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## A Theory of Cognitive Development: The Control and Construction of Hierarchies of Skills

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A theory of cognitive development, called skill theory, attempts to provide tools for the prediction of developmental sequences and synchronies in any domain at any point in development by integrating behavioral and cognitive-developmental concepts. Cognitive development is explained by a series of skill structures called levels together with a set of transformation rules that relate these levels to each other. The levels designate skills of gradually increasing complexity, with a specific skill at one level built directly from specific skills at the preceding level. The transformation rules specify the particular developmental steps by which a skill moves gradually from one level to the next. At every step in these developmental sequences, the individual controls a particular skill; that is, he or she controls a structure composed of one or more sources of variation in what he or she does or thinks in a specific context. In development, these skills are gradually transformed from sensory-motor actions to representations and then to abstractions. The transformations produce continuous and gradual behavioral changes; but across the entire profile of a person's skills and within highly practiced task domains, a stagelike shift in skills occurs as the person develops to a new optimal level. The theory suggests a common framework for integrating developmental analyses of cognitive skills, social skills, language, and perceptual-motor skills, as well as certain behavioral changes in learning and problem solving.

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A newborn baby is mostly helpless and unable to deal with much of the world around him. Over the years the baby grows into a child, the child into an adult. Explaining the psychological transformation that the individual undergoes in these 20-odd years is one of the most challenging tasks facing psychology.

The theory presented in this article, called skill theory, attempts to explain a large part of this psychological transformation. It focuses primarily on cognition and intelligence, and it deals with aspects of learning and problem solving. Skill theory treats cognitive development as the construction of hierarchically ordered collections of specific skills, which are defined formally by means of a set-theory description.

Of course, other psychologists have dealt

with these same general issues before, and skill theory builds on their ideas, including concepts from the work of Piaget (1936/1952, 1970; Piaget, Grize, Szeminska, & Vinh Bang, 1968; Piaget & Inhelder, 1966/1969), Bruner (1971, 1973), Werner (1948, 1957), and Skinner (1938, 1969), information-processing psychology (Case, 1974; Pascual-Leone, 1970, Note 1; Schaeffer, 1975), and the study of skill learning (Baron, 1973; Gagné, 1968, 1970; Reed, 1968). The intent of skill theory is to integrate ideas from these various approaches to produce a tool for explaining and predicting the development of behavior and thought.

Before describing skill theory in detail, I will discuss several of the key issues that it attempts to deal with: the relation between organism and environment in cognitive development and the issues of sequence and synchrony. The theory will then be presented quasi-formally in terms of assumptions, definitions, notation rules, and descriptions of both the hierarchical levels of cognitive control and the transformation rules for development from level to level. Several experiments testing the theory will be described, corollaries of the theory will be proposed, and general implications and limitations of the theory will be discussed.

### *Both Organism and Environment*

Most psychologists agree that psychological theories, to be adequate, must reckon with both organism and environment (e.g., Aebli, 1978, Note 2; Endler & Magnuson, 1976; Greenfield, 1976). The interaction of organism and environment is even more obvious in development than in most other areas of psychology. Even the maturation of the child results from a combination of organismic factors (including genes) and environmental factors. For example, myelination of nerve fibers in the cortex is controlled not only by genes but also by environmental stimulation (Fischer & Lazerson, in press; Peiper, 1963). G. Gottlieb (1976) reports that specific experiences are necessary for many aspects of normal physical and behavioral development even when the infant is still in the womb, and Cornell and Gottfried (1976)

find that stimulation facilitates physical development in premature infants.

Despite the general agreement on the interaction of organism and environment, developmental psychologists have had difficulty incorporating both organism and environment into their theories. When attempting to include both, they have effectively emphasized one side or the other. For instance, Piaget is perhaps the developmental psychologist best known for his interactional approach (1936/1952, 1947/1950, 1975), yet his explanatory constructs have focused primarily on the organism. It is the organism that changes from one stage to the next, with the environment playing only a minimal role (see Beilin, 1971, and Flavell, 1971a). Piaget himself has recognized this problem: Faced with a host of environmentally induced instances of developmental unevenness in performance (called horizontal decalage; Piaget, 1941), he has said that he simply cannot explain them (Piaget, 1971, p. 11).

At the other extreme are the behaviorists, who, like Piaget, recognize the importance of both organism and environment. Their explanatory constructs, however, have effectively emphasized the environment and neglected the organism: Concepts such as reinforcement, punishment, practice, and imitation are used to explain behavior and development (Bandura & Walters, 1963; Reese & Lipsitt, 1970; Skinner, 1938, 1969). Useful as these concepts are, they require important modifications to deal adequately with organism and environment (Catania, 1973, 1978; Herrnstein, 1977; Premack, 1965).

To take advantage of the insights of such diverse positions as Piaget's genetic epistemology and Skinner's behaviorism, one must somehow put organism and environment together in the working constructs of a theory. The present theory is based on the concept of skill, which itself connotes a transaction (Sameroff, 1975) of organism and environment. The skills in the theory are always defined jointly by organism and environment. Consequently, the skills are characterized by structures that have properties like those described by organism-oriented psychologists and that simultane-

ously are subject to the functional laws outlined by environmentally oriented psychologists. The sets that describe the skill structures are always jointly determined by the actions of the organism and the environmental context that supports those actions: The organism controls its actions in a particular environmental context. This resolution of the organism–environment dilemma allows some progress toward explaining and predicting cognitive development, although it also raises some problems of its own, which will be discussed later.

One of the most immediate implications of defining specific skills in terms of both organism and environment is that relatively minor alterations in the environmental context of action will literally change the skill being used. That is, the organism's control of a skill depends on a particular environmental context. This implication should be kept in mind because it has many important ramifications for the theory and its corollaries.

#### *Sequence and Synchrony*

Within the context of this proposed resolution of the organism–environment dilemma, skill theory attempts to provide a precise answer—or at least a framework that will allow the pursuit of a precise answer—to five interrelated questions. On first reading, several of the five questions may seem similar, but as the theory is presented, the distinctiveness of the questions should become clear. (a) What is the structure of an individual's cognitive skills at any one point in development? (b) Which skills develop into which new skills as the child moves step by step from infancy to adulthood? (c) What is the process by which present skills develop into new skills? (d) How do present skills relate to the skills that they have developed from? For example, are the previous skills included in the present skills, supplanted by the present skills, or what? (e) Why is cognitive development so often uneven in different domains? The attempts to answer these questions are anchored to specific cognitive skills investigated in the developmental research literature.

Underlying these five questions are two central issues that operationally form the

very core of the study of cognitive development: the issues of sequence and synchrony in development. Under what circumstances will skills show invariant developmental sequences, and under what circumstances will specific skills develop with some degree of synchrony? In practice, a theory of cognitive development must be able to predict and explain developmental sequences and synchronies. This is, I believe, the most essential criterion for evaluating any theory of cognitive development.

#### The Theory

Skill theory provides an abstract representation of the structures of skills that emerge in cognitive development, together with a set of transformation rules that relate these structures to each other. The structures and transformation rules comprise a tool for explaining and predicting developmental sequences and synchronies from birth to young adulthood. As I will demonstrate later, they may also allow for the explanation and prediction of cognitive development in adulthood. The theory thus focuses on the organization of behavior; it is primarily a structural theory, although it is in no way incompatible with functional analyses (see Catania, 1973, 1978; Fischer, 1972; Piaget, 1968/1970).

Here is a brief overview: Skills develop step by step through a series of 10 hierarchical levels divided into three tiers. The tiers specify skills of vastly different types: sensory–motor skills, representational skills, and abstract skills. The levels specify skills of gradually increasing complexity, with a skill at one level built directly on skills from the preceding level. Each level is characterized by a reasonably well defined type of structure that indicates the kinds of behaviors that a person (child or adult) can control at that level. The skills at each level are constructed by a person acting on the environment. She performs several actions induced by a specific environmental circumstance, and the way those actions occur in that circumstance provokes her to combine the actions: The person thus combines and differentiates skills from one level to form skills at the

next higher level. The movement from one level to the next occurs in many micro-developmental steps specified by a series of transformation rules. Notice that the skills develop through levels, not stages: Development is relatively continuous and gradual, and the person is never at the same level for all skills. The development of skills must be induced by the environment, and only the skills induced most consistently will typically be at the highest level that the individual is capable of. Unevenness in development is therefore the rule, not the exception. The level of skills that are strongly induced by the environment is limited, however, by the highest level of which the person is capable. As the individual develops, this highest level increases, and so she can be induced to extend these skills to the new, higher level.

#### *Relation Between the Theory and Its Data*

The formulation of Levels 1 to 7 is based on the large empirical literature on cognitive development between birth and adolescence. Both the specific structures of the levels and the numbers of levels were inferred from these data. To the best of my judgment, a larger number of levels did not seem to be warranted by the data, and a smaller number did not seem sufficient to explain the data. The validity of this judgment will, of course, be determined by future research.

The basis for prediction of developmental sequences, like the sequence of seven levels, has been at issue in the cognitive-developmental literature. A number of developmental psychologists have argued that developmental sequences can be predicted on a purely logical basis, where the term *logical* seems to mean internally consistent (e.g., Brainerd, 1978; Kaplan, 1967; Kohlberg, 1969). According to this way of thinking, if a coherent, "logical" argument can be made for a predicted developmental sequence, that sequence must occur. Although the sequence of cognitive levels predicted by skill theory is internally consistent, I do not believe that this consistency itself provides an adequate test of the sequence (Fischer & Bullock, in press). Also, research that has explicitly tested for develop-

mental sequences has frequently found that certain "logical" sequences do not actually occur (e.g., Hooper, Sipple, Goldman, & Swinton, 1979; Kofsky, 1966).

The reciprocal give and take between theory and data is, in my opinion, essential for theoretical progress in cognitive-developmental psychology (Feldman & Toulmin, 1975; Furby, 1972; Hanson, 1961). The most important test of the levels and of all other predictions from skill theory is empirical. The theory must also be internally consistent, but internal consistency will be for naught if the theory cannot describe, predict, and explain the development of actual cognitive skills.

In this article, I do not attempt to provide a comprehensive review of the large body of relevant research. Instead, the primary goal is to make the concepts of skill theory as clear as possible and to show how these concepts can be tied to behavior. Concrete examples of specific skills are used to illustrate most concepts. To demonstrate how the concepts relate more broadly to the research literature, a few instances of research relating to each concept are cited. These examples have been chosen to represent a wide variety of behaviors, including research from many different laboratories. I also indicate which concepts or predictions do not yet have good research documentation.

#### *Assumptions and Definitions*

Skill theory is based on a number of specific assumptions and concepts. This discussion of them is not exhaustive but focuses on ideas that need to be especially clear at the outset. The assumptions and concepts divide roughly into three topics: the concept of cognitive control, the nature of skills, and the characteristics of the levels and transformation rules.

#### *Concept of Cognitive Control*

Cognition is a complicated concept. In much of the developmental literature, the term *cognition* is used to refer to skills of a particular type of content—typically knowledge of the physical world (as op-

posed to the social, emotional, or linguistic worlds) or knowledge as measured by standard Piagetian tasks. But there is confusion and controversy about how the concept of cognition should be used (Chandler, 1977; Flavell, 1977; Kessen, 1966).

In skill theory, cognition refers to the process by which the organism exercises operant control (Catania, 1978; Skinner, 1938, 1969) over sources of variation in its own behavior. More specifically, the person can modulate or govern sources of variation in what he or she does or thinks. These sources of variation are denoted in the theory by sets: sensory-motor sets, representational sets, and abstract sets. As cognitive development progresses, infants first control variations in their own sensory-motor actions, then children control variations in their own representations, and finally adolescents or adults control variations in their own abstractions. Representations subsume sensory-motor actions, and abstractions subsume representations.

According to this conception, cognition includes anything that involves the person's controlling sources of variation, even when these sources have conventionally been called emotions, social skills, language, or whatever. All these various domains share the same processes of developing more and more effective cognitive control.

### *Nature of Skills*

Skill theory assumes that cognitive skills can be described effectively and precisely in terms of elementary intuitive set theory (see Suppes, 1957). The general definition of a *set* is a collection of things. Why is it necessary to talk about collections to explain cognitive development? When people control sources of variation in what they do or think, each such source is a collection or set, since it is a class of variations. This quality of cognition can be made more concrete by discussion of how cognition is based in action.

*Cognition and action.* All cognition starts with action, in a very broad sense. Piaget (1936/1952; Piaget & Inhelder, 1966/1969) has pointed out that cognition is essentially what the organism, from its own point of view, can *do*, whether the doing is

commonly classified as motor, perceptual, or mental. For example, an infant not only grasps a doll or shakes a rattle or kicks a blanket but also watches the doll, listens to the rattle, and feels the blanket. According to skill theory, the higher-level cognitions of childhood and adulthood derive directly from these sensory-motor actions: Representations are literally built from sensory-motor actions.

The definition of action in skill theory is, however, different from Piaget's use of the term. First of all, within Piaget's framework, the sense in which cognitions beyond infancy are themselves actions (not merely derivative from actions) is not clear: When a child represents a leaf fluttering in the breeze, falling to the ground, having a green color, and turning red in the fall, in what sense is the child acting? According to skill theory, the child is controlling representational sets for leaves' fluttering, falling to the ground, being green, and turning red. This control of variations can be conceived as an action on the part of the child, in that the child actively controls the variations cognitively. Also, all representational sets are literally composed of sensory-motor actions, as I will illustrate later.

Second, an action involves a set (rather than merely a point) because it must always be applied to something, and in being applied, it must always be adapted to that thing. Every time an infant grasps a rattle or every time an adult recognizes a familiar face, the action is adapted to the specific thing acted upon. Thus, every time an action is carried out, even on the same thing, it is done a little differently. Notice that each specific realization of an action always includes both a subject and an object—an organism and an environment. An action is therefore a set of similar behaviors on things, but not just any such set: In an action, the person can control the relevant variations in the behaviors on things. An infant who can consistently grasp a rattle has a set for grasping that rattle. An adult who can repeatedly recognize a specific familiar face has a set for recognizing that face. The thing is always included with the behavior in the definition of a set. In many ways, this definition of action is closer to the behavioral concepts of operant and skill than to Piaget's

conception. Indeed, the term *behavior class* might be superior to the term *set*, but *class* is commonly used in psychology to refer to a type of concept, and *set* has no such surplus meaning.

