: Chomsky’s work on the acquisition of the structures of natural language, and T. Kuhn’s (1962) work on theory change in science. According to Chomsky (1957), the reason that children come to understand and speak language as rapidly as they do is that they have an innate language acquisition device: one that is modular in nature, and that sensitizes them to the features in their environment that are relevant. According to T. Kuhn (1962), progress in science does not take place evenly. Rather it takes place in spurts: ones in which relatively short periods of revolutionary change are punctuated by long periods of problem solving within the general paradigm that any new theory affords.

Putting these two notions together, investigators in this second group suggested that the mind is best conceived as a loosely connected set of modules, each of which is specialized for executing its own particular function in the same way as is the system for natural language (Carey, 1985; Fodor, 1982; Gardner, 1983). Certain theorists in this school believed that children possess “naive theories” of the world at birth, one whose properties are universal (Spelke, 1988). Other theorists in this school emphasized the innate property of theories less strongly (see Gelman & Wellman, this volume). Regardless of the degree to which they took an innatist stance, however, theorists in this school were agreed that, by the preschool years, children possess a coherent, albeit a naive theory of the world, which they then rework as they enter their years of formal schooling (Carey, 1985, 1988). Such reworkings were seen as taking place in one of two fashions: Existing concepts can be related in new ways, as children encounter more experience with the world, or more experience in trying to understand adult explanations. (This sort of change is analogous to the sort that occurs during stable periods in science, when new data are being gathered, and the problems with the existing theoretical structure are being worked out.) Alternatively, existing conceptual structures can be radically restructured. This corresponds to the change that takes place during scientific revolutions. When this second, more revolutionary form of transformation takes place, three cognitive changes were hypothesized to take place in close synchrony:

1. The first involves a change in the phenomena that children see as needing explanation in the domain in question.

2. The second involves a change in the nature of what counts as an explanation in their eyes.

3. The third involves a change in the concepts that form the core of such explanations (Carey, 1985).

Once again, a specific example may help to clarify the theory-theory position. According to Carey and her colleagues, preschoolers have one naive theory that they apply to human beings and animals, in which action is explained in terms of social and motivational factors. They have a second naive theory that they apply to objects such as rocks, bicycles, or trees, in which action is explained in terms of mechanical causation. However, they do not yet have a uniquely biological theory: one that applies equally to humans, animals, or plants, and that explains surface phenomena in terms of underlying biological processes. Between the ages of 4 and 10 they acquire such a theory, or at least its rudiments. The result is that a major change takes place in their conceptual understanding.

This change has many of the revolutionary properties described above, and provides children with a radically different framework for responding to a wide variety of tasks, situations, and questions. To understand this transformation, theorists in this school developed a number of interesting new tasks. In one, children were told about an imaginary new human organ (e.g., an omenta) and how it works. They were then asked what other things they think might possess an omenta (a sheep? a worm? a cloud? a rock?). In another task, they were told about a biological process with which they have some first-hand knowledge (e.g., breathing), and asked about the range of objects to which this process applies. (Does a worm breathe? Does a rock breathe? Do clouds breathe?) In still another task, children were shown a situation in which one animal was made to look like another by the application of paint, and asked whether they thought it was still “really” the same kind of animal, or whether it had been changed into an animal that fit more with its appearance (Keil, 1986). These questions were interspersed with questions of the sort posed by Piaget in his work on children’s naive concepts, namely, questions concerning what sorts of objects are and are not alive.

The general results across all these tasks were quite similar. At the age of 4, children presume that animals whose faces look like human faces will tend to have the same organs and processes as humans, but that animals which do not look like humans (e.g., snakes) will not. They also assume that, when the appearance of an animal is changed in
some way, its behavior will tend to change also. By the age of 8 to 10 years, children’s view of the natural world is quite different. Now they presume that most of the organs found in humans will be found in all other animals, and will not be found in inanimate objects, regardless of their visual similarity to humans. They also presume that plants will share certain underlying processes with humans, (e.g., the need for air), and that changes in the appearance of any living thing will not impact its behavior, unless they impact these underlying biological processes.

