CHAPTER 15

The Development of Conceptual Structures

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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 earlier 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 review this work, with special attention to the age range for
which the largest body of empirical data has been gathered
amelessly, 4 to 10 years.

Most previous treatments of this topic have been orga-
nized in one of four ways: chronological, substantive, the-
monic, or theoretical. When adopting the chronological
approach, the standard procedure is to review the concep-
tual structure that has 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 stan-
dard 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
spatial); 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 com-
bined with them. Its distinctive feature is that a general set
of issues or questions are presented at the outset: Do gen-
ereal 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 devel-
ompment qualitatively different? Is the transition from one
form of structure to the next gradual or a rapid one? Each of
these questions has a long history in the field; accord-
ingly, each can be treated in a separate section. Alterna-
tively, the questions as a group can be used as a leitmotif to
provide unity and coherence to the material that is re-
viewed throughout. The final form of organization is theo-
retical. 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 at-
tempt some sort of systematic comparison and/or integra-
tion 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
in 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 fundamen-
tal 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 those theories.
In order to highlight the role that background as-
sumptions 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 theore-
ies is seen as emerging within each of the three cate-
gories, in response to criticisms that were leveled at the
previous theory by those subscribing to a rival episte-
monological 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 back-
ground assumptions that they entail about human knowl-
dge. In subsequent sections, I describe the (a) 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 merit of the different posi-
tions 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 investiga-
tion: ones that suggest a way in which work in the three
categories may possibly be integrated. Finally, in the last
two sections, I consider the question of how to conceptual-
ize 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 consti-
tute a good introduction. All the classic positions on the
concepts 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 treat-
ment of the history of the field will be of some interest as
well. The assignment of theories to groups is somewhat dif-
ferent 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 pro-
ductive, 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 (Billin, 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 (1755/1748). 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 "combinations" 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 processes 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 toward 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 new 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 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 (Mumkauer & Odom, 1967; Oslor & 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
dimensions 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).

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 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; Grouven, 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 empiricism, 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 exercising 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 empiricism. 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 they take place in these concepts with age. The first developmental theorist to apply this approach was Baldwin (1908/1894). According to Baldwin, children's conceptual schemas 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 "circu-
lar 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 red- 
working 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 ap-
plied 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 develop-
ment, and that it is this difference that gives the thought of
young children its unique character. To highlight the im-
portance of these structures, he rebalanced Baldwin's sec-
ond and third stages of development, calling them the stages of "pre-operational" and "operational" thought, re-
spectively. 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 pro-
cedure 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 reason-
ing at different ages, and to test this pattern as a clue re-
garding the underlying logical structure that was present.
The conservation task is perhaps the most famous of Piaget's problems (Piaget, 1952). A prerequisite 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, basic 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 illu-
sonary, 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 ob-
ject. If dealing with two lumps of plasticine, 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 con-
tained 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 con-
tained more than the other. By contrast, older children con-
cluded 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 arrow 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 justifi-
cations was that they had acquired a new logical structure in which the illusions of the sensory world can be com-
penated for by a set of internal, logical-mathematical oper-
ations. He further asserted that these operations were systemwide in their applicability, and signaled 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 chap-
ter—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 it 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 \( A \) stands for the value of the first dimension at time 1, \( B \) 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 (Slobodder & Piaget, 1938, 1964). Included among these was another task that became a classic: 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 composed 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 logico-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 stimuli 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 its spontaneous cognition (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...
Three Theoretical Traditions in the Study of Conceptual Growth

Concepts, and symbol systems that the culture has developed for interacting with its environment. Developmental psychologists who adopted the socialhistorical perspective viewed the study of children's conceptual understanding as occurring 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 means that the 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 socialhistoric 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 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.