*Skills, schemes, and operants.* Set and action are clearly synonyms within the theory. How do they relate to skills? A *skill* is a unit of behavior composed of one or more sets. The characteristic structure for each level is a type of skill, varying in complexity from a single set at Level 1 to a very large number of sets at the highest levels. What makes a group of sets into a skill is the person's control over both each individual set and the relations between the sets. For example, an infant who can shake a rattle in order to listen to it has a skill composed of two related sets, shaking the rattle and listening to the noise it makes.

The relation between the concept of skill in the theory and the concepts of scheme and operant from Piaget and Skinner may help to clarify the meaning of skill. Piaget's general word for cognitive structure is *scheme*<sup>1</sup>—a structure for knowing, a procedure that the child actively applies to things in order to understand them. In broad conception, there are many similarities between scheme and skill, as already indicated in the discussion of action, but there are also major differences. One of the most important differences involves the organism-environment problem: Piaget's schemes allot much less importance to the environment than the skills of the present theory do. Schemes are assumed to have a high degree of generality, encapsulated in Piaget's concept of the *structure d'ensemble* (Piaget, 1957, 1968/1970; Inhelder & Piaget, 1955/1958). This powerful generality of schemes should produce a high degree of synchrony in development. Two tasks that according to Piagetian analysis require the same scheme should develop at the same time. Yet rather than synchrony, researchers typically find unevenness in development (e.g., Flavell, 1971b; Jamison, 1977; Liben, 1977; Toussaint, 1974).

The number of well documented instances of unevenness has been increasing astronomically in recent years; American psychologists seem to take special delight

in documenting new instances, especially when the unevenness can be attributed to environmental causes. Unevenness has been found so often and synchrony so seldom that many developmental psychologists have begun to suggest that unevenness may well be the rule in development, and synchrony the exception (e.g., Carey, 1973; Cole & Bruner, 1971; Feldman & Toulmin, 1975). Unevenness has been demonstrated repeatedly for every Piagetian period of development.<sup>2</sup>

The concept of skill, in contrast to Piaget's scheme, requires that unevenness be pervasive in development, because skills are defined in terms of the environment as well as the organism. Changes in the environmental context of action produce changes in a skill. In this regard, skills share important similarities with Skinnerian operants (Skinner, 1938). The term *operant* refers to a behavior that is emitted by an organism, not elicited by a stimulus. At the same time, the specific form of the behavior and the probability that the organism will emit the behavior are affected by environmental stimuli. The behavior is therefore controlled by both the individual organism and environmental stimuli. Hunt (1969) and Aebli (1978, Note 2) have pointed out that most of the behaviors studied by Piaget and his colleagues are in fact operants.

The phenomena of developmental unevenness make good sense from a behaviorist perspective. Behavioral research has shown repeatedly that task factors have potent effects on most kinds of behavior in

<sup>1</sup> Many of the English translations of Piaget's works use the word *schema* instead of *scheme* to translate the French *schème*. There is a problem with this usage: In recent years Piaget has differentiated *scheme* from *schéma* (Furth, 1969; Piaget & Inhelder, 1966/1971). *Schéma* refers to an internal image of something, which is very far from the meaning of *schème*.

<sup>2</sup> Here are just a few of the relevant references: for the sensory-motor period, Butterworth, 1976; Jackson, Campos, & Fischer, 1978; Kopp, O'Connor, & Finger, 1975; Uzgiris & Hunt, 1975; for the pre-operational period, Gelman, 1978; Goldstein & Wicklund, 1973; Watson & Fischer, 1980; for the concrete operational period, Achenbach & Weisz, 1975; Hooper et al., 1971; Jackson, 1965; Smedslund, 1964; and for the formal operational period, Martarano, 1977; Neimark, 1975; Piaget, 1972; Wason, 1977.

both animals and people. The effects are so powerful that a number of analyses of human abilities have been developed that deal primarily with the influences of task on performance (e.g., Fleishman, 1975; Horn, 1976). In addition, specific experience with a task has repeatedly been shown to be important. These two factors, task differences and experience, likewise account for many instances of unevenness. For example, the type of task, the materials used in a task, and simple changes in the format of a task have all repeatedly produced unevenness (e.g., Barratt, 1975; Jackson et al., 1978; Kopp, O'Conner, & Finger, 1975). Even simple practice with a task affects stage of performance (e.g., Jackson et al., 1978; Wohlwill & Lowe, 1962).

The usefulness of the concept of operant does not extend, however, to analysis of the organization of behavior. Although reinforcement and punishment can be useful experimental operations for analyzing organization, they are insufficient. What the concept of operant lacks in behaviorist theory is a system for analyzing the organization of operants and how that organization changes with learning and development. Skill theory is designed to provide such a system.

In general, then, scheme and operant are synonyms for skill within the present theory, although of course they have different psychological frameworks. The levels of cognition are a hierarchy of skills, schemes, or operants in which each higher-level skill, scheme, or operant is actually composed of lower-level skills, schemes, or operants. The theory thus provides a tool for analyzing skills, schemes, or operants into units of widely varying complexity.

The definition of sets has an important implication for the meaning of skill, scheme, and operant. Because an action always involves a particular object or thing, a skill must be specific to particular objects or things. This implication is equivalent to saying that as children develop, they master specific cognitive skills; they do not develop uniformly across the entire range of skills.

Similarly, since cognitive development proceeds by the coordination of specific skills or schemes or operants, development

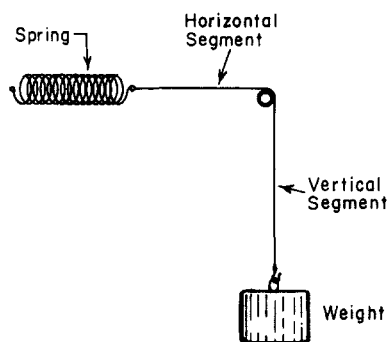


Figure 1. The spring-and-cord gadget.

through the seven levels must occur within a skill domain, not across skill domains. In other words, the development of cognitive skills occurs in much the way that behaviorally oriented psychologists have suggested (Baron, 1973; Gagné, 1968, 1970; Schaeffer, 1975). The child masters specific skills, builds other specific skills upon them, and transfers skills from one domain to another. This mastery process involves qualitative changes in skills, but the specific changes occur gradually, not abruptly.

*Induction of a new skill.* An example will show how development is induced jointly by both the person's skills and the environmental circumstances in a particular situation. The development of conservation of length in the gadget shown in Figure 1 (adapted from Piaget et al., 1968, chap. 4) provides a simple illustration of this joint induction by organism and environment. In the gadget, a cord is attached to a spring and draped over a nail, so that the cord is divided into two segments by the nail, a horizontal segment and a vertical segment. Differing weights attached to the cord will produce changes in the length of the horizontal segment of the cord and concomitant changes in the length of the vertical segment.

Consider a 5- or 6-year-old girl who already has two skills (or schemes or operants) for the length of the cord: (a) She understands approximately how the length of the vertical segment relates to the length of the horizontal segment; that is, she can roughly control the relation between the vertical length and the horizontal length, using the vertical to predict the horizontal.

(b) She also understands approximately how the horizontal length relates to the vertical length; that is, she can use the horizontal to roughly predict the vertical. But she does not yet understand that the changes in the horizontal length compensate for the changes in the vertical length, so that the total length of the cord does not change; she does not yet understand conservation of the length of the cord.

To construct an understanding of this conservation, she must coordinate her two skills for predicting the length (vertical predicts horizontal, and horizontal predicts vertical). This combination will occur only if (a) the child has the two skills and (b) she plays with a gadget in which length in fact conserves. As she applies the two skills repeatedly to the gadget, the task itself induces the child to notice a connection between them, because the properties of the task make the two skills closely related. Then the child explores the connection and gradually constructs a new, higher-level skill for conservation of the total length of the cord.

The importance of the contribution from the gadget (the environment) should not be underestimated. If the cord were not a cord but a rubber band, conservation of the length would not obtain, because the different weights that stretch the spring would also stretch the rubber band. More generally, the child's possession of two skills cannot by itself produce coordination of those skills. The child must be induced to coordinate them by applying them to something for which they do coordinate.<sup>3</sup>

The joint action of organism and environment in cognitive development is equally important for all the skill levels in the theory. A 1- or 2-month-old infant, for example, will typically not be able to control the relation between shaking a mobile and watching it jiggle. But when she has mastered the two individual skills, shaking the mobile and watching it, she will be induced by the mobile to coordinate the shaking and the watching. It is a property of mobiles—and of many other things in the world—that shaking them produces interesting changes in their appearance.

*Developmental synchronies.* This es-

sential contribution of the environment to skill development requires, of course, that unevenness be the rule in development, but it by no means excludes instances of synchrony. Developmental synchrony in various degrees is predicted by the theory. Analysis of skill structures plus control of environmental factors such as practice and familiarity allow the prediction of special instances of near-perfect synchrony, as well as predictions of various degrees of synchrony under differing circumstances. Such predictions will be illustrated later.

Because of the connotation of the word *skill*, the phrase *skill domain* implies a fairly broad grouping of behaviors. However, methods for determining the developing child's groupings of behaviors into skill domains are crude at best (see Beilin, 1971; Flavell, 1971b, 1972; Wohlwill, 1973). So as not to beg the question of which skills develop together in a single domain, I will distinguish *task domain* from skill domain. A task domain is a set of behaviors that involve only minor variations in the same task, in contrast to the broad grouping of behaviors across tasks in a skill domain. Within a task domain, there is virtually no problem in determining which behaviors belong to that domain. As will be shown later, the theory can predict developmental sequences within a task domain. It may also prove useful in determining the nature and scope of skill domains, but that usefulness remains to be demonstrated.

*Task analysis.* Because task factors are so important in skill theory, task analysis

<sup>3</sup> This analysis differs from that of Piaget et al. (1968) in three major ways: (a) They do not grant the same inductive role to the task. (b) They do not ascribe to the 5-year-old the ability to relate vertical to horizontal and vice versa, although they do describe an ability to relate weight to length of the spring (which is also consistent with skill theory). These several abilities are both predicted by skill theory and supported by some research (Wilkening, 1979). (c) They do not explain conservation as arising from the coordination of skills relating vertical and horizontal. Instead, they describe three stages: relating weight to spring, then understanding conservation, and finally understanding the proportional relation between weight and amount of displacement. Their third stage develops much later than what is discussed in the present example.



is clearly central to using the theory. The central question for task analysis is: What sources of variation must the person control to perform a task? That is, what sets must she or he control, and what relations between sets? Guidelines for task analysis will be described later after the theory has been more fully elaborated.

Closely related to the problem of specifying which sets and relations a person must control in a task is the problem of defining the boundaries of a set. Indeed, the most useful form of set theory may prove to be the theory of fuzzy sets (Negoita & Ralescu, 1975), which does not require precise definitions of set boundaries. The problem of defining the boundaries of a set is virtually identical to the problem encountered by behaviorists in defining the boundary of an operant (Schick, 1971). The problem may be more serious theoretically than practically (Catania, 1978), but it is still a problem.

Skill theory at least points in the direction of a solution by specifying a universe of possible skill structures and thus providing a tool for partially defining behavioral units. Development is analyzed into a hierarchy of operants—skill levels of increasingly complex cognitive control—plus various transitional forms specified by the transformation rules. A particular behavior can be related to one of the possible skill structures, and at the minimum, the theory will then imply particular kinds of *changes* in the cores and boundaries of sets across transformations and levels.

#### *Concepts for Defining Levels and Transformations*

Through the joint contributions of the person and the environment, skills, schemes, or operants develop through at least seven hierarchical levels. The skills at each level are characterized by a structure that indicates the kinds of behaviors that the person can control at that level. Also, at each level, the skills include all the lower levels. For example, when a child is at Level 5 for a specific skill, that skill subsumes skills at Levels 4 through 1. Note, however, that these lower-level skills become more differentiated at each higher level to which the superordinate skill develops.

Before the levels themselves can be described, a number of key concepts must be introduced.

*Relations between skills and levels.* Contrary to the use of stage or period in most cognitive-developmental models, the levels are used generally to characterize a child's skills, not the child in general. A child will normally be at different levels for different skills. To characterize a specific child, a *cognitive profile* is required, indicating level of performance on a wide range of skills (see, for example, Rest, 1976).

There is, however, one sense in which the levels are used to characterize the child. Each child has an *optimal level*, indicating the best performance the child shows, which is presumably a reflection of both practice and the upper limit of his or her processing ability. Just as in information-processing theories, this central processing limit increases with development (Case, 1974; Flavell & Wohlwill, 1969; Halford & Wilson, 1980; Pascual-Leone, 1970; Scandura, 1973). But skill theory does not require the homogeneity of performance demanded by many information-processing theories, since the optimal level is merely an upper limit, not a characteristic of all cognitive behavior at a given point in development. Also, the limit is characterized by a skill structure (one of the cognitive levels) rather than a simple whole number of items in working memory.

The postulation of levels instead of continuous monotonic increases in complexity has implications for the form of the increase in optimal level with age: Associated with the levels, there will be spurts in the speed of developmental change. That is, as a child moves into a new level, she will show rapid change; but once the level has been attained, she will show slower change. In this way, the speed of development will vary cyclically with the skill levels. Note that this hypothesis does not mean that developmental change is abrupt or discontinuous. The child moves into a new level gradually over a long period, but the speed of change during this period is relatively rapid.

Although I have defined the optimal level as a single upper limit, there is a possibility suggested by ability research that at the

Table 1  
*The Cycle of Four Levels That Repeats  
 in Each Tier*

Level	Characteristic structure	Set-theory description
I	Single set	{W} or {X}
II	Mapping	{W — X}
III	System	{W <sub>A,B</sub> ↔ X <sub>C,D</sub> }
IV	System of systems	$\begin{bmatrix} W & \leftrightarrow & X \\ & \updownarrow & \\ Y & \leftrightarrow & Z \end{bmatrix}$ or {M}

highest levels, a person may have a few different optimal levels in different broad domains. For example, an adult's optimal level in spatial skills may be different from his or her optimal level in verbal skills (see Horn, 1976).