The foregoing changes fit well with one set of changes documented by Piaget: namely, the change from an “animistic” to a more “scientific” way of explaining natural phenomena, which normally occurs somewhere between the age of 5 and 7 years. And indeed, theorists in this school sided with Piaget, not with empiricists, in asserting that animistic responses are ones involving a genuine misunderstanding on the part of the child, not simply the absence of empirical experience with the object being talked about, or a lack of familiarity with the type of question being posed (Carey, 1985, 1988). It is important to realize, however, that the theory-theory explanation for these changes was also different from Piaget’s in two important respects. It was different, first, in the locus of conceptual change that it proposed. Change was not held to occur as a function of some system-wide transformation, such as the development of “concrete logical operations,” or an increase in information processing capacity. Rather, it was held to occur as a result of a change that was modular, that is, domain-specific. Second, the particular kind of domain-specific change proposed by theory-theorists was different from the one proposed by Piaget. The change was not one in which an animistic response was replaced with a more “logical” one. Rather, the change was one in which a social/psychological theory was replaced by a biological one.

Children’s theories of biological life are not the only ones that were studied from the theory-theory perspective. A second line of work examined children’s theories of human intentionality (Astington, Harris, & Olson, 1989; Wellman, 1990). This work will be described in a later section. For the moment, the general point is simply this. The theory-theory view of conceptual development remained more squarely in the rationalist tradition than did neo-Piagetian theory, by characterizing children’s conceptual development as a series of qualitative transformations in internal structures, whose field of application was quite broad, and which were relatively impervious to experience of a task-specific sort. As a consequence, this view also remained united with classical Piagetian theory in adopting a research strategy that examined children’s reasoning across a broad range of situations, on tasks where some sort of misleading feature had to be overcome, rather than examining one task in detail in a multi-trial learning context.

Conceptual Development as the Acquisition of Expertise

A third view of conceptual structures that has been proposed since the last Handbook has its origins in the empiricist tradition, in work on expert systems. Early studies of chess experts revealed—somewhat to everyone’s surprise—that these individuals do not appear to have a set of general problem-solving heuristics that are more powerful than those of novices. Nor do they have more powerful spatial memories. To be sure, they can perform powerful feats of memory. For example, if presented with a chess board for only a few seconds, they can reproduce the entire configuration of pieces without error. However, this is true only if the pieces are placed in the sort of configuration that they might typically assume in a real chess game. If the pieces are placed on the board randomly, the ability of experts to remember their position is no better than that of novices (DeGroot, 1966). This study, and others like it, convinced many investigators that the main thing which distinguishes chess experts from others—other than some innate love of, or talent for, the game—is that they possess a huge repertoire of chess patterns that they can recognize (e.g., presence of an open file), and good moves that they can make in response to these patterns (e.g., move a rook to this file). This notion of expertise fit well with attempts to simulate the performance of chess experts on a computer. With about 10,000 patterns of the above sort, computer programs were created that did a very good job of simulating expert performance: beating human novices in the same general fashion, and in the same number of moves, as would a real expert, and losing to world champions or grand masters.

This early work on expertise was soon extended to domains of knowledge that were less perceptually based, such as Medicine and Physics. Studies in these domains also found that the distinguishing feature of experts was the vast network of specific knowledge that they possessed—not a more powerful set of general heuristics or strategies. Equipped with this specific knowledge, experts would classify new problems in a different fashion from novices, typically according to the deep “principles” that
they embodied, rather than with regard to their superficial features (Chi & Rees, 1983). Once the problems were classified in this fashion, experts were able to solve them with less effort, and less elaborate problem solving processes than were novices. Once again, attempts to create expert systems on a computer were more successful when they built a huge repertoire of specific knowledge, and a powerful way of representing that knowledge, than when they tried endowing the system with more powerful problem solving strategies.