Fellows 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 socialhistoric 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 reflective abstraction, is the major instrument of cognitive growth. This inference has not gone unchallenged in recent years. Nevertheless, the data 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, 1965). As this tradition developed, ethnographic and historical methods were utilized with increasing frequency in order to place children's reasoning in context. Use of these methods further differentiated the socialhistoric 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 challenges 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 socialhistoric tradition demonstrated that the emergence of a "logical" (and supposedly universal) pattern of responding during
Table 15.1. Comparison of the Three Views of Knowledge and Their Embodiment in Philosophy, Psychology, and Education

<table>
<thead>
<tr>
<th>Psychological Constructs</th>
<th>Empiricist</th>
<th>Rationalist</th>
<th>Sociocultural</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Knowledge</strong></td>
<td>Repertoire of patterns or problems that one has learned to detect and operations that one can execute on them.</td>
<td>Structure caused 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 daily interactions and praxis, and both adapts to and transforms the environment around it.</td>
</tr>
<tr>
<td><strong>Learning</strong></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 a new experience, in order to understand it.</td>
<td>The emergence and training of the symbolic and tool-making capacities that make social initiation possible.</td>
</tr>
<tr>
<td><strong>Development</strong></td>
<td>Cumulative learning.</td>
<td>Long-term transformational change that takes place in the structures to which new experience is assimilated.</td>
<td>Distributed across a group, and most intimately tied to the tools, artifacts and symbolic systems that the group develops.</td>
</tr>
<tr>
<td><strong>Intelligence</strong></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>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><strong>Motivation</strong></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>Process by which a community takes charge of its young, and imparts to them from a peripheral to a central role in its daily practices.</td>
</tr>
</tbody>
</table>
| **Education**            | 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. | Child-centered process; one that involves the provision of an environment that will stimulate children’s natural curiosity and constructive activity, any promote active reflection on the results of that activity. | }
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 procedures for measuring the factors in a particular situation, and predicting their combined effect.

From the rationalist perspective, such theories often appeared to be oversimplified, polemical, and/or trivial. In the rationalist tradition, good science was seen as involving the articulation of a sophisticated intellecutal system, and the exploration of its implications across a wide range of circumstances. Although a theory's power to accommodate new data was acknowledged to be important, theoretical change was seen as equally likely to result from the discussion, clarification, and rationalization of the elements 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 constructs 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 technique was not seen as having much scientific import in and of itself. What was seen as being important was the extent to which any given method flowed from, or could contribute to, an 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 cultural and historical context, and as depending on a particular 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 perspective, 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 practices 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 developmental 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 position was born in continental Europe, and had its greatest impact in this sphere of influence. Finally, the socialistic tradition was born in postrevolutionary Russia, and had its main impact, at least in its early years, in the countries of the Soviet bloc. Thus, it should be realized that—to some extent, at least—the early discussions and debate that took place among the three traditions involved a confrontation 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 philosophy, 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 behaviorism failed to do justice to the organization of human behavior, and the complex inner processes that are responsible for generating it (Bruner, Goodnow, & Austin, 1956; Chomsky, 1957; Miller, Galanter, & Pribram, 1960; Newell, Shaw, & Simon, 1958). At the same time as this criticism was being voiced, computers were emerging as a new economic form, and a new discipline was being created whose province was the design of software for them. Eventually, investigators from the newly formed discipline of computer science joined hands with psychologists, linguists, 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 re-orientation" 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 pre-
sumed that the ultimate locus of knowledge was the em-
pirical world, and that the acquisition of knowledge by psy-
chologists should follow the rational canons of empiri-
cist 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 Pi-
aget had pioneered. When Flavell's (1965) English language
summary of Piaget's work became available, it was widely
read and discussed. Although reactions were varied, and by
and large Piaget's theory was seen as offering a far deeper un-
derstanding 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 philosophe-
cal 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 structure
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 "reflective abstraction." Fi-
ally, they viewed Piaget's method of interviewing children
as too clinical and subjective, and his methods of sampling
and data-analysis as too synectic.