*Mappings and systems.* The concepts of mapping and system define the possible relations between sets within a skill, and both of these concepts can be described in set-theory terms. A *mapping* is a structure relating two sets: a collection of ordered pairs in which the first member in each pair is from one set (W) and the second member is from another set (X). The first set is said to be mapped onto the second: [W — X].

A *system* is composed of a relation between two subdivided sets. Each set is divided into two subsets, which are related to the two subsets in the other set. The two subdivided sets are said to form a system, with the subsets noted by subscripts: [W<sub>A,B</sub> ↔ X<sub>A,B</sub>]. The double-headed arrow indicates that the structure is a system even when the subsets are not expressly listed in the formula: [W ↔ X].

The psychological interpretation of mappings and systems is straightforward. In a mapping, a person can relate two sets in a single skill—two sensory-motor actions, two representations, or two abstractions. In a system, a person can relate two subsets of each of two sets in a single skill—two components of two actions, representations, or abstractions. The ability to deal with two subsets in each set means that the person can control two sources of variation in each set. As a result, a system can in-

clude much more complexity and detail than a mapping.<sup>4</sup>

A third type of structure, called a *system of systems*, is a relation between two systems, as shown for Level IV in Table 1. The psychological interpretation of a system of systems is that people can relate two systems in a single skill, which allows them to form a new kind of set: the most elementary set M at the next higher tier. In this new set, each system is one element, so that the simplest set has just two elements.

Note that in all these structures, a set is a source of variations that the person can control—variations in actions, representations, or abstractions. In each case, the variations involve behaviors-on-things, but the level of complexity of the organization of those behaviors increases markedly at the higher levels. Consequently, I will at times use simplified descriptions of higher-level

<sup>4</sup> The concepts of mapping and system are both derived in part from Piaget's and Werner's work. Piaget and his colleagues (Piaget et al., 1968; see also Flavell, 1977) have analyzed several behaviors of the preschool child in terms of what they call a function, which is similar to a mapping. But they seem to restrict their analysis to only a limited group of behaviors and analyze those behaviors in terms of the degree to which the behaviors match the characteristics of a mathematical function. Their conclusion is therefore that preschool children can sometimes show quasi functions (called constituent functions) but not real functions (called constituted functions). The skill-theory concept of mapping may be viewed as a re-definition, generalization, and extension of Piaget's concept of function. The concept of system is not directly present in Piaget's work, but it derives in part from Piaget's concept of concrete operations (Inhelder & Piaget, 1959/1964; Piaget, 1942, 1949). One of the most central aspects of a concrete operation is that it is reversible, but research does not support Piaget's argument that reversibility is absent in the pre-operational period and first emerges in the concrete operational period (Moore & Harris, 1978; Schmidt & Paris, 1978; Fischer & Roberts, Note 3). The concept of system in skill theory is intended to explain the behaviors that have been documented by Piaget's research on concrete operations but without requiring that reversibility be absent from mappings. Both mapping and system also incorporate explicitly Werner's hypothesis that development proceeds by simultaneous differentiation and hierarchical integration (coordination). The meanings of mapping and system are sufficiently different from Piaget's usage that attempts to plug Piaget's usage into skill theory will lead to serious errors.

sets; phrases such as *variations in length* or *the doctor role* will be used as shorthand in place of longer descriptions such as *the child's representation of variations in the seen lengths of the cord* or *the child's representation of variations in what she can make a doctor doll do in examining a patient doll*.

*Transformation rules.* The five major transformation rules specify how a skill can be transformed in development. Several rules deal with the ways that skills can be combined to produce more complex skills and how they change as a result of the combinations. The other rules indicate alterations in skills that are less drastic but that nevertheless produce clear-cut developmental orderings of skills. Although the rules specify qualitative changes in skills, these changes occur gradually, not abruptly.

The transformation rules are central to the theory, for they allow much more detailed predictions of sequence and synchrony than the cognitive levels alone. The levels produce only macrodevelopmental predictions (across levels), but the transformation rules also provide microdevelopmental predictions (within a level). By the microdevelopmental transformations, more complex skills can be constructed than the ones shown in Tables 1 and 3, which are the simplest possible at each level. Adequate formal definitions of the transformation rules depend on the formal descriptions of the levels, and so the rules will be defined precisely later.

#### *Notation*

The introduction of a notation system will allow semiformal description of both the characteristic structures for the levels and the transformation rules. It will thus facilitate use of the theory as a tool for analyzing development. The notation system and the structural descriptions are not rigorously formal; they are only as elaborate as is necessary to convey the intended meanings.

The notation rules are described in Table 2. Numbers and plain capital letters J, K, and L designate skill levels. Lowercase italic letters indicate skills of unspecified

level. Uppercase letters designate sets, with different typefaces specifying the tier of the set, as shown in Table 2.

Superscripts and subscripts on a capital letter give additional information about a set. Lines and arrows indicate relations between sets, and letters above or next to a line or arrow indicate a particular relation. Brackets designate a skill, and certain mathematical symbols and abbreviations specify the application of transformation rules.

#### *Recurring Cycle of Four Levels*

The progression of skills through the hierarchical levels shows a repetitive cycle, diagramed in Tables 1 and 3. This kind of repetition of structure has been discussed by both Piaget (1937/1954, 1967/1971) and Werner (1948), although neither of them has described the exact nature of the proposed parallels. The structures of Levels 1 to 4 are parallel to the structures of Levels 4 to 7 and 7 to 10, but at each cycle the structures are composed of a different type of set, as illustrated in Table 3.

Each cycle of four levels is a *tier* and is named for its type of set. For the first tier, Levels 1 to 4, the sets are *sensory-motor*; they are actions and perceptions of the child on things or events in the world. Within this tier, the combinations of sensory-motor sets grow more and more complex as the child develops through the first four levels, until at Level 4 the combinations create sets of a new kind, *representational* sets.

These representational sets designate concrete characteristics of specific objects, events, or people (including the child herself). Note that the new sets subsume sensory-motor sets, as shown in Table 3; the sets from the earlier tier do not disappear. For Levels 4 to 7, the representational tier, the new sets are again combined in more and more complex ways, producing a cycle parallel to that for Levels 1 to 4.

At Level 7, the combinations of representational sets create new sets of another kind: *abstract* sets, which are general, intangible attributes of broad categories of objects, events, or people. These new sets subsume the representational and sensory-motor sets from earlier tiers, as shown in

Table 3. What happens after Level 7 is primarily conjecture, because there has been so little research on cognitive development in adulthood. Yet the predictions of the theory are clear and direct: The abstract sets should produce an abstract tier—another progression through the cycle of four levels. When the combinations of abstract sets reach Level 10, they should produce still another new kind of set. Specification of the nature of the new sets at Level 10 must await future research on cognitive development in adults.

To distinguish the general cycle of levels from the specific levels, the Roman numerals I to IV will be used to refer to the levels of the cycle, and the Arabic numerals 1 to 10 will be used to refer to the actual behaviorally defined cognitive levels.

As shown in Table 1, Level I is characterized by *single sets*—single sources of variation that the child can control by themselves but not in relation to each other. That is, the child cannot yet coordinate sets into a higher-level skill.

The characteristic structure for Level II is a *mapping*—a relation between two sets, indicated by the long line in Tables 1 and 3.

When a mathematician says that one set is mapped onto another, he or she means, roughly speaking, that variations in the first set produce predictable variations in the second one. In an analogous way, at Level II a child can understand situations where he or she can relate one set of variations to a second set of variations.

Level III is characterized by a *system*—a relation between two sets each of which is divided into two subsets, indicated by the two-headed horizontal arrow between sets in Tables 1 and 3. The child is no longer limited to the two simple sets in the mappings of the previous level but can control relations between two subsets for each set. That is, the child can understand situations where he or she can systematically relate two components of one set of variations to two components of a second set of variations. In this way the child can deal with one subset while still keeping the other in mind and as a result can control much finer covariations in the two sets than at Level II.

The characteristic structure for Level IV is a *system of systems*—a relation between two systems, indicated by the two-headed vertical arrow in Tables 1 and 3. At this

Table 2  
Notation Rules

Type of symbol	Examples	Meaning
Roman numerals	I, II, III, IV	Cycle of levels that repeats in each tier
Arabic numerals	1, 2, . . . 5, . . . 10	The ten hierarchical levels
Plain capital letters J, K, and L	L, L + 1	Undesignated level
Lowercase italic letters	<i>b, s, e</i>	Skills of unspecified level
Boldface capital letters	<b>M, G, P</b>	Sensory-motor sets
Italic capital letters	<i>A, F, R</i>	Representational sets
Script capital letters	<i>D, N</i>	Abstract sets
Plain capital letters	W, X, C	Sets of undesignated tier
Superscript to the right	$G^A, F^N$	Sets designated by the main letter are components of the set designated by the superscript, which is at the next higher tier
Superscript to the left	${}^1A, {}^2P$	Level of set

Table 2 (continued)

Type of symbol	Examples	Meaning
Subscript to the left or right	$G_N, {}_2G_N, G_{N,P}, {}_N G_P$	Information of interest about the sets; used to discriminate related sets; two letter subscripts indicate the set is composed of two subsets
Brackets	$[A \leftrightarrow F]$	Sets and relations inside brackets constitute a single skill
Long line connecting two letters	$[A - F]$	Mapping: Relation between two sets
Horizontal two-directional arrow	$[A \leftrightarrow F]$	System: Relation between two sets, each composed of two subsets
Vertical two-directional arrow	$\begin{bmatrix} A & \leftrightarrow & F \\ & \updownarrow & \\ R & \leftrightarrow & S \end{bmatrix}$	System of systems: Relation between two systems
Lowercase letters above or next to line or arrow	$[A \xrightarrow{b} F], [A \xrightarrow{m} F]$	A particular relation
Multiplication sign	$[A \leftrightarrow F] \cdot [R \leftrightarrow S]$	Intercoordination of two skills
Addition sign	$[A \leftrightarrow F] + [F \leftrightarrow R]$	Compounding of two skills
Sign for greater than	$[A \leftrightarrow F] > [F \leftrightarrow R]$	Change in focus from the first skill to the second
Equals sign	$[A \leftrightarrow F] + [F \leftrightarrow R] = [A \leftrightarrow F \leftrightarrow R]$	The skill on the right is the result of the transformation indicated on the left
Foc	$\text{Foc}(e, f) = [e > f]$	A change in focus between the two skills on the left produces the skill on the right
Sub	$\text{Sub}[A \leftrightarrow F] = [A \leftrightarrow F_1]$	Substitution of a set in the skill on the left produces the skill on the right
Diff	$\text{Diff } A = A_M, A_N$ $\text{Diff}[A \leftrightarrow F] = [A_{G,H} \leftrightarrow F_{X,Y}]$	Differentiation of the set or skill on the left into the sets or skills on the right

level, a person can control the relation between two systems, keeping in mind one system while dealing with the other. This coordination of two systems produces a new kind of set, the most elementary set M at the next tier, as shown in Table 1.

The metaphor drawn in Figure 2 illustrates the cycle of four levels and the pro-

cess by which Level IV of one tier becomes Level I of the next tier. Level I can be thought of as a simple building block. Level II is then a combination of those building blocks in one dimension to form lines. At Level III, lines are combined to make two-dimensional objects, such as the square in the figure. Finally, at Level IV,

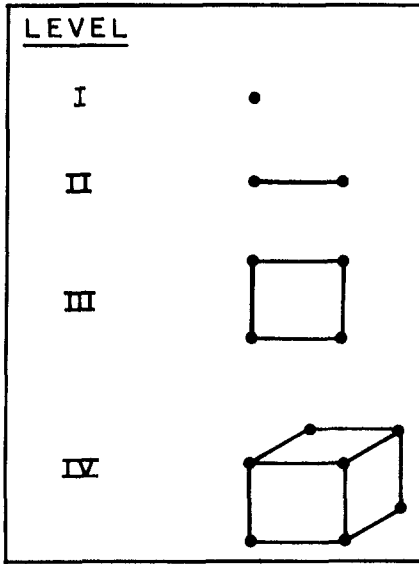


Figure 2. A metaphor for the cycle of four levels.

planes are combined to form three dimensional objects, such as a cube—a new type of building block. In this way the cycle begins over again, with Level IV of one tier serving as Level I of the next tier.

An elaboration of how this cycle of Levels I to IV applies in the sensory-motor,

representational, and abstract tiers will help to clarify the general picture of cognitive development presented by the theory. The child's potential skills with the spring-and-cord gadget in Figure 1 will be traced through the levels as a continuing example.

*Sensory-Motor Tier: Levels 1 to 4*

The first four levels constitute the sensory-motor tier, as shown in Table 3. In this tier, all skills are composed of sensory-motor sets—actions (including perceptions) on objects, events, or people in the world. Skills at this tier have most of the characteristics that have been called "sensory-motor" by a long and distinguished line of psychologists (e.g., Baldwin, 1925; Dewey, 1896; Hobhouse, 1915; Lashley, 1950; Piaget, 1936/1952; Werner, 1948): Both sensory and motor components are integral parts of the skills and for most purposes cannot be genuinely separated. Because the infants can control only sensory-motor actions, their skills are purely practical: They understand how to act on specific things in the world but cannot think about those things independently of acting on them. They understand what they can do

Table 3  
*Sensory-Motor and Representational Levels of Skills*

Level	Name of structure	Sensory-motor sets <sup>a</sup>	Representational sets	Abstract sets <sup>b</sup>
1	Single sensory-motor set	[ <sup>1</sup> A] or [ <sup>1</sup> B]		
2	Sensory-motor mapping	[ <sup>2</sup> A — <sup>2</sup> B]		
3	Sensory-motor system	[ <sup>3</sup> A <sub>G,H</sub> ↔ <sup>3</sup> B <sub>G,H</sub> ]		
4	System of sensory-motor systems, which is a single representational set	$\begin{bmatrix} {}^4A^R & \leftrightarrow & {}^4B^R \\ & \updownarrow & \\ {}^4C^R & \leftrightarrow & {}^4D^R \end{bmatrix} \equiv [{}^4R]$		
5	Representational mapping		[ <sup>5</sup> R — <sup>5</sup> T]	
6	Representational system		[ <sup>6</sup> R <sub>J,K</sub> ↔ <sup>6</sup> T <sub>J,K</sub> ]	
7	System of representational systems, which is a single abstract set		$\begin{bmatrix} {}^7R^{\mathcal{E}} & \leftrightarrow & {}^7T^{\mathcal{E}} \\ & \updownarrow & \\ {}^7V^{\mathcal{E}} & \leftrightarrow & {}^7X^{\mathcal{E}} \end{bmatrix} \equiv [{}^7\mathcal{E}]$	

<sup>a</sup> Sensory-motor sets continue after Level 4, but the formulas become so complex that they have been omitted. To fill them in, simply replace each representational set with the sensory-motor formula for Level 4.