As Hayes (1985) pointed out, a repertoire of the magnitude required by these simulations takes many years for humans to acquire. Indeed, his review of the literature suggested that—even in the extreme case of “child prodigies”—one never finds a lasting contribution to a field being made until at least ten years of study have been logged, with a daily investment on the order of 8 to 10 hours. Needless to say, one of the obvious things that distinguishes 10-year-olds from newborns is that they have had ten additional years of experience. It was not long, therefore, before developmentalists in the empiricist tradition began to view the work on expert systems as providing a model for children’s intellectual development. According to their view, extremely young children are best viewed as “universal novices,” while adults are best viewed as individuals who have become expert in the wide range of problems that daily life (and/or school) presents.

In an early series of studies designed to demonstrate this point, Chi and her colleagues modeled children’s knowledge about a particular class of objects (dinosaurs), in terms of the features of each dinosaur that they were aware of, and could talk about (has sharp teeth, eats meat, is large, etc.). She then showed that, as children’s knowledge of dinosaurs increases, the knowledge network that they possess becomes increasingly coherent, in the sense that local groups of dinosaurs acquire more and more internal connecting links, which serve to distinguish them from other groups (Chi & Koeske, 1983). Finally, she showed that 6-year-olds with a lot of dinosaur experience (and coherent knowledge networks) tend to sort dinosaurs in the classic hierarchical fashion that is normally not seen until the age of 7 years (after the 5 to 7 shift), while 7-year-old children with the same I.Q. who have had little experience (and whose knowledge networks are not well differentiated) tend to sort dinosaurs in the syncretic and error prone fashion that is normally typical of children who are 5 years of age or younger (Chi, Hutchinson, & Robin, 1989). Chi’s interpretation of Piaget’s findings on classification and class-inclusion, therefore, was that the performance typically displayed by young children often results from an immature knowledge network, not from the absence of some powerful general logic that specifies how classes and subclasses are related, or some powerful general “processing capacity.” Indeed, Chi, (1976) suggested that the age-related growth of processing capacity itself might just be an epiphenomenon. The real source of growth, she proposed, might be the acquisition of a huge knowledge-network, one which is in turn acquired through the accumulation of a vast amount of specific experience.

Chi’s interpretation of the data that had been gathered by theory-theorists was more subtle. While she agreed with them that the fundamental source of children’s cognitive growth was knowledge, she preferred to see the underlying process as one in which different knowledge networks gradually become more elaborate and coherent, rather than as one in which one type of theory is replaced with another as a result of some sort of “cognitive revolution.” In accord with this interpretation, she pointed out that Carey’s own (1985) data on children’s acquisition of biological knowledge betokens a rather gradual (6 year) rather than a revolutionary change. Extending this point of view downwards, one could argue that infants are not born with—nor do they construct—naive “theories” about the world around them. Rather, they are born with a biological pre-disposition to pay attention to certain broad classes of features in the world, which disposition leads them to create certain general types of knowledge network. To begin with, different knowledge networks may be rather restricted in their domain of application. However, as children acquire more experience, their networks gradually become more tightly linked with each other, and hence more general.

This view of conceptual development, based as it is on the gradual accumulation of elements via experience, is consistent with the classical empiricist view of cognitive development. As will be shown later, it is also consistent with contemporary attempts to model cognitive development via “neural nets.” One problem that this account raises, however, is how to account for the sort of revolutionary changes that occur in the history of science. For certain developmental theories, this might not be a problem: One could simply argue that the two sets of phenomena are only superficially similar, and thus require no deep or integrating explanation. Since the “expertise” view of children’s development holds that the underlying mechanisms of knowledge acquisition are identical in the two cases (or at least very similar), however, the problem of explaining revolutionary theory change in science is a serious one. If scientific knowledge networks are also acquired gradually,
and more powerful ones emerge by the linking of specific networks, how is one to explain those dramatic watershed in the history of science—the ones that theory-theorists take as models for the watershed in children's cognition between 4 and 10 years of age?