The continuing split between the two epistemological tradi-
tions, and the ambivalent way in which Piaget's theory
was received in North America as a result, was well re-
lected in the way in which children's conceptual develop-
ment 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 chap-
ter, 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 pri-
ors. 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 interest-
ing 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 compre-
henable, his method, as presented in the title, was to provide
search 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 de-
vised, 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 find-
ings could be replicated (by and large the answer to this
question was affirmative); (c) data gathered on instru-
ments that had been modified in various ways (here the
general pattern was that modifications produced differ-
ences in the passing age of tasks, but not the general se-
quence); and (d) instructional studies that had been done,
in an attempt to determine whether the overall sequences
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, how-
ever, 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 gen-
eral logical structures, the process by which they are
formed, and their supposedly stage-like progression? 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 es-
tablish an indispensable operational criterion for determin-
ing when, exactly, any logical competence is fully in place
at 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 per-
haps 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 fairly
usually wrong to argue that this structure emerged as 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 commen, 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 salutary as opposed to con-
tinuous 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 compe-
tence. 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 as-
sumptions about the role of logico-mathematical struc-
tures 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 devel-
oped—which called Piaget's general view of these struc-
tures 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 rela-
tion to the structures Piaget had hypothesized; (b) data on
the sequence of cognitive development, which clearly
showed logico-mathematical structures emerging before the
conceptual competencies they were supposed to gen-
erate; (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 like-
wise indicated that they could often be acquired during
the pre-operational period; and (e) data on logical compe-
tencies in adolescence and adulthood, which often demon-
strated 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
tough 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 contri-
butions. 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 logi-
co-mathematical structures in their cognitive development;
and (b) his view of the stage-like nature of children's cogni-
tive growth.

This general evaluation was a pervasive one among em-
piricists in the late 1970s and early 1980s. (For a dissemin-
ing view, see Chapman, 1988.) The dilemma with which it left
equations, 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 elimi-
nating 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 assump-
tions of one of the three classic traditions, in the light of
the criticisms that had been levelled at it from other quar-
ters, 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 be-
tween 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 reflective 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-e (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 & Collins, 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 var-
ients of the problem where a second dimension needs to be
focused on in order to arrive at a judgment, they will be un-
likely to pass it before 7 to 8 years (Case, 1977). Third,
children need a cognitive style of fields independence: that
is, a style that will allow them to integrate the first three
schemes, (E, F, and F), and reach a logical conclusion,
even in the face of the misleading schema F. 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, 1975a; Pascual-Leone, 1970).

2. Subjects whose information processing capacity develops in
an unusually rapid or slow manner show a correspond-
ing acceleration or delay in acquiring new conceptual un-
derstandings of the sort studied by Piaget (Case, 1983;
Comarr, 1993).

3. Subjects whose information processing capacity is nor-
mal, 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 (Gilbert, 1983; Pascual-

Finally, the age at which conceptual tasks are passed
may 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;

Is keeping with the general rationalist tradition, such
demonstrations were not just attempted for logical tests
such as conservation of class/amount. They were also at-
tempted 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),
at (Bloaker, 1995; Denh, 1992; Mora Molizo, & Sco-
pesi, 1988), classical learning tasks (Halford, 1982), social
interception (Fischer, Hand, Watson, Venn Parys, & Tucker,
1994), motor skill (Todor, 1979) and even attachment
(Case, 1993b). Finally, an attempt was also made to ana-
lize the data from the concept learning studies cited ear-
lier in order to show that, 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 re-
liance 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 capac-
ity of 4 + 2 units. By the same token, if children are to de-
center from this dimension, and focus on some other, less
salient dimension, then they need an information process-
ing capacity of 4 + 3 units (Case, 1985, p. 200). For this
reason it was argued, rehearsing does not become rapid
until 7 to 8 years of age, whereas the second dimension hap-
pens to be more salient that the first one.

As work in this tradition progressed, neo-Piagetian
analyzes of individual tasks became much more detailed.
They also became a good deal broader, and expanded to in-
clude an analysis of skills (Fischer, 1980) executive con-
trol structures (Case, 1985), and mental models (Case,
1992a; Halford, 1993). Finally, an attempt was made to ac-
count for the growth of information processing capacity it-
self, on the basis of neurological change on the one hand
(Case, 1985, 1995a; Pascual-Leone et al., 1990), and auto-
maticity and improved speed of processing on the other
(Case, 1985). The basic postulates described above, how-
ever, 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 in-
tegrate 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 nature 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.

Pursuing 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; Garrett, 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 properties 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 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 is 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 an innate 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 omentum) and how it works. They were then asked what other things they think might possess an omentum (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 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 assume 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 assume 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 assume 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 the 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 due 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, 1986). 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 (Arlington, 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 remains 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 large set of situations. One consequence of these sort of misleading feature had to be overcome, rather than examining one task in detail is a multi-trial learning context.