<sup>b</sup> Development through the abstract tier shows the same cycle as development through the sensory-motor and representational tiers. Abstractions are built from representational and sensory-motor sets in the same way that representations are built from sensory-motor sets.

and what they make happen. They do not understand that objects, events, and people have their own characteristics independent of what the infants themselves do; that ability awaits the development of representational sets at Level 4. Consequently, a child does not realize, for example, that her favorite rattle has properties like hardness and the capacity to make noise that are independent of her own actions on it. Nor does she understand that people and many other things can act by themselves independently of her actions. To emphasize the domination of this world by action and to avoid confusion from terms like *object* or *person*, I will refer to objects, people, and other things in the infant's experience as *tableaus*.<sup>5</sup> For example, an infant grasps a tableau, not an object, and listens to a tableau, not an object.

Several independent investigators have recently reported data that generally support the pattern of developmental changes predicted by the four sensory-motor levels (Emde, Gaensbauer, & Harmon, 1976; Kagan, 1979; McCall, Eichorn, & Hogarty, 1977; Uzgiris, 1976). McCall's analyses are especially relevant: In examining patterns of correlations among items in infant tests, he found changes in correlation patterns that suggested four successive periods of change and consolidation in the first two years of life—times of instability in correlations followed by times of stability. If infants are in fact developing through Levels 1 to 4 in an age-related progression, one would expect periods of change and consolidation in correlations exactly like those that McCall found. Further research to test the relation between McCall's findings and the levels clearly needs to be done.

The characteristic structure of *Level 1* is the single sensory-motor set (shown in the top row of Table 3), a set, <sup>1</sup>D, of acting on tableaus, such as looking at a doll. A 12-week-old infant may look for long periods at the tableau produced by a doll hanging on a string in front of her. Even when the doll swings back and forth in a wide arc, she can keep her gaze on it. This is a single sensory-motor set or action, the set <sup>1</sup>D of adaptations of looking at the doll tableaus. Similarly with the spring-and-cord

gadget, one set, <sup>1</sup>S, involves the infant's looking at the gadget when it crosses her field of vision and maintaining it in her sight. Another set, <sup>1</sup>G, involves her grasping the spring when it touches her hand and maintaining her grasp on it. Most of Piaget's (1936/1952) primary circular reactions seem to be Level 1 single sensory-motor actions. The infant can control many such single sets at Level 1, but she cannot control the relations between sets.

Single sensory-motor sets are not limited to adult-defined modalities in perception and action. The young infant does not know, for example, that seeing is different from listening. When she is attempting to look at the doll swinging in front of her, any sounds it makes can be incorporated into her set <sup>1</sup>D. So long as she does not have to relate the sights and sounds independently, sight and sound can be mixed together in the same Level 1 skill. This lack of differentiation at Level 1 contrasts with Piaget's (1936/1952) argument that young infants have differentiated schemes for seeing, hearing, grasping, and so forth, which must be coordinated together. The undifferentiated and uncoordinated status of Level 1 skills in the present theory fits Werner's (1948, 1957) characterization of a developmentally primitive state. Many of the studies of classical and operant conditioning in young infants may involve such undifferentiated multi-modality sets (see Papousek, 1967; Sameroff, 1971).

Although infants cannot control any relations between sets at Level 1, they do readily drift from one set to another, usually led by some tableau. Consequently, even though they cannot yet coordinate two sets, they do not become stuck on one set for long. Indeed, their drifting from set to set eventually leads them to explore the relation between two sets and so to intercoordinate them into a Level 2 skill, simultaneously differentiating them from each other.

The characteristic structure of *Level 2* is

<sup>5</sup> For the same reasons, Piaget occasionally used this term in his works on infancy (Piaget, 1936/1952, 1937/1954). He did not, however, use it consistently in these works, and he has not used it in subsequent works.

the sensory-motor mapping, in which one sensory-motor set, <sup>2</sup>A, is mapped onto a second sensory-motor set, <sup>2</sup>B, as shown in Table 3. One type of sensory-motor mapping is a means-end mapping, in which a child can use one action in order to bring about a second action. For example, a 7-month-old infant looks at a tableau of a doll and uses what she sees to guide her attempts to grasp the tableau (Field, 1976; Lasky, 1977; Ruff, 1976). She has combined two simple actions, looking at the doll and grasping it, into one means-end mapping in which looking is used as a means to bring about grasping. That is, she has mapped the sensory-motor set <sup>2</sup>D of looking at the doll onto the sensory-motor set <sup>2</sup>H of grasping it, as shown in Table 3. She may also have a separate, complementary mapping, in which she maps grasping the doll onto looking at it. For example, she grasps the tableau of the doll and brings it before her eyes so that she can look at it. Similarly, with the spring-and-cord gadget, an infant pulls on the spring, <sup>2</sup>G, so that she can watch it stretch, <sup>2</sup>S. Many of Piaget's (1936/1952) secondary circular reactions are means-end actions of this sort, although a number of the behaviors that he classifies in this category seem to be complex forms of Level 1 actions.

Sensory-motor mappings should include many types of skills besides means-end mappings, especially skills involving two components within the same modality. Bertenthal, Campos, and Haith (in press) describe one such skill: By 7 months, infants can apparently relate several visual components such as angles to form a line (see Level II in Figure 2). Presumably many more such mapping skills develop within modalities such as looking, grasping, and the like in infants.

Just as with Level 1, however, Level 2 skills cannot be subdivided according to adult conceptions of modalities. If stimuli from two different adult-defined sensory modalities, for instance, co-occur in such a way that the infant can treat them as one source of variation, then at Level 2 the infant can treat them as a single set that she can relate to a second set. The same kind of concern about the definition of sets must be

considered at every level and especially at the earliest levels within a tier, where differentiation is always poor.

*Level 3* is characterized by the sensory-motor system, in which two components of one sensory-motor set, <sup>3</sup>A<sub>G,H</sub>, are related to two components of a second sensory-motor set, <sup>3</sup>B<sub>G,H</sub>, as shown in Table 3. The most investigated type of sensory-motor system is the means-end system. Unlike the means-end mapping of Level 2, the means-end system allows the infant to control complex variations in means and ends (Fischer, Note 4). For example, Piaget's 10.5-month-old son Laurent drops a piece of bread, watches it fall, breaks off a crumb and drops it, watches it fall, and so forth (Piaget, 1936/1952, Observation 141). He constantly varies the means (the way in which he drops the bread) and watches closely the variations in the end (seeing the bread fall).

At Level 2, he was unable to perform such a complicated experiment in action; he could learn little more than that dropping produced falling. The reason for this limitation was that he could relate only one aspect of dropping the bread to one aspect of seeing the bread fall.

At Level 3, he can relate two aspects of each action, and therefore he can build skills that coordinate and differentiate types of variations in dropping with types of variations in falling. Similar kinds of skills can be built with the spring-and-cord gadget—for example, learning not only that pulling the string makes it stretch but that pulling it in different ways makes it stretch differently. Examples of such means-end systems abound in the research literature (e.g., Bryant, 1974, p. 162 ff.; Koslowski & Bruner, 1973; Fischer & Roberts, Note 3). As with earlier levels, researchers have neglected other types of Level 3 skills, such as those within a modality (see Fischer & Corrigan, in press).

Despite all the sensory-motor sophistication of Level 3, the skills are still definitely limited: The infant is only able to control one sensory-motor system at a time, and therefore he cannot yet deal with many of the complexities of acting on objects, nor can he understand objects independently



of his own actions. In the world, every object is in fact the focus of a number of different sensory-motor systems; that is, every object can be made to participate in or produce many different types of actions. The ability to understand objects in this way (as independent agents of action) first develops at Level 4 (Watson & Fischer, 1977).

*Representational Tier: Levels 4 to 7*

Level 4 is the culmination of the sensory-motor tier, and so it produces a new type of set and begins a new tier, the representational tier. In terms of the repetitive cycle of levels, the characteristic structure for Level 4 is the system of sensory-motor systems (sensory-motor Level IV), which is the same as the single representational set (representational Level I). This type of skill is a relation between two sensory-motor systems, as shown in Table 3. The combination of these systems generates the single representational set in which children can represent simple properties of objects, events, and people independently of their own immediate actions.

With the spring-and-cord gadget, the child can combine Level 3 systems for the gadget into a single Level 4 representation. One such skill involves the child's understanding that the spring itself stretches. For example, the following two systems can be coordinated at Level 4: When he pulls the spring, it stretches; when he sees someone else pull the spring, it stretches. Therefore, a characteristic of the spring is that it stretches; the child controls a representational set <sup>4</sup>L for the spring's stretching. In the same way, he constructs a set <sup>4</sup>W representing that the weight itself can "pull," independently of his feeling it; and he constructs a set <sup>4</sup>C representing that the cord can be big, independently of his making it move.

With these single representations, the child shows a lack of differentiation analogous to that with Level 1 single sensory-motor actions. In the gadget, he will confuse the pressure exerted by the weights with their size, mixing them both together as "big." Similarly, he will confuse the total length of the cord with the length of the

vertical or horizontal segment. Tasks can be designed that will help him to separate such factors in one situation, but when the factors covary in a task, the child will treat them in a single representation.

Many different types of representational sets should develop at Level 4, according to the theory; and Piaget (1946/1951, Observation 64) described a behavior that demonstrates a second type, a set of objects or events that all share a single action or characteristic. His daughter Jacqueline used the word *bimbam* to mean swaying or fluttering. She combined her sensory-motor system for rocking back and forth on a piece of wood with her system for making a leaf flutter and used "bimbam" to refer to both. Then she gradually extended this representational set to a wide range of objects.<sup>6</sup> Other examples of the construction of single representational sets from sensory-motor systems have been described by Bertenthal and Fischer (1980), Watson and Fischer (1977), Fischer and Corrigan (in press), Fischer and Roberts (Note 3), and Fischer and Jennings (in press).

A word of caution may be helpful at this point about the meaning of representation. The term is often used as a virtual synonym for recall memory or for symbol use. But in skill theory, representation is different from both of these meanings. It refers to the coordination of two or more sensory-motor systems to form a single representational set, not to recall memory or symbolization per se. Skills involving both recall memory and symbol use can develop before Level 4, and in addition skills can be constructed at Level 4 that do not centrally involve either recall or symbol (Fischer & Corrigan, in press). A single representation is defined by its structure, not by its function as recall, symbol, or any other such psychological category.

The characteristic structure for Level 5 is the representational mapping, in which one representational set, <sup>5</sup>R, is mapped onto a second representational set, <sup>5</sup>T, as shown

<sup>6</sup> The rules of compounding, substitution, differentiation, and intercoordination nicely account for the sequence by which this skill developed, as described by Piaget (1946/1951).

in Table 3. With this kind of skill, the child can relate variations in one representation to variations in a second representation.<sup>7</sup> Consider a 4- or 5-year-old who is given the spring and several weights of different sizes from the gadget in Figure 1. If he has had sufficient experience with the task, he can roughly use the size of the weight (one set) to control the length of the spring (the other set), thus understanding in an approximate way that large weights will make the spring stretch farther than small weights.

Notice in Table 3 that this structure (like all representational structures) can be described either in terms of representational sets without visible reference to their sensory-motor origins or in terms of the sensory-motor sets on which the representational sets are based. For example, the child's understanding of the relation between weight and spring ties directly to his overt actions of manipulating and seeing the weight and spring, because the representational sets are actually composed of sensory-motor systems specifying what the child can do with the gadget.

Besides the representations for weight and length of spring, the child could also construct representations for the length of the vertical segment of the cord and the length of the horizontal segment (or depending on the nature of the specific gadget, a representation for the total length of the cord). A child who is very familiar with the gadget could conceivably possess at least 12 different mappings, all possible pairings of the four sets—weight, spring length, vertical and horizontal lengths of cord (see Wilkering, 1979). Despite all this knowledge, the child's understanding of the gadget would be peculiarly disjointed because of his inability to consider two aspects of each set simultaneously. That is why, for example, he has difficulty treating the vertical and horizontal lengths as segments of a single cord of constant length.

*Level 6* is characterized by a representational system, in which the child relates two subsets of one representation,  ${}^6R_{J,K}$ , to two subsets of a second representation,  ${}^6T_{J,K}$ , as shown in Table 3. For example, he can understand conservation of length of the cord in the gadget, as described earlier. He

combines the vertical and horizontal lengths of the cord when one weight is used with the same length when another weight is used, and thus he knows how the lengths vary together and compensate for each other (Piaget et al., 1968; Verge & Bogartz, 1978). With the gadget, he can also construct several other Level 6 systems, each involving the relation of two concrete variables to each other. Other representational systems that have been studied in the research literature include most of Piaget's concrete operational tasks (e.g., Inhelder & Piaget, 1959/1964) and a number of other tasks (e.g., Watson & Fischer, 1980; Winner, Rosenstiel, & Gardner, 1976).

Despite all this sophistication, however, the skills of Level 6 are still definitely limited. The child can only deal with one Level 6 system at a time. He cannot relate various systems to one another. Even if he understands every one of the possible Level 6 systems in the gadget, for example, he cannot integrate them into a single higher-level skill. More generally, he cannot yet understand objects independently of their overt characteristics, because he is limited to dealing with one Level 6 system at a time. That is, he cannot think of objects in the abstract.