In response to this problem, Chi (1994) pointed out that many major theoretical changes in the history of science have lacked the revolutionary character that T. Kuhn's theory postulates. The historical discovery of the principles governing blood and its circulation, for example, was quite slow, and took place over a long time period. What about the sort of change that took place when Einstein's theory was adopted? This change did have a revolutionary character, Chi acknowledges. However, her claim is that the revolutionary character of this change did not stem from the fact that it conflicted with an existing theory (which, of course, any new theory must do) but from the fact that it conflicted with a fundamental and universal way of categorizing reality. Things that are normally placed into one primitive and universal ontological category (the category of objects) had now to be placed into a different but equally primitive ontological category (the category of a process). Whenever this requirement for radical re-parsing is present, Chi argued, a new theory will be difficult to understand. By the same token, however, when it is understood, it will have the potential to produce changes that are sweeping and revolutionary in their nature.

Conceptual Development as Initiation into a Community of Praxis

The fourth line of inquiry in the post-Piagetian era had its roots in the sociohistoric tradition. The general starting point from which this work took off was Vygotsky and Luria's demonstration that the performance of adults in a traditional agricultural setting, on a set of high level mnemonic and logical tasks, is a function of their degree of exposure to modern schooling. Several important questions were raised by this finding. First, how general is this effect? Is it one that applies across-the-board, and produces a change in the full range of intellectual competencies that individuals in the culture display, or is it restricted to school-type tasks? Second, what aspect of schooling is responsible for producing this effect? Is it the acquisition of a new symbol system, such as that involved in literacy and numeracy (Olson, 1977)? Is it the exposure to a new form of instruction, one that originally evolved to teach these systems, and that did so in a "decontextualized" context (Greenfield & Bruner, 1966)? Is it the mastery of the formal systems of Western thought: ones which the new symbolic systems were designed to represent, and that evolved with them?

A good deal of work has been devoted to pursuing these questions since the publication of the last Handbook. Although many questions remain to be answered, the pattern of the findings that has emerged is remarkably coherent. Consider first the work that has been devoted to analyzing the acquisition of literacy, and its cognitive consequences. Early studies suggested that the acquisition of literacy—both within a culture and within an individual child—produces a transformation in cognitive structures that is revolutionary in its consequences, and that applies to a full range of activities in which a literate individual engages (Olson, 1977). More recent work, while continuing to reinforce the notion that literacy is important, has suggested that its effects are a good deal more differential, as a function of the local social, economic, and institutional context (Olson, 1994).

The classic study that led to this conclusion was conducted by Cole and his colleagues in Liberia, with the Yye. What made the Yye so interesting for Cole's purposes was that, some time during the late eighteenth century, they developed a script of their own. Of even greater interest, this script is still taught today, in several different institutional contexts. In one context (secular schools), taught via a form of schooling that resembles the one used in the West; once acquired in this context, the script is then used for Western purposes. In another context (religious schools), it is taught via chant and recitation, so it can be used for further reading, memorization, and recitation of the Koran. In a third (family) context, it is taught more informally, so that it can be used by relatives who are separated but want to stay in touch with each other by writing letters. Cole and his collaborators demonstrated that each of these contexts leads to a unique pattern of cognitive consequences. There is no universal transformation that takes place, which differentiates the thinking of those who are literate from those who are not. Rather, the particular transformation that takes place is a function of the context in which literacy is acquired, and the use to which it is put (Scribner & Cole, 1981).