Conceptual Development as the Acquisition of Expertise

A third view of conceptual structures that has been proposed above is the last Handbook has its origins in the empiricist tradition, in work on expert systems. Early studies of expert systems showed—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 retrace 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 encoding 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 need 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 an additional year 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 experts in the wide range of problems that daily life (and our 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.). The 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 had had little experience (and whose knowledge networks are not well differentiated) tend to sort dinosaurs in the synthetic and error prone fashion that is normally typical of children who are 5 years of age or younger (Chi, Hutchinson, & Robe, 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 has 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 Casey’s own (1985) data on children’s acquisition of biological knowledge betokens a rather gradual (6 year) rather than a revolution in change. Extending this point of view downwards, one could argue that infants are not born with—not or do they construct—naïve “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 seen later, it is also consistent with contemporary attempts to model cognitive development via “natural acts.” One problem with this account, 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 deeper integrative explanation. Since the “explosive” 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 as 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 the-
ory postulates. The historical discovery of the principles
of stable 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 charac-
ter, Chi acknowledges. However, her claim is that the revolu-
tionary 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 catego-
rizing 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 pres-
ent, Chi argued, a new theory will be difficult to under-
stand. By the same token, however, when it is understood,
it will have the potential to produce changes that are sweep-
ing and revolutionary in their nature.

Conceptual Development as Initiation into a
Community of Praxis

The fourth line of inquiry in the post-Platonic era had its
roots in the sociocultural 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 ef-
fect? Is it one that applies across-the-board, and produces a
change in the full range of intellectual competencies that in-
dividuals in the culture display, or is it restricted to scho-
type tasks? Second, what aspect of schooling is responsible
for producing this effect? Is the acquisition of a new sym-
bol system, such as that involved in literacy and numeracy
(Olson, 1977)? Is it 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. Al-
though 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.
Earl W. Whipple suggested that the acquisition of literacy—
both within a culture and within an individual child—pro-
duces a transformation in cognitive structures that is
revolutionary in its consequences, and that applies to the
full range of activities in which a literate individual en-
gages (Olson, 1977). More recent work, while continuing to
reinforce the notion that literacy is important, has sug-
gested that its effects are a good deal more differentiated
as a function of the local social, economic, and institu-
tional context (Olson, 1994).

The classic study that led to this conclusion was con-
ducted by Cole and his colleagues in Liberia, with th-
Vye. What made the Vv most interesting for Cole's purpose
was that, some time during the late eighteenth century
they developed a script of their own. Of even greater inter-
est, this script is still taught today, in several different in-
stitutional contexts. In one context (secular schools), it is
ught via a form of schooling that resembles the one that
is used in the West; once acquired in this context, the script
is then used for Western purposes. In another context (rel-
gious schools), it is taught via chant and recitation, so
that it can be used for further reading, memorization, an
recitation of the Koran. In a third (family) context, it is
ught more informally, so that it can be used by relative
who are separated but want to stay in touch with each oth-
writing letters. Cole and his collaborators demonstrate
that each of these contexts leads to a unique pattern of co-
native consequences. There is no universal transformati
that takes place, which differentiates the thinking of the
who are literate from those who are not. Rather, the parti-
tural transformation that takes place is a function of the
context in which literacy is acquired, and the use to whi
it is put (Scribner & Cole, 1981).

In the face of this evidence, and other evidence implic-
such factors as economic exchange and authority (Stee-
1984), even those who still view literacy as the gateway
higher cognitive functioning now take a much more differ-
tiated view of the process by which this transformati
akes place, and the aspects of literate practice that are
crucial for it (Olson, 1994). The same applies to the acqui-
tion of other power-bounded cultural systems, such as th-
The Development of Conceptual Structures

involved in the use of arithmetic (Dunnrow, in press; Hooykaas, 1994; moxey (McDermott, 1994) or cartography (Lea, 1994, Ch. 10). Although interesting cognitive conse-
cquences often do appear to be associated with the acquisi-
tion of these systems, the nature of the effects that they
produce appear to be a function of the context and purpose
of their use. Literacy, by itself, does not appear to be suffi-
cient to produce a cognitive transformation.