#### *Abstract Tier: Levels 7 to 10*

*Level 7* is the culmination of representational development, generating a new kind of set and starting a new tier, the abstract tier. In the recurring cycle of four levels, the characteristic structure for Level 7 is the system of representational systems (representational Level IV), which is the same as the single abstract set (abstract Level I). In an abstract set, the person abstracts an intangible attribute that charac-

<sup>7</sup> Piaget does not postulate the existence of a major cognitive-developmental change in the middle preschool years, but some of his own research suggests that there might be such a change (Piaget et al., 1968), and many studies over the last two decades have documented that preschool children's abilities are far greater than prior research had indicated (Gelman, 1978). Also, two developmental theories that are not as well known as Piaget's posit a major developmental shift at about age 4 (Bickhard, 1978; Isaac & O'Connor, 1975).

terizes broad categories of objects, events, or people. (Note that, as with representation, abstraction has many different meanings in psychology; see Piaget, 1965. These various meanings should not be confused with the specific meaning used here.)

In a Level 7 skill, the person can control the relation between two representational systems, as indicated by the Level 7 structure in Table 3. Consider a 15-year-old boy who can control a system of systems for the sets in the spring-and-cord gadget. He can integrate several of the systems from the previous level into a single Level 7 system that controls the relations among the weight, the vertical length of the cord, the horizontal length of the cord, and the length of the spring. When he is thinking, for example, about how the changes in weight produce changes in the length of the spring, he can simultaneously consider how those changes relate to the changes in the vertical and horizontal lengths of the cord. He can thus understand how all the changes covary. This skill not only allows him to control the gadget effectively, but it also gives him an abstract set for the general state of the gadget.

Many different kinds of abstractions can be constructed at Level 7. For example, a person can for the first time understand the abstract concept of conservation—variations in two related quantities compensate for each other so as to produce no change in some superordinate quantity. With only Level 6 skills, the person can understand most of the individual kinds of conservation that Piaget and his colleagues have documented (Piaget & Inhelder, 1941/1974; Piaget & Szeminska, 1941/1952), but cannot integrate those separate conservations into an abstract concept of conservation.

For instance, the person combines the skill for conservation of the length of the cord in the gadget with the skill for conservation of amount of clay (where the same piece of clay is squeezed into different shapes, such as from a ball to a sausage). In the conservation-of-length task, the two lengths are equal because the vertical and horizontal lengths compensate for each other. In the conservation-of-clay task the two amounts are equal because changes in

length and width compensate for each other. The coordination of these two concrete conservation skills produces the abstract concept of conservation, which can then be generalized to other tasks. Other instances of Level 7 skills include most analogies (Lunzer, 1965), political concepts like law and society (Adelson, 1972), and a few of Piaget's simpler formal operational tasks (Inhelder & Piaget, 1955/1958).

Following the recurring cycle, abstractions should develop through Levels 7 to 10. For example, with the spring-and-cord gadget, the individual will start with single abstractions such as conservation, then relate two such abstractions in a mapping, and so forth. Because so little research has been done on cognitive development beyond adolescence, however, no data are available to provide a strong test of such predictions. To illustrate the kind of developmental progression that is predicted and to emphasize the applicability of the theory to things other than cold cognition, I will present a hypothesized sequence in the development of a person's identity (Erikson, 1963)—one's sense of the kind of person one is.

At Level 7, single abstract sets, a person can for the first time construct abstract identity skills (see Erikson, 1974). These identity concepts result from the coordination of two representational systems about the self. For instance, a certain 9-year-old may have a Level 6 system for identification with his father's career as a psychologist. He relates his representation of himself to his representation of his father as a psychologist (Kagan, 1958). Likewise, he has another system relating his representation of himself as both skilled with other people and good at science to his representation of what psychologists do: They are people-oriented scientists. Most 9-year-olds are not yet capable of coordinating two such Level 6 systems into a Level 7 skill.

A few years later, when the child can coordinate the two systems, he can thus construct his first abstract set for his career identity. With the addition of a few other representational systems to the Level 7 skill via microdevelopmental transformations, he can build a complex abstract set relating

various of his own characteristics to various aspects of the career that he is considering.

At *Level 8*, abstract mappings, the person can relate one abstract identity concept with another. For example, he can coarsely relate his own career identity with his conception of his potential spouse's career identity: Perhaps he sees his own career identity as requiring that his spouse be in a closely related career or perhaps as requiring that his spouse be primarily a homemaker.

*Level 9* abstract systems produce a much more flexible, differentiated relation between two identity concepts. For instance, the person can relate two aspects of his own and his spouse's identity, such as career and parental identities, and thus consider in a more differentiated way what his own identity requires of his spouse's identity and what his spouse's identity requires of his own identity.

Finally, at *Level 10*, systems of abstract systems, this person can coordinate two or more abstract identity systems. He might relate his own and his spouse's career and parental identities now (one *Level 9* system) with their career and parental identities 10 years ago when they were first married (a second *Level 9* system). The result is a higher-level conception of what their joint career and parental identities have been like during their marriage.

Although I know of no rigorous tests of this or any other developmental sequences in abstract skills during adolescence and adulthood, several investigators have reported data that generally support the predictions of development from Levels 7 to 10. Some of the most detailed findings involve developments in the history of science. Both Miller (Note 5) and Gruber (1973; Gruber & Barrett, 1974) have described developments of scientific theory that seemed to them to roughly follow Piaget's description of cognitive development from the pre-operational period to the formal operational period. Miller illustrates this parallel for the development of quantum mechanics, and Gruber for the development of Darwin's theory of evolution. If these scientific theories were developing through Levels 7 to 10, their progression would resemble the

progression from pre-operational to formal operational thought, according to skill theory, because both the Piagetian periods and the scientific progressions involve development within a tier from Levels I to IV.<sup>8</sup> Oddly, Piaget too (1970; Piaget in Beth & Piaget, 1961/1966) has suggested that there may be general parallels between the development of scientific theories and the development of cognition in the child. I say "oddly" because his position on formal operations seems to preclude such parallels.

Within Piaget's framework, cognitive development virtually ends with formal operations: Adolescents entering the formal operational period have achieved fully logical thinking, and there is little more for them to do, except perhaps to extend their logical thinking to new content areas (Piaget, 1972). Many people have been dissatisfied with this conception of formal operations (e.g., Arlin, 1975; Gruber & Vonèche, 1976; Riegel, 1975; Wason, 1977), but there has been no alternative position for analyzing development beyond early adolescence. Consequently, major age differences in the acquisition of various of Piaget's formal operational tasks have been interpreted primarily as resulting from performance factors, not from developmental changes (Inhelder & Piaget, 1955/1958; Martarano, 1977; Neimark, 1975). According to skill theory, many of these age differences may well arise because the tasks require different levels of abstraction.

Piagetian scientific tasks and the rarefied atmosphere of theory construction are not the only places that skills should develop through Levels 7 to 10. Most adults probably master at least a few skills beyond *Level 7*, like the hypothesized identity concepts. Other skills that probably belong to Levels 7 to 10 include moral judgment, the managerial skills of the director of a corporation or a school system, the skills required to write an effective essay or novel, and the skills involved in programming and operat-

<sup>8</sup> Within the present theory, Piaget's pre-operational, concrete operational, and formal operational periods are explained by Levels 4 to 7.

ing a computer (Fischer & Lazerson, in press, chap. 13).

### *Transformation Rules*

Now that the structures of the levels have been described, the operation of the five transformation rules can be illustrated with some precision. The five rules specify how a skill is transformed into a new, more advanced skill. These rules are thus the heart of the mechanism for predicting specific sequences of development. The need for such a set of transition rules to account for developmental change has been recognized for a long time by many developmental psychologists (e.g., Beilin, 1971; Brainerd, 1976; Flavell, 1963; Kessen, 1966; Van den Daele, 1976). The rules are also intended to apply to changes in the organization of behavior during learning or problem solving (Fischer, 1975, 1980; Leiser, 1977).

The transformation rules and the skill structures of the levels should be able to explain most of the developmental sequences documented in the research literature. In addition, many new sequences can be predicted that have not yet been investigated. In this section on the transformation rules, however, I will refrain from reviewing empirical support for the rules, so that I can present the concepts briefly and directly. In a later section, several studies testing predictions based on the rules will be described.

The five transformation rules are intercoordination, compounding, focusing, substitution, and differentiation. Intercoordination and compounding specify how skills are combined to produce new skills. Intercoordination describes combinations that produce development from one level to the next (macrodevelopment), and compounding describes combinations that produce development within a level (microdevelopment). Focusing and substitution specify smaller microdevelopmental steps than compounding. Focusing deals with moment-to-moment shifts from one skill to another, and substitution designates certain cases of generalization of a skill. The fifth rule, differentiation, indicates how sets become separated into potentially distinct sub-

sets when one of the other four transformations occurs, but it can also be used separately to predict microdevelopmental steps. The microdevelopmental transformations of differentiation, substitution, focusing, and compounding eventually produce the macrodevelopmental transformation of intercoordination. These five transformation rules are probably not exhaustive; future research will indicate whether additional transformation rules are required.

All the transformations are defined structurally. Two or more skills with given structures are transformed into one or more skills with a new type of structure. The induction of a specific structural transformation always involves both organismic and environmental factors. At least two organismic factors are involved: The person must initially have the skills required for application of the transformation and must be capable of applying the transformation rules to those skills. For example, if a person has the necessary initial skills but they are already at her optimal level, then she will not be able to apply the transformation for combining those skills to reach the next higher level.

Likewise, at least two environmental properties are necessary. First, the environment must have properties such that if the initial skills are transformed, the resulting new skill will work. Second, the specific environmental situation must have properties such that it will induce the person to use the initially separate skills in juxtaposition, thus leading her to explore the relations between the initial skills and construct the transformed skill (see also Schaeffer, 1975). The transformation therefore requires both organism and environment; transformations cannot be attributed to either organism or environment alone.

Two of the transformation rules, intercoordination and compounding, involve combinations of two skills to produce a new, more complex skill. Many psychologists have talked about combinations of skills as a mechanism to explain the development of more complex skills, especially in the literature on skill acquisition (e.g., Bruner, 1971, 1973; Fitts & Posner, 1967) and the Piagetian literature (e.g., Cunningham, 1972; Hunt,

1975; Piaget, 1936/1952). The first two transformation rules attempt to specify exactly how such skill combinations occur.

*Intercoordination*

Intercoordination specifies how the person combines skills to develop from level to level, all the way from Level 1 to Level 10. The process is analogous to the combination of atoms to form a molecule. At the beginning of the process of intercoordination, the child has two well-formed skills, *a* and *b*, at a specific Level 1. The two skills are functioning separately from each other until some object or event in the environment induces the child to relate the two skills to each other. The child then works out the relationship between the two skills with that object or event and so gradually intercoordinates the skills. When the intercoordination is complete, the two skills, *a* and *b*, from Level *L* have been transformed into a new skill, *d*, at Level *L* + 1, which includes them. The process is diagramed as follows:

$$a \cdot b = d. \tag{1}$$

The multiplication symbol signifies intercoordination (Table 2).

The essence of the process of intercoordination lies in what seems to most adults to be a paradox. A child is given a task that normally requires a Level *L* understanding, but her skill for that task is only at Level *L* - 1. Consequently, she seems to have all the knowledge that is needed to perform the task, yet cannot do it. Only when she intercoordinates the relevant skills at Level *L* - 1 to form the new skill at Level *L* will she be able to perform the task. Note, however, that this process of intercoordination is gradual and continuous. The fact that it involves qualitative change does not in any way imply that the change is abrupt or discontinuous.

The development of conservation of length in the gadget (Piaget et al., 1968) provides a clear illustration of this paradox. As stated before, the child must have a Level 6 skill to understand that the length of the cord conserves despite changes in the lengths of the vertical and horizontal seg-

ments. When her skills with the gadget are only at Level 5, she can understand two separate representational mappings involving the vertical and horizontal segments of the cord. She can understand the mapping from the horizontal segment,  ${}^5C_H$ , to the vertical segment,  ${}^5C_V$ , using the horizontal length to predict the vertical length; and she can understand the mapping from the vertical segment,  ${}^5C_V$ , to the horizontal segment,  ${}^5C_H$ , using the vertical length to predict the horizontal. As a result, the child's behavior with the cord at Level 5 seems paradoxical to an adult. The child seems to understand how the horizontal and vertical segments of the cord change and how the changes relate to each other, yet she does not recognize that the total length of the cord must always remain the same because the changes compensate for each other (Wilkening, 1979).

The paradox is resolved when the child intercoordinates the two mappings to produce the Level 6 skill for conservation of length in the gadget, as follows:

$$[{}^5C_H \text{ --- } {}^5C_V] \cdot [{}^5C_V \text{ --- } {}^5C_H] = [{}^6C_{H,V} \leftrightarrow \frac{1}{2}C_{H,V}]. \tag{2}$$

The child with this Level 6 skill can understand how vertical and horizontal length interrelate, instead of merely how vertical relates to horizontal and how horizontal relates to vertical (Verge & Bogartz, 1978). That is, she has constructed a skill for the total length of the cord (composed of horizontal and vertical components), and that skill allows her not only to predict how horizontal and vertical vary but also how their covariations sum to a constant length.

The formal descriptions of Levels 1 to 7 in Table 3 indicate graphically how intercoordination occurs at each level. Repeatedly as one moves down the table, the combination of two skills at one level produces a new kind of skill at the next level. The diagrams in Table 3 also show how each skill at one level still includes the two skills from the previous level. The formal descriptions thus show both the origin of each higher-level skill in the lower-level skills and the emergence of a new type of skill at the higher level.

I chose the term *intercoordination* be-

cause it provides a specifically appropriate description of the process of combination of two skills at one level to form a new skill at the next level. Intercoordination means reciprocal coordination. Two lower-level skills become coordinated with each other and thereby produce a new higher-level skill. In this article, the term *intercoordination* is reserved explicitly for this process. The term *coordination* is used to refer in general to all instances of a person's relating two or more actions whether or not he or she is going through the process of intercoordination.

### Compounding

The second rule for combination of skills, compounding, specifies the most important microdevelopmental transformation. In compounding, two skills, *a* and *b*, at Level *L* are combined to form a more complex skill, *c*, at the same Level *L*.<sup>9</sup> The process is diagramed as follows:

$$a + b = c. \quad (3)$$

The addition symbol signifies compounding. Just as with intercoordination, compounding is induced by both organismic and environmental factors. First, the person must possess skills *a* and *b*, and second, some object or event in the environment must induce him or her to combine them.