In the face of this evidence, and other evidence implying such factors as economic exchange and authority (Stigler, 1984), even those who still view literacy as the gateway to higher cognitive functioning now take a much more differentiated view of the process by which this transformation takes place, and the aspects of literate practice that are crucial for it (Olson, 1994). The same applies to the acquisition of other paper-based cultural systems, such as the...
involved in the use of arithmetic (Damerow, in press; Hoyrup, 1994), money (McDermott, 1994) or cartography (Olson, 1994, Ch. 10). Although interesting cognitive consequences often do appear to be associated with the acquisition of these systems, the nature of the effects that they produce appears to be a function of the context and purpose of their use. Literacy, by itself, does not appear to be sufficient to produce a conceptual transformation.

Nor does literacy appear to be necessary for the acquisition of sophisticated conceptual structures. Neisser (1976) was one of the first to make this point. Drawing on the work of Gladwyn (1970) with the Pulawatt, Neisser pointed out that the navigational competence of this group is remarkable. With the knowledge acquired from their elders, young Pulawatt men can travel thousands of miles across uncharted stretches of ocean in small outrigger canoes, arriving precisely at their intended destination. This remarkable achievement does not appear to depend on any formal logical system of the sort that Piaget postulated. Nor does it depend on literacy or the use of modern Western artifacts such as a compass or a map. On the other hand, it does depend on the acquisition of a complex knowledge structure: one that entails principled and sophisticated understanding of celestial movements in the region, and that utilizes this understanding for navigational purposes (Oatley, 1977).

In a related study, this line of reasoning was taken further. Frake (1985) studied the system that was used by medieval sea-farers for the reckoning of tides. The conceptual framework that was used for this purpose in Northern Europe during the middle ages was a highly sophisticated one, which related solar and lunar time via the device of the compass rose. With an understanding of this system, mariners could calculate the time at which high and low tide would occur at any harbor they might visit—provided only that they had knowledge of the height the tide had reached there on one prior date and time. In analyzing this capability, Frake made a number of interesting points. One is that this capability did not require any formal ability to read and write. Like the Pulawatt, seafarers in the middle ages were often illiterate. Another is that the acquisition of the relevant structure did not produce a general change in the mental capabilities of those who understood it. Rather, it produced a change that was domain-specific. A third point is that—with the transition to literacy and modern technology—this remarkable capability has been lost. Modern tide tables give the tidal heights at all harbors in an area, for any given date and time of the day. Deprived of this table, most modern seafarers cannot begin to use their general understanding of tides, lunar movement, and local conditions to calculate the height of the tide in a particular location. Not only can non-Western cultures develop structures that are as powerful as ours, then, it would appear that our own culture has had structures in the past which were more powerful than those we use now—at least in certain respects. Frake's conclusion is that one should not see conceptual development as proceeding in a unique or privileged direction, even within the West, as we move from the pre-industrial to the post-industrial period.

If the conceptual capabilities of adults are particular to their geographic locale and historical period, it follows that social transmission must play a vital role in the developmental process. In our own culture, much of this transmission takes place via schooling. As mentioned above, one early hypothesis about modern schools had to do with their "decontextualized" nature. The notion was that protracted formal schooling—which originally emerged as a vehicle for teaching children to read and write—also exposes children to a form of learning that is unique and extremely powerful: namely, one where the conceptual content that must be mastered is learned in a context remote from that in which it must ultimately be applied. In an early essay on this topic, Greenfield and Bruner (1966) suggested that this decontextualized form of learning might produce a corresponding decontextualization of children's thought, that is, the ability to apply that thought, in a more logical, principled fashion, across a wide variety of contexts.

Just as the presumed superiority of Piaget's formal structures was challenged by cross cultural investigations, however, so was the presumed superiority of formal schooling. The most widely cited studies were those that looked at the development of children's conceptual understanding of the whole numbers, and the base system that underlies their use. These understandings show a typical pattern of development during the early school years which progresses from an understanding of how small whole numbers work, through to an understanding of groupings and exchanges, to an understanding of the principles underlying such operations such as multiplication and division (Resnick, 1989).