Nor does literacy appear to be necessary for the acquisi-
tion of sophisticated conceptual structures. Neisser (1976)
was one of the first to make this point. Drawing on the
work of Gladwyn (1970) with the Pulawat, Neisser pointed
out that the navigational competence of this group is
remarkable. With the knowledge acquired from their el-
ders, young Pulawat men can travel thousands of miles
across uncharted stretches of ocean in small outrigger ca-
noes, 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 West-
ern artifacts such as a compass or a map. On the other
hand, it does depend on the acquisition of a complex knowl-
edge structure: one that entails principled and sophisti-
cated understanding of celestial movements in the region,
and that utilizes this understanding for navigational pur-
poses (Ostby, 1977).

In a related study, this line of reasoning was taken fur-
ther. Fiske (1985) studied the system that was used by
medieval sea-farers for the reckoning of tides. The concep-
tual 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
ability, Fiske made a number of interesting points. One is
that this capability did not require any formal ability to
read and write. Like the Pulawat, 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. Modem
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. Literacy, by itself, does not appear to be suffi-
cient to produce a cognitive transformation. However, these
cases show that our culture has had structures in the past which
were more powerful than those we use now—at least in cer-
tain respects. From this perspective is that of examining the
conceptual development as proceeding in a unique or privi-
eged 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 the
social transmission must play a vital role in the develop-
mental process. In our own culture, much of this transmis-
sion takes place via schooling. As mentioned above, one
early hypothesis about modern schools had to do with their
"decontextualized" nature. The notion was this prototypical
formal schooling—which originally emerged as a vehicle
for teaching children to read and write—also exposes chil-
dren 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 school-
ing. The most widely cited studies were those that looked
at the development of children's conceptual understanding
of the whole numbers, and the Zero system that underlies
their use. These understandings show a typical pattern of
development during the early school years which pro-
gresses from an understanding of how small whole num-
bers work, through to an understanding of groupings and
exchanges, to an understanding of the principles underly-
ing such operations such as multiplication and division (Res-
nick, 1989).

One might think that, if formal schooling had had an ad-
antage, it would manifest itself in this precise and well
articulated domain. In fact, however, this does not appear
to be the case. Studies with untaught children who work
as street vendors in Brazil have shown that these chil-
dren's understanding of the number system proceeds quite
normally in such unschooled contexts (Carraber, Carabher, & Schleuvisen, 1983). Indeed, children who grow up in this environment have a fairly 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 principleless 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 compe-
tencies that are superior to those of street vendors (Snow, 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 oth-
ers like them have been used by love (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 “apprentices-
ship” in thought (Regoff, 1990).

Summary

Early work in the sociocultural tradition accepted Vygotsky’s notion that children’s conceptual development de-
pends 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. Re-
cent 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 pic-
ture that is a good 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 by 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 im-
portant 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-
Plagian 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 the product of local learning factors, and the relationship between learning and develop-
ment 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 knowl-
edge 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 un-
derstanding has been enriched by contemporary analyses of theory-change in science. Contemporary sociocultural theorists, too, still by and large see conceptual change in the
fashion described in the original sociocultural position. However, as a result of developments in Cognitive Anthro-
pology, their models have become less Euro-centric, and more contextualized in their analysis of cognitive benefits and deficits. Of the four groups reviewed, neo-Plagian the-
orists have made the most explicit attempt to cross the epis-
temological 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 and their foundational assumptions; the principle new postu-
lates 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 speci-
cificity, 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 influ-
ence children’s conceptual growth on particular tasks and in particular contexts.

Given the continuing commitment to different episte-
mologies, it is perhaps not surprising that the methods that have been employed to explore the different positions con-
tinue to be quite distinctive, and that each group occasion-
ally flies methodological broadsides across the bows of another. The primary methodological innovation that ex-
pertise theorists have introduced has been the coupling of
detailed studies on children’s learning with studies de-
signed 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 reasoning abilities, and an emphasis on tasks relating to their theory of life (Carey, 1985), their theory of mind (Ashton, Harris, & Olsen, 1989) and their theory of the physical world (McClure, 1983). The primary methodological innovation in the sociocultural tradition has been the examination of different forms of cultural practice 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 data 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 theories 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 much 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 coherences 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 unitary 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; Wyn, 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 lists six 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 as 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