An example will clarify the compounding process. Consider an 18-month-old who has one Level 3 skill relating holding a pillow, <sup>3</sup>P, to placing her head on the pillow, <sup>3</sup>H, and a second Level 3 skill relating placing her head on the pillow, <sup>3</sup>H, to going to sleep, <sup>3</sup>S. (Going to sleep is originally an involuntary response, but like blinking and breathing, it can be brought under partial voluntary control. Many children at this age expend a lot of effort trying to control sleeping and the circumstances that accompany it. Usually, the specific response that is signified by <sup>3</sup>S is voluntarily closing the eyes or saying "sleep.") With these two skills, the child still cannot control all three actions at once: holding the pillow, placing her head on the pillow, and going to sleep. To do so, she must compound the two Level 3 skills:

$$[\text{<sup>3</sup>P} \leftrightarrow \text{<sup>3</sup>H}] + [\text{<sup>3</sup>H} \leftrightarrow \text{<sup>3</sup>S}] = \text{<sup>3</sup>P} \leftrightarrow \text{<sup>3</sup>H} \leftrightarrow \text{<sup>3</sup>S}. \quad (4)$$

She thus produces a more complex Level 3 skill that allows her to control the relations among all three actions.

What behavioral consequences does such a skill have? When the child is actually in bed, it is difficult to assess whether she has the skill, because the context alone produces all three components. As a result, she can show all three actions together without controlling the relations among them. The existence of this environmentally elicited conjunction of the three actions, on the other hand, shows how the environment can induce combination of the actions into a complex skill. At least once or twice every day, the child is faced with a situation where the three actions go together. Almost inevitably, then, she will explore the relations among the actions and ultimately produce the compounded skill in Equation 4.

For assessment of this compounded skill, pretend play provides a better situation than going to bed, because in pretend play the child must actively put the three actions together. When she can control all three actions in a single system, then she can pretend to go to sleep—holding the pillow, placing her head on it, and closing her eyes (Watson & Fischer, 1977). Other developmental sequences involving compounding have been tested and supported by Bertenthal and Fischer (1978), Watson and Fischer (1980), Hand (1980), and Fischer and Roberts (Note 3).

The process of compounding is not necessarily limited to combining just two simple skills. It also has more complex forms, with combinations of larger numbers of skills. For example, the child might compound the Level 3 skill in Equation 4 so that it included four or five actions instead of only three.<sup>10</sup> Indeed, such successive compound-

<sup>9</sup> Compounding of another sort might also occur. The skill *d* at Level *L* + 1 might be combined with skill *c* at Level *L* to form the more complex skill *e* at Level *L* + 1. Research is required to determine whether both types of compounding exist.

<sup>10</sup> Two points should be noted about this complex kind of compounding. First, the number of skills compounded cannot be endless because compounding

ing may ultimately account for much of the process of intercoordination, as I will illustrate later.

Compounding describes relatively large microdevelopmental steps. The next two transformation rules, focusing and substitution, describe smaller microdevelopmental changes.

*Focusing: Moment-to-Moment Behavior*

Focusing deals with one kind of shift in what is commonly called attention. It describes not only a type of developmental change but also a type of moment-to-moment change in behavior. In a specific task or context, a person will normally have a collection of skills available, and those skills will generally be related to each other because subgroups of them will share one or more sets. For example, recall the hypothetical child who has a complete Level 5 understanding of the gadget (without compounding): She understands 12 different two-set mappings, all possible pairings of the four sets involving the gadget. In this collection of skills, each set is included in six of the mappings. At a given moment with the gadget, the child will be using one of the mappings. When she shifts focus, she shifts from one specific mapping to a second closely related mapping that shares at least one set with the first mapping.<sup>11</sup> A shift in focus from skill  $e$  to skill  $f$  is represented symbolically as follows:

$$e > f. \quad (5)$$

The symbol for "greater than" thus signifies a shift in focus. When a shift in focus can be consistently controlled by the child, the transformation is diagramed:

$$\text{Foc}(e, f) = [e > f]. \quad (6)$$

The levels of the collection of skills that a person has available to her on a specific

task determine the limit of what the person can handle cognitively in that task. At any one moment, she cannot bring to bear all of her skills; normally, she can deal with only one skill at a time. Focusing describes the person's shifts from one skill to another within the level or levels at which she is functioning in the task. For instance, the hypothetical child knows a lot about the gadget, because she has mastered all 12 mappings. Nevertheless, her understanding of the gadget is severely limited by the fact that she can focus on only one mapping at a time.

Say that at a certain moment she is considering the set,  ${}^5W$ , of weights. She cannot deal with all six of the mappings for weight but must focus on just one, such as the mapping of weight,  ${}^5W$ , onto length of the spring,  ${}^5L$ . A few moments later, she shifts focus to a second, related skill, the mapping of horizontal length of the cord,  ${}^5C_H$ , onto length of the spring,  ${}^5L$ , and then she shifts focus to the mapping of length of the spring,  ${}^5L$ , onto horizontal length of the cord,  ${}^5C_H$ . These changes in focus are diagramed as follows:

$$[{}^5W - {}^5L] > [{}^5C_H - {}^5L] > [{}^5L - {}^5C_H]. \quad (7)$$

Clearly, changes in focus can produce very complicated sequences of behavior. In assessing a person's skills with a task, care must be taken to separate mere changes in focus from the actual control of relations between sets. The shifts in focus indicated in Formula 7 do not demonstrate control by the child of the compounded skill  $[{}^5W - {}^5L - {}^5C_H - {}^5L - {}^5C_H]$ , although under the proper environmental circumstances they can be transitional to the formation of such a compounded skill.

Focusing is not, however, merely a statement of a methodological difficulty.

is probably seriously limited by memory. Limitations should be much less severe when the skills are intercoordinated into a higher-level skill. Second, a mere string of behavior, occurring once or twice, does not indicate that the person has compounded all the behaviors in the sequence into a single skill. Just as with the little girl in bed, one must be certain that the person actually controls the relations between sets.

<sup>11</sup> Notice that according to this definition, focusing could not happen at Level 1, because skills at Level 1 each include only one set. However, the theory predicts that Level 1 sensory-motor sets are generated by a prior reflex tier, which specifies the components of a Level 1 set and thereby indicates how focusing applies to Level 1. The nature of this tier will be suggested later.



It allows predictions of certain kinds of developmental orderings. Consider a task that can be solved with, at a minimum, two skills at Level L and a shift in focus from one of the skills to the other. This task is more complex than a task that can be solved with, at a minimum, one skill at Level L. If the two tasks are within the same task domain, then the first, more complex task is predicted to develop after the second task.

For example, suppose that the gadget is partially covered, so that only two variables are visible at a time. The child first deals with only the weight,  ${}^5W$ , and the vertical segment,  ${}^5C_v$ , using the skill

$$[{}^5W - {}^5C_v]. \quad (8)$$

Once she has used this skill, the cover is changed so that she can see only the vertical segment and the spring, which requires the skill

$$[{}^5C_v - {}^5L]. \quad (9)$$

By shifting what is covered, the experimenter can thus control the child's change in focus:

$$[{}^5W - {}^5C_v] > [{}^5C_v - {}^5L]. \quad (10)$$

For the child to do this task as described in Formula 10, she must have both Level 5 skills. The focusing rule therefore predicts that the skills in Formulas 8 and 9 will develop before the change in focus in Formula 10. A developmental sequence of this type has been demonstrated by Gottlieb, Taylor, and Ruderman (1977).

With the covering procedure, the experimenter can teach the child to change focus consistently. The child will thus learn a new skill involving a change of focus:

$$\text{Foc} ([{}^5W - {}^5C_v], [{}^5C_v - {}^5L]) = [({}^5W - {}^5C_v) > ({}^5C_v - {}^5L)], \quad (11)$$

which will allow her to do the task even when all three variables are uncovered. This controlled-focusing skill is slightly more advanced developmentally than the simple change in focus in Formula 10. It is also transitional to the compounded Level 5 skill

$$[{}^5W - {}^5C_v - {}^5L], \quad (12)$$

which involves control of all three variables at once instead of only two.

According to this analysis, then, the child will show the following microdevelopmental sequence of skills: first Formula 8 or 9, then Formula 10, then Formula 11, and finally Formula 12. Similarly, the focusing rule predicts many microdevelopmental sequences, such as transitional steps between acquisition of the simple Level 3 skills on the left-hand side of Equation 4 and acquisition of the compounded Level 3 skill on the right-hand side of Equation 4. See Hand (1980) and Watson (1978) for tests of additional sequences involving focusing.

### Substitution

The transformation rule of substitution deals with one type of generalization: A skill at Level L is mastered with one task, and then the person attempts to transfer it to a second, similar task. The rule applies when all components but one in the first task are identical with those in the second task and when that one different component can be generalized to the second task. At Levels II and III, the component must be a set; at Level IV (which is Level I of the next tier), it can be a set or a system. The skill with the substitute component will be mastered after the original skill and before any skills of greater complexity in the same task domain. Substitution is diagramed as follows:

$$\text{Sub } d = d_1, \quad (13)$$

or for a specific level,

$$\text{Sub } [{}^5A - {}^5B] = [{}^5A - {}^5B_1]. \quad (14)$$

The set  ${}^5B_1$  is the substitute set.

The skill for pretending to go to sleep provides an example of the application of this rule. After the child develops the skill in Equation 4, she extends that skill to a substitute object. Instead of holding her pillow and pretending to go to sleep, she substitutes a piece of cloth for the pillow:

$$\text{Sub } [{}^3P \leftrightarrow {}^3H \leftrightarrow {}^3S] = [{}^3P_c \leftrightarrow {}^3H \leftrightarrow {}^3S]. \quad (15)$$

The set  ${}^3P_1$ , holding the cloth, is substituted for the original set  ${}^3P$ , holding the pillow. The extension of the pretending skill to the cloth develops after the original skill (on the left-hand side of Equation 15) and before any more complex skills (Watson & Fischer, 1977).

### *Differentiation*

The final transformation rule for explaining development is differentiation, in which what was initially a single set becomes separated into distinct subsets. Differentiation is probably always a product of one of the other transformations, especially intercoordination or compounding. As Werner (1948, 1957) has argued, differentiation and integration always occur together. In skill theory, differentiation and integration (combination) are thus complementary, whereas in many other approaches they are opposed (e.g., Kaye, 1979; McGurk & MacDonald, 1978).

Differentiation can therefore be either microdevelopmental or macrodevelopmental, depending on which other transformation is involved. For macrodevelopment, the degree of differentiation is so great that a set at Level L should be considered a different set when it reaches Level L + 1. At higher levels, earlier global sets are divided into distinct new sets that serve in place of the earlier sets. (The superscripts to the left of the capital letters designating sets—see Tables 2 and 3—indicate the level of the set and thereby serve as a reminder that a set differentiates as it develops to higher levels). Because of the formation of these new sets, the person controls an ever larger repertoire of sets as development proceeds. The expansion of the number of sets leads to a corresponding increase in the number of skills, since the newly differentiated sets can become separate components in new skills.

The process of differentiation is diagrammed as follows:

$$\text{Diff } d = d_{x,y}, \quad (16)$$

where the subscripts indicate subsets in the skill  $d$ . Differentiation of a specific set A is designated:

$$\text{Diff } A = A_M, A_N. \quad (17)$$

The development of conservation of length in the gadget illustrates how differentiation occurs when a new skill is formed. A child with Level 5 mappings for the gadget understands generally how the length of the vertical segment relates to the length of the horizontal segment and vice versa but does not yet understand conservation of the total length of the cord. Another way of stating this confusion is that in this task, the child has not adequately differentiated the total length of the cord from the lengths of the horizontal and vertical segments. When asked about the total length of the cord, the child confuses it with the length of the horizontal or vertical segment. Although this kind of lack of differentiation may seem odd to an adult, it occurs commonly in children and indeed is characteristic of earlier cognitive levels (Smith & Kemler, 1977; Werner, 1948).

The lack of differentiation in the gadget is resolved when the child intercoordinates the two Level 5 mappings to form the Level 6 system for conservation of the total length of the cord, as shown in Equation 2. The intercoordination produces differentiation of the set for total length,  ${}^6C_{V,H}$ , from the sets for vertical length,  ${}^6C_V$ , and horizontal length,  ${}^6C_H$ :

$$\text{Diff } ({}^5C_V, {}^5C_H) = {}^6C_V, {}^6C_H, {}^6C_{V,H}. \quad (18)$$

In the set for total length, the child combines covariations in vertical and horizontal lengths into a concept of total length. Note also that the sets for vertical and horizontal lengths can be differentiated more finely at Level 6 than at Level 5: The child can deal with smaller variations in length in each of the sets.

The specific variables that are separated in a child's behavior are a function not only of the level but also of the particular task. For a child with skills at a given level, changes in the task alone can produce separation. For example, if the cord in the gadget (Figure 1) were straightened out, a child with the Level 5 skills in Equations 2 and 18 could easily control the set for the total length of the cord in the modified gadget, since it would be only a single set.

At the same time, with a gadget like the original one, in which the cord is still divided into vertical and horizontal segments, he or she could tell that the vertical and horizontal segments were each different from the total cord in the modified gadget. Likewise, certain experimental training procedures can produce such separation or discrimination (Denney, Zeytinoglu, & Selzer, 1977).

The interaction of task and level helps to resolve a paradox in the developmental literature. In some experiments, young children confuse variables like the several types of cord length in the gadget, but in other experiments children of the same age easily separate variables that seem at first to be the same as the ones they confused (Kemler & Smith, 1978; Smith & Kemler, 1978). Indeed, the same child can show both kinds of skills—ones demonstrating a global, syncretic whole that confounds several variables and ones using virtually the same variables separately (Peters, 1977). In the tasks where she uses the variables syncretically, the child must deal with a number of related variables at the same time, and her skill level is not sufficiently advanced for her to separate the variables. But in the tasks where she separates them, she does not need to deal with all of them simultaneously; able to work with first one variable and then another, she can easily separate them.

This separation is, of course, not the same as the differentiation that is required to coordinate all the variables in a single skill. For instance, with the Level 6 conservation skill in the gadget, the child must differentiate covariations in vertical and horizontal lengths and combine them into a concept of total length. The three types of length are not merely separated; they are also integrated.