One might think that, if formal schooling had any advantage, it would manifest itself in this precise and well articulated domain. In fact, however, this does not appear to be the case. Studies with unschooled children who work as street vendors in Brazil have shown that these children's understanding of the number system proceeds quite
normally in such unschooled contexts (Carraher, Carraher, & Schliemann, 1985). Indeed, children who grow up in this environment often display an understanding of numerical principles and operations that is superior to that displayed by children who learn their mathematics in school. These latter children sometimes apply the algorithms that they learn in a rote or unprincipled fashion, whereas children who grow up as street vendors rarely if ever make mistakes of this sort. If the problem that is presented is unique to a schooled setting (as is the case for certain kinds of ratio problems), schooled children do show occasional competencies that are superior to those of street vendors (Saxe, 1988). By and large, however, what is more salient is that the informal learning in the market is every bit as powerful as, and perhaps more powerful than, the decontextualized learning provided by the academy. These results, and others like them have been used by Lave (1988) to argue for the superiority of contextually based "apprenticeship" over more formal learning. Intellectual competencies can then be seen as being acquired through a sort of "apprenticeship" in thought (Rogoff, 1990).

Summary

Early work in the sociohistic tradition accepted Vygotsky's notion that children's conceptual development depends on the acquisition of an intellectual and physical technology: one that is normally acquired in school and that depends on the acquisition of literacy and numeracy. Recent work in this tradition has continued the emphasis on the importance of mastering the intellectual technology that one's culture provides. However, it has painted a picture that is a good deal more complex and context-specific. Not only is there no formal structure that applies across all contexts, but literate structures are not necessarily superior to other structures, and may in fact lead to practices that are less rather than more sophisticated. The same holds for the institutions with which literacy has been associated, and the historical practices that have developed within them. Although they may offer certain advantages, they may also offer certain disadvantages that are equally important to understand.

Comparing the New Models and Abstracting Common Principles

As will no doubt be apparent, the epistemological differences that divide different schools of thought in the post-Piagetian era are still considerable, as is the view which the different schools offer of the process of conceptual growth. For expertise-theorists, the growth of knowledge is still by and large seen as being under the control of local learning factors, and the relationship between learning and development is still seen as the one indicated under the empiricist rubric in Table 15.1. What has changed, largely as a result of developments in cognitive science, is the sophistication of the models of knowledge that can be proposed and the ease with which they can be simulated on a computer. A similar point may be made for theory-theorists. By and large theorists in this school still view children's knowledge as qualitatively different from that of adults, and still subscribe to most of the general propositions that are listed under the rationalist rubric in Table 15.1. However, their attempt to model the structure of children's conceptual understanding has been enriched by contemporary analyses of theory-change in science. Contemporary sociohistic theorists, too, still by and large see conceptual change in the fashion described in the original sociohistic position. However, as a result of developments in Cognitive Anthropology, their models have become less Euro-centric, and more contextualized in their analysis of cognitive benefits and debits. Of the four groups reviewed, neo-Piagetian theorists have made the most explicit attempt to cross the epistemological boundaries that are indicated in the table. Even in this group, however, most theorists still lean quite strongly in either the empiricist or rationalist direction in their foundational assumptions; the principle new postulates which they hold in common are: (a) conceptual growth is neither a monolithic process, nor a process that is driven by a universal logic; (b) notwithstanding its specificity, there are still general maturational constraints to which the process is subject; (c) using the best analytic tools available, detailed models must be created which specify how general-maturational and more specific domain- and task- and cultural factors interact, to influence children's conceptual growth on particular tasks and in particular contexts.