The relation between differentiation and cognitive level has many other implications for analyzing development, according to skill theory. For example, when a person has at some point developed a skill to Level  $L$  but is now using the skill or some of its components at a lower level, the sets will still show the effects of the earlier differentiation at Level  $L$ . Suppose that a child has developed the Level 6 skill for conserva-

tion of the cord, but because of fatigue or emotional upset is now functioning at Level 5. She can use a skill that would not be possible for someone who has never developed this skill to Level 6. She might use the coordinated lengths of the two segments of the cord to make coarse, qualitative Level 5 predictions about the length of the spring:

$$[{}^6C_{V,H} - {}^6L] \quad (19)$$

So far, I have emphasized general issues about differentiation because they are important for understanding how differentiation and combination work together in skill theory. But differentiation can also be used as a developmental transformation rule. That is, it can be used to predict steps in a developmental sequence. In the spring-and-cord gadget, a skill for coarsely predicting vertical length from horizontal length is less differentiated than a skill for predicting the same thing more exactly; and the coarser skill will develop earlier than the more differentiated one. In a sorting task, the skill for putting different shades of red into a single category is more differentiated than the skill for putting identical shades of red into a single category, and the more differentiated skill will develop later (Fischer & Roberts, Note 3).

#### *Ordering the Results of Transformations*

With five different transformation rules, some principles are needed for ordering the results of the different transformations into developmental sequences. First of all, for a clear-cut prediction of a sequence to obtain, all skills must be in the same task domain. Given that they are in the same domain, the following principles allow ordering of steps:

1. If one of the transformations is applied to a skill or skills, the skill resulting from the transformation will develop after the initial skills.

2. Starting with specific skills at Level  $L$ , a skill resulting from an intercoordination transformation will develop after a skill resulting from microdevelopmental transformations, because the skill resulting from intercoordination will be at Level  $L + 1$ .

3. When Principles 1 and 2 do not provide

an ordering, then for skills at the same level, those with more sets will develop later.

4. If more than one skill is involved in a behavior (e.g., because of the focusing transformation), that behavior will develop later than the behaviors specified by each skill separately (by Principle 1). A skill that compounds the several skills into one will develop later than the same skills connected by a change in focus. If the focusing skills involve a greater number of distinct components than the compounded skill, then as a rule of thumb the focusing skills will develop later.

Notice that by these principles, many pairs of skills cannot be ordered developmentally. Of course, skills that have the same type of structure but different components cannot be ordered because they are in different task domains. But in addition, many skills within the same domain cannot be ordered—for example, two skills that are the same except that one has a substituted set and one has a differentiated set.

With the descriptions of the transformation rules, all the major concepts of the theory have been presented. The next step is to demonstrate how the theory functions as a tool for explaining and predicting development. After describing a set of guidelines for analyzing tasks and relating them to the constructs of the theory, I will present several experiments that have used the theory to predict specific developmental sequences and synchronies and will then explain a few of the many possible general deductions from the theory.

#### Using the Theory to Predict Development

The theory can be used to predict and explain various developmental phenomena, including developmental sequences and synchronies, certain effects of the environment on developing skills, individual differences in development, the nature of developmental unevenness, and structural relations among developing skills. But all of these predictions and explanations depend on a prior step—task analysis (Brown & French, 1979; Gollin & Saravo, 1970; Klahr & Wallace, 1976).

#### *Guidelines for Task Analysis*

Use of the theory to explain development requires a behavioral analysis of performance on the specific task or tasks in question: What exactly must a person do to perform each task?

This kind of behavioral analysis is not as simple as it may seem. The situation is analogous to that of a behaviorist trying to determine which specific operants or responses comprise performance on a given task. Finding the operants is no easy matter (Breland & Breland, 1961; Schick, 1971).

On the other hand, many investigators have been highly successful in analyzing behavior into its natural units (see de Villiers & Herrnstein, 1976; Marler & Hamilton, 1966). Premack (1965), for instance, found that simple observation of the actions that tend to recur regularly in an animal's behavior allowed him to infer a long list of natural operants that formed a hierarchy of reinforcers. And Fischer (1970, 1980) found that changes in patterns of responding over trials in common learning situations demonstrated the formation of new, higher-level behavioral units.

The skill structures specified in the theory are intended to reflect the natural units of behavior (both thought and action), including its hierarchical character, with higher-level units subsuming lower-level ones. Determination of the validity of these structures will, of course, require extensive research.

Use of the theory to analyze behavior into skill structures necessitates, first of all, a thorough knowledge of the available universe of skill structures defined by the levels and transformation rules. Given that one has this knowledge, then task analysis can be facilitated by using a set of guidelines that have been helpful for me and my colleagues. To illustrate the use of these guidelines, I will show how each one applies to an analysis of the development of an understanding of a social role during childhood (Watson, 1978; Watson & Fischer, 1980).

For a social category to be a social role, according to role theory, it must involve at least two social categories in relation to each

other (Brown, 1965; Mead, 1934). For instance, the social role of mother requires the complementary role of child, and the social role of doctor requires the complementary role of patient. Which skill structure is required, then, for a child to understand a social role, such as a doctor examining a patient?

The guidelines for task analysis fall within two general categories: guidelines for determining what the person must control and guidelines for designing and interpreting particular tasks.

### *Control*

At least three major questions are involved in analyzing what the person must control.

1. Does the skill require sensory-motor, representational, or abstract sets? For understanding a social role, sensory-motor sets are clearly not sufficient, since the role involves more than the child's own actions. Representational sets are necessary, because the role involves the characteristics and actions of people independent of the child. Abstract sets are not needed, since social roles as defined here require only concrete characteristics and actions of specific people (a doctor relating to a patient) rather than intangible attributes. Understanding the general definition of a social role as involving one social category and its complement would necessitate the control of intangible attributes, that is, abstract sets.

2. What are the sources of variation that the person must control in the skill? For the doctor role, the child would have to control two representational sets, not only the set for a person acting as doctor,  $R_D$ , but also the set for a person filling the complementary role of patient,  $S_P$ . Both of these sets are required because according to the definition of social role, a role must be related to its complement.

Also, note that, by definition, at least two sensory-motor action systems must comprise each representational set, because representational sets are formed from combinations of sensory-motor systems. For the roles of doctor and patient, the action

systems are essentially role-specific behaviors or characteristics. For example, a doctor gives a patient inoculations (one sensory-motor system) and examines her ears (a second system), and a patient takes the inoculation and poses for the ear examination.

3. What are the relations between sets that the child must control (among the various possible relations shown in Table 3)? Once the first two questions have been answered, determination of the relations between sets is often simple. For the doctor role, the set for doctor must have at least a mapping relation with the set for patient:

$$[{}^5R_D - {}^5S_P]. \quad (20)$$

With a mapping, the child can relate the doctor role to the patient role, which is all that is necessary to meet the minimal criterion of relating a social role to its complement.

### *Tasks*

Thus far, the skill analysis for the role of doctor has proceeded as if the skill could be considered independently of a particular task. But in fact, the analysis must take the particular task into account. At least three major issues are involved in designing and interpreting specific tasks.

4. What is the particular task, and what must the person control to perform it? For the role example, Watson and I devised a task for assessing the child's understanding of the role of doctor (Watson & Fischer, 1980). Seated at a table, a child was shown two rigid-cardboard, stand-up dolls (a doctor and a child patient) and a few doctor's instruments. The experimenter acted out the doctor's examination of the patient and then asked the child to act out a similar story. The child was not asked to copy the story precisely, so that no requirement of exact imitation would interfere with the child's demonstrating her knowledge. To show the role of doctor, the child had to have the doctor doll carry out at least two appropriate actions in relation to the patient doll. The doctor might, for example, give the patient a shot and look in her ears or take the patient's temperature and examine her throat.

In analysis of a particular task, sources of variation will often become apparent that are not evident if one erroneously attempts to consider the skill independently of a task. In the present case, the task brings no change in the basic mapping skill as diagrammed in Formula 20. But the components of the representational sets are a little more complicated than they appeared in the analysis of Question 2. Because the child must manipulate the dolls, each representational set must include a minimum of not just two but three sensory-motor systems. For each representational set, the child must manipulate the appropriate doll in addition to performing at least two role-specific actions, such as giving an inoculation and an ear examination.

One problem that can arise in interpreting particular tasks is that incorrect task analyses in the developmental literature may interfere with determination of what a person actually must do to perform a task. For instance, for Piaget's final object-permanence task, where the child must find an object that has been put through a series of invisible displacements, most investigators have assumed that the task requires the cognitive recreation of the invisible displacements by the child (Piaget, 1937/1954; Uzgiris & Hunt, 1975). Recently, this interpretation has been questioned (Jennings, 1975; Harris, Note 6), and several investigators have shown that the task does not produce cognitive manipulation of representations of invisible displacements (Bertenthal & Fischer, in press; Corrigan, in press).

5. What is the minimal task that would demonstrate the skill in question? If the skill is a specific concept, for example, one must first specify exactly what is meant by the concept and then determine the easiest task that would demonstrate it. Without specification of a minimal task, erroneous inferences may be made about the child's ability (Shatz, 1977). Task complexities that are basically irrelevant to the ability in question will overload the child cognitively and prevent him from showing his ability. The skill level at which a person can control an ability or concept is a function of the complexity of the task used to

assess that ability or concept (Bertenthal & Fischer, 1978; Opaluch, 1979).

For the doctor role, the definition is that one agent must show doctorlike behaviors in relation to a second agent, which must show reciprocal patientlike behaviors. A minimal task for this concept is the doll-play task, with just two dolls, the doctor and the patient. Many children who can demonstrate the doctor role in this task will not show it in a more complex task: If the experimenter's story involves, for instance, a mother bringing her child patient to the doctor's office and consulting with the doctor and nurse while the patient is being examined, many of the children will demonstrate an apparent inability to understand the role of doctor (Watson & Fischer, 1980).

6. To go beyond an analysis of an individual task and predict a developmental sequence, one must keep all tasks in the sequence within the same task domain. With the doctor role, for example, the levels and transformation rules can be used to produce an ordering of developmental complexity, with tasks more (or less) complex than the basic doctor-role task. But if those tasks use different procedures or varying roles (such as mother-child), the theory cannot predict a precise developmental sequence. The many environmental and organismic factors that produce unevenness mean that developmental sequences can only be predicted unambiguously when as many sets as possible are kept the same from one developmental step to the next. To make clear predictions from the task analysis of the doctor role, the same demonstration procedure should be used at every step, the same dolls should be included, and the doctor-patient relation should remain the basis of every step. The more microdevelopmental the predicted sequence, the more essential it is that the content and procedure remain the same from one step to the next.

Even with these six guidelines, doing a task analysis is no trivial matter. Unfortunately, it still involves a degree more art than I would like. Yet once a task analysis is in hand, predictions based upon it follow fairly easily from the levels and transformation rules.

*Predicting Developmental Sequences*

Beginning from a task analysis, one can use the transformation rules to predict a developmental sequence. The sequence can be either macrodevelopmental or microdevelopmental or both, and it can have virtually any number of steps, depending on the number of transformations that are used. There is no one true sequence that all children will always show, because the exact sequence that a child demonstrates will be determined to a great extent by the particular tasks that he or she experiences. Previous studies attempting to test detailed developmental sequences (mostly predicted from Piaget's work) have shown a singular lack of success (e.g., Hooper, et al., 1979; Kofsky, 1966). Tests of sequences predicted from skill theory, however, have been highly successful (Bertenthal & Fischer, 1978; Hand, 1980; Tucker, 1979; Watson & Fischer, 1977, 1980; Fischer & Roberts, Note 3).

Starting from the task analysis for the doctor-role skill, one can predict many developmental steps (Watson & Fischer, 1980). Table 4 shows just a few of them. Application of the compounding rule to the doctor-role skill (Step 2) expands the doctor role to include a second complementary role, that of nurse,  ${}^5T_N$ , thus producing a more complex Level 5 skill (Step 3). The child starts out with the two simple Level 5 skills on the left of the transformation equation in Table 4: one relating the doctor role to the complementary patient role and the other relating the doctor role to the complementary nurse role. When those two skills are combined by compounding,<sup>12</sup> they produce the skill on the right of the equation: The child can make the doctor deal with both the nurse and the patient in such a way that the doctor takes into account the nurse's role relation to the patient (symbolized by the mapping of  ${}^5T_N$  and  ${}^5S_P$  in the compounded skill).

Besides the steps shown in Table 4, many other microdevelopmental steps can be predicted. With application of the focusing rule, for instance, an intermediate step can be predicted that is less developmentally advanced than the compounded skill relating

doctor, nurse, and patient (Step 3) but more advanced than the doctor-role skill (Step 2):

$$\text{Foc } ([{}^5R_D \text{ --- } {}^5S_P], [{}^5R_D \text{ --- } {}^5T_N]) = \\ [({}^5R_D \text{ --- } {}^5S_P) > ({}^5R_D \text{ --- } {}^5T_N)]. \quad (21)$$

The child can make the doctor deal with the patient and then make the doctor deal with the nurse, but does not integrate doctor, nurse, and patient all together in the appropriate role relations. This behavior is more advanced developmentally than the doctor role at Step 2 because the child must possess two complete Level 5 skills. The behavior is less advanced than the compounded skill at Step 3 because although it contains the same components, they are not unified into a single skill.

Another microdevelopmental step can be predicted by use of the substitution rule:

$$\text{Sub } [{}^5R_D \text{ --- } {}^5T_N \text{ --- } {}^5S_P] = \\ [{}^5R_D \text{ --- } {}^5T_{N,1} \text{ --- } {}^5S_P]. \quad (22)$$

The child shows the same behaviors as for Step 3 but replaces the nurse doll with a substitute object that does not normally fit the nurse role, such as a plain adult male doll. This skill is more advanced developmentally than the skill on the left of Equation 22.

Thus, Equations 20, 21, and 22 lead to prediction of a four-step developmental sequence. First, the child develops the basic doctor-role skill in Equation 20 (shown as Step 2 in Table 4), then the skills resulting from the indicated transformations in the following order: Equation 21, Step 3 in Table 4, and Equation 22.