Given the continuing commitment to different epistemologies, it is perhaps not surprising that the methods that have been employed to explore the different positions continue to be quite distinctive, and that each group occasionally fires methodological broadsides across the bows of another. The primary methodological innovation that expertise theorists have introduced has been the coupling of detailed studies on children's learning with studies designed to diagnose the semantic organization of children's knowledge (Chi, Hutchinson, & Robin, 1989). The primary
methodological innovation in the rationalist tradition has been the introduction of new tasks for probing children's semantic (as opposed to logical) structures—especially tasks relating to their theory of life (Carey, 1985) their theory of mind (Aastingon, Harris, & Olson, 1989) and their theory of the physical world (McCloskey, 1983). The primary methodological innovation in the sociocultural tradition has been the examination of different forms of cultural praxis and learning, and the tighter linkage of these to cognitive performance. Finally, the primary innovation in the neo-Piagetian tradition has been the combination of studies of conceptual development with assessment of change in more basic cognitive capacities such as speed of processing or working memory. Since the methods of the various traditions have continued to vary so greatly, so, too, has the new database that has been built up, and the interpretative stances that have been taken toward it.

To say that large differences still separate the different traditions is not to say that the process of dialogue has had no effect. To the contrary, if one looks at the general structure of the new theories in each tradition, and compares them to their predecessors, one sees a number of important points of convergence that were not present in previous years. In contrast to the state of affairs that obtained 20 years ago, for example, contemporary theorists in each school are now agreed (a) that the notion of a systemwide cognitive structure should be replaced by a notion of structures that are more specific; (b) that children's cognitive structures should not be modeled as systems of logical operations, but as systems for making meaning, each with its own distinctive conceptual and/or symbolic content (this is a move that Piaget also made in his later years; Piaget & Garcia, 1991); and (c) that children's physical and/or social experience should be assigned a more central role in explaining the process of structural change than early theories gave it.

For theorists in the empiricist tradition, the move to this middle ground meant a move away from a view of knowledge that focuses exclusively on isolated elements and their associations, and toward a view where broad structural and/or disciplinary coherencies are considered as well. For theorists in the rationalist tradition, the move to this middle ground has meant a move away from analyses that are systemwide, and toward a detailed consideration of factors that are domain specific. For theorists in the sociocultural tradition, the new position has entailed a similar movement away from a general and unilinear model of social and intellectual change, and toward a model in which culture practices and patterns of reasoning are viewed in terms that are more specific.

Given the trend toward greater convergence, it seems possible that we may see a greater convergence still in the years to come. In the extreme, it seems possible that the different perspectives may ultimately be seen as more complementary than incompatible, and that it may be possible to contemplate the possibility of a more general and unified theoretical framework. With this possibility in mind, I turn now to a description of several recent lines of inquiry: ones which give some hint of the outline that such a framework might ultimately assume.

TOWARD AN INTEGRATED VIEW OF CHILDREN'S CONCEPTUAL STRUCTURES

Considerable progress has been made in the last few years in clarifying children's understanding of a number of foundational domains of knowledge (see Wellman & Gelman, Ch. 11, this Volume). Three lines of work that are of particular relevance in the present context are those dealing with children's understanding of number, space, and narrative.

Young Children's Understanding of Number

Throughout the 1980s and 1990s, increasingly strong empirical evidence was obtained that children are born with a natural sensitivity to number (Starkey, 1992; Wynn, 1992) and that—by the time they enter school (if not earlier)—their intuitions with regard to small numbers are well developed. By the preschool years, children possess a good deal of intuitive knowledge that permits them to answer questions about the effects of addition, subtraction, and spatial transformation when these operations are applied to small quantities. The top panel of Figure 15.1 lays out the major semantic nodes and relations that appear to underlie these competencies.

As Gelman (1978) has shown, preschoolers also possess a good deal of knowledge about counting. They can reliably count a set of objects by the age of 4 years. They can also understand that the answer to the question "How many objects are there in this group?" is the final number tag assigned to a set. Finally, they can respond with insight to a variety of novel counting requests: such as the request to begin counting in the middle of a line of objects rather than at the end. Although there is some disagreement as to whether this capacity stems from a conceptual or a procedural knowledge base (Gelman, 1978; Siegler, 1992), there