Besides these and many other microdevelopmental predictions, macrodevelopmental predictions can be made, of course. The intercoordination rule specifies transformations from level to level. Reversal of the intercoordination rule decomposes the doctor-role skill (Step 2 in Table 4) into its two component Level 4 skills: the simple representational sets for doctor,  ${}^4R_D$ , and

<sup>12</sup> Several alternative pairs of simple Level 5 skills could be combined to produce the same compounded Level 5 skill relating doctor, nurse, and patient roles. For example,  $[{}^5R_D \text{ --- } {}^5T_N]$  could be compounded with  $[{}^5T_N \text{ --- } {}^5S_P]$ .

Table 4  
A Developmental Sequence of Social Role Playing

Step	Cognitive level	Role-playing skill	Example of behavior	Skill structure	Transformation rule
1	4: Representational sets	Behavioral role	The child pretends that a doctor doll uses a thermometer and a syringe.	$[{}^4R_D]$	Intercoordination: $[{}^4R_D] \cdot [{}^4S_P] = \text{Step 2}$
2	5: Representational mappings	Social role	The child pretends that a doctor doll examines a patient doll, and the patient doll makes appropriate responses during the examination.	$[{}^5R_D \text{ --- } {}^5S_P]$	Compounding: $[{}^5R_D \text{ --- } {}^5S_P] + [{}^5R_D \text{ --- } {}^5T_N] = \text{Step 3}$
3		Social role with two complementary roles	The child pretends that a doctor doll examines a patient doll and is aided by a nurse doll. Both patient and nurse respond appropriately.	$[{}^5R_D \text{ --- } {}^5T_N \text{ --- } {}^5S_P]$	Focusing: $\text{Foc}([{}^5R_F \text{ --- } {}^5S_C], [{}^5R_D \text{ --- } {}^5T_N \text{ --- } {}^5S_P]) = \text{Step 4}$
4		Shifting between family role and doctor role	The child pretends that a doctor doll is the father of the patient doll, and then he or she switches to having the doctor doll fill only the doctor role — examining the patient doll with the help of the nurse doll, as in Step 3.	$[({}^6R_F \text{ --- } {}^5S_C) > ({}^5R_D \text{ --- } {}^5T_N \text{ --- } {}^5S_P)]$	Intercoordination: $[{}^5R_D \text{ --- } {}^5S_P] \cdot [{}^5R_F \text{ --- } {}^5S_C] = \text{Step 5}$
5	6: Representational systems	Intersection of two roles and their complements	The child pretends that a doctor doll examines a patient doll and also acts as a father to the patient, who is his son or daughter. The patient doll acts appropriately as both patient and offspring.	$[{}^6R_{D,F} \leftrightarrow {}^6S_{P,C}]$	Compounding: <sup>a</sup> $[{}^6R_{D,F} \leftrightarrow {}^6S_{P,C}] + [{}^6R_{D,H} \leftrightarrow {}^6V_{M,W}] + [{}^6V_{M,W} \leftrightarrow {}^6S_{P,C}] = \text{Step 6}$

(Table continues)



Table 4 (continued)

Step	Role-playing skill	Example of behavior	Skill structure
6	Intersection of three roles and their complements	The child pretends that the doctor doll is doctor, father, and husband, relating to the patient doll, who is a patient and the man's offspring, and to the woman doll, who is the patient's mother and the man's wife.	$[{}^6R_{D,F,H} \leftrightarrow {}^6V_{M,W} \leftrightarrow {}^6S_{P,C}]^b$

*Note.* In the formulas, the italicized capital letters stand for the child's representation of a particular doll as an independent agent: *R* for the doctor doll, *S* for the child doll, *V* for the nurse doll, and *V* for the woman doll. The subscripts designate the role or roles that the child represents for each doll, as follows: C = child; D = doctor; F = father; H = husband; M = mother; N = nurse; P = patient; W = wife.

<sup>a</sup> For most steps, several alternative forms of skills involving the same sets could be combined to produce essentially the same new skill. An example of such alternative forms is given in Footnote 12.

<sup>b</sup> In Step 6, the doctor doll carries out three roles, whereas only two roles are listed for each of the other two dolls. Formal distinctions can be made between closely related roles so that these two dolls would also each carry out three roles. For example, the woman doll could be not only mother and wife but also adult-responsible-for-child-in-the-doctor's-office. In practice, however, children will usually ignore such subtle role differentiations.

patient,  ${}^4S_P$ . Thus, the theory predicts that at Level 4 the child will be able to handle behavioral roles—behaviors relating to the doctor role alone or the patient role alone. He or she will know, for example, that a doctor uses a thermometer or a syringe, but will not include the patient as a participant in these actions by the doctor.

Going in the other direction—up the developmental scale—the skill for the doctor role can be intercoordinated with the related skill for the father role, in which the adult male plays the role of father,  ${}^5R_F$ , in relation to the role of child (son or daughter),  ${}^5S_C$ . Since an adult male can be both a doctor and a father, and a young person can be both a patient and a son or daughter, the child can intercoordinate the two skills as shown for Step 5. The symbol  ${}^6R_{D,F}$  stands for the representation for the behavior of a man who is both doctor and father to his child, and the symbol  ${}^6S_{P,C}$  stands for the representation for the behavior of a young person who is both a patient and a son or daughter to the father. Each new Level 6 representation is thus a combination of two of the Level 5 representations on the left of the transformation equation in Table 4. With the new Level 6 skill, the subject takes the perspective of a man who is a doctor and is treating his son or daughter and simultaneously takes the perspective of the son or daughter who is a patient of the doctor father. That is, at Level 6, the subject can act out this kind of social-role intersection with the doctor and patient dolls. This type of social-role intersection is what the child needs to understand how one of his parents can fill two roles, such as parent and job holder or parent and spouse (Fischer & Watson, in press).

Given any careful task analysis, the levels and transformation rules thus make direct predictions about developmental sequences. Application of the microdevelopmental rules to the analysis for the gadget task, for example, produces predictions of a large number of developmental steps between the levels. And application of the transformation rules to any other task analysis presented in this article will likewise predict developmental sequences.

*Predicting Developmental Synchronies  
Across Task Domains*

Because of the importance of environmental factors, precise predictions of micro-developmental sequences can be made only within a task domain, where most of the components are the same or very similar for adjacent steps in a sequence. The prediction of synchronies across task domains is much more complicated, because few or no components are shared across domains. Yet predictions about synchrony are clear. First, because unevenness is the rule in development, the degree of developmental synchrony between two task domains will seldom be high. It will usually be moderate for familiar domains, because each independent skill develops with age and this relation with age produces some correlation between the two skills.

Second, manipulation of environmental factors such as degree of practice will drastically alter the degree of synchrony. For instance, sequences in two highly practiced domains should show nearly perfect synchrony, as will be explained later.

Third, whenever developmental sequences in two different domains intersect so that a skill in one domain becomes part of a skill in the other, the development of the skill in the first domain will predict the development of the skill in the second. This correspondence will be precise, with virtually every child that develops through the two intersecting sequences showing the predicted correspondence.

Corrigan (1977, 1978, 1979, 1980) has found support for these predictions about synchrony between task domains for the relationship between the development of object permanence (finding hidden objects) and the development of language. First, the general correlation between object permanence and language development in a group of infants between 10 and 26 months of age was only moderate,  $\tau(29) = .36, p < .01$ . Further analyses indicated that this correlation was produced entirely by the relation of performance in each task domain to age.

Second, one point of precise correspondence between the two skills could be predicted. When the child reached Level 4 for

the object-permanence tasks, it was predicted that he would also begin to use words to ask about or refer to objects that were not present, especially in the object-permanence tasks.<sup>13</sup> For example, he would start using "all gone" and "more" appropriately for the absent objects. This correspondence was predicted from skill theory because with Level 4 skills, the child controls representational sets and therefore can understand that objects are agents of action independent of him: He can control the representational set or sets for objects in those tasks even when he cannot perceive the objects. He should, therefore, be able to speak spontaneously about objects that disappear in those tasks or in similar situations. Corrigan's findings supported this prediction of precise correspondence between object permanence and use of "all gone" and "more."

Testing for developmental synchronies between task domains is unfortunately more complex methodologically than it at first appears. The correlation produced by age alone is a difficulty that is too often ignored. If the age range tested is wide, the correlations can be substantial. The development of classification skills between 1 and 7 years, for example, correlates highly with shoe size,  $r(68) = .85, p < .001$  (Fischer & Roberts, Note 3).

Skill theory suggests several ways of overcoming this problem in testing for developmental synchronies. First, when precise predictions can be made about exactly which developmental steps in the different domains should coincide, then correspondence between domains can be tested directly rather than indirectly through correlations.

Second, predictions about *relative de-*

<sup>13</sup> This hypothesis may seem at first to contradict the earlier discussion of the problems with the Piagetian task analysis of the invisible-displacements tasks. There is no contradiction for two reasons: First, Corrigan used a more complex testing procedure that seemed to provide a better assessment of the use of representation in object-permanence tasks than the Piagetian procedure. Second, an object-permanence task can require representation for reasons other than those embodied in the Piagetian task analysis (Fischer & Jennings, in press).

degrees of synchrony can be tested. Consider developmental sequences  $x$ ,  $y$ , and  $z$ , where  $x$  and  $y$  are hypothesized to involve virtually the same skills, and  $z$  is hypothesized to involve different skills. Within a given age range, sequences  $x$  and  $y$  should correlate together more highly than either of them correlates with sequence  $z$ . Similarly, if a particular environmental condition such as practice is hypothesized to increase the synchrony between two developmental sequences, then the correlation between the sequences under that condition should be higher than the correlation under other environmental conditions. Indeed, according to skill theory, an experimenter should be able to control the degree of synchrony that he or she will obtain by simple environmental manipulations.

#### *Role of the Environment*

According to skill theory, environmental factors play a central role in determining the relative degree of synchrony between developmental sequences, and they also affect the specific developmental sequences that people show. Some of these predictions are presented below, primarily for the effects of specific testing procedures, including the differences between longitudinal and cross-sectional procedures and the effects of the specific tasks used to test developing skills.

#### *Effects of Testing*

Longitudinal and cross-sectional procedures should produce very different patterns of synchrony across task domains, as a function of the effects of practice. Because skills must be practiced to be mastered, a skill that is practiced regularly should develop faster than a skill that is practiced less often. In most longitudinal studies, children are effectively given repeated practice with the skills being investigated, because they perform the same or similar tasks session after session. In most cross-sectional studies, on the other hand, children are not given regular practice with the skills being investigated, because they are tested on each task only once.

Longitudinal testing should therefore produce faster movement through a developmental sequence than cross-sectional testing. Jackson, Campos, and Fischer (1978) tested this prediction by comparing the effects of longitudinal and cross-sectional procedures on development through an eight-step sequence of object permanence. Longitudinal testing produced a large practice effect, as predicted: two to three steps in the eight-step sequence.

Because of this practice effect, longitudinal testing should produce an inflated estimate of the synchrony between development in two different task domains. Usually, in a group of children who have not experienced longitudinal testing, most of the children will have differential experience with the skills in any two domains. Consequently, in cross-sectional testing, the synchrony between the two developmental sequences will not be high, except in the case where the sequences actually belong to the same skill domain. (Recall that a skill domain is composed of a group of task domains that develop in close synchrony.) On the other hand, the extensive practice that occurs in much longitudinal testing virtually eliminates this differential experience and elevates the skills in both task domains to the person's optimal level. Consequently, even when the skills are in fact from independent skill domains, longitudinal testing will usually produce a high synchrony between them—and a high correlation.

Corrigan's study of language development and object-permanence development tested this prediction (Corrigan, 1977, 1978). As I reported above, she found that for a group of infants tested cross-sectionally, the correlation between the developmental sequences was only .36. But for three infants who were tested longitudinally over the same age range, the correlations were much higher: .75, .78, and .89 for the individual infants. Liben's (1977) study of the effects of training and practice on memory improvement and Jackson et al.'s (1978) comparison of cross-sectional and longitudinal procedures also corroborate the prediction.

These findings thus support the argument

that cross-sectional testing in general provides a better test of the naturally occurring synchrony between task domains than longitudinal testing. Developmental psychologists commonly disparage the usefulness of cross-sectional methodology in developmental research, but the ability to predict developmental sequences makes cross-sectional testing a powerful developmental tool (Fischer, Note 7): Specific parallel sequences can be predicted in different task domains, and a separate task can be devised for each step in each sequence. Then, with cross-sectional testing of every person on every task, scalogram analysis can be used to test the validity of the sequences, and the synchrony between sequences can be compared step by step (Bertenthal & Fischer, 1978; Watson, 1978; Watson & Fischer, 1977).

Variations in testing procedure will affect not only the degree of synchrony but also the particular developmental sequences that people show. Many developmental psychologists assume that every skill domain shows only one true developmental sequence, one set of stages of a fixed number (e.g., Kohlberg, 1969). Skill theory predicts, to the contrary, that the developmental sequence that a person progresses through will vary depending upon the assessment tasks and procedures used, as well as analogous environmental factors that occur naturally, outside the experimental context (Fischer & Corrigan, in press).

The variation in sequences as a function of testing is especially obvious for microdevelopmental sequences. The developmental transformation rules can be used to predict a large number of microdevelopmental steps. For example, use of the substitution rule on Steps 2, 3, and 4 in Table 4 would have produced six microdevelopmental steps instead of three. Yet if children are not exposed to the specific tasks corresponding to each predicted step, many of the steps will not appear in their behavior. If their environment never induces the use of a substitute object, for example, they will never show these three new substitution steps for Table 4, nor any of the other possible substitution steps in the development of social role playing. Likewise, steps in-

volving focusing, compounding, or differentiation will not appear in their behavior if they are not exposed to the specific tasks or situations that will induce those particular skills.

Even macrodevelopmental steps involving intercoordination may be skipped for particular sequences. Recall, for instance, the Level 7 skill for the abstract concept of conservation, that is, the concept of quantities that do not change because they are composed of two constituent quantities that compensate for each other. Suppose that a person develops this concept of conservation without ever having developed the Level 6 skill for conservation of length. Perhaps he coordinates a Level 6 skill for conservation of amount of clay with another Level 6 skill for conservation of number and so generates the abstract concept of conservation without ever dealing with conservation of length. When he is then tested for conservation of length in the spring-and-cord gadget, he can generalize the Level 7 skill for abstract conservation to conservation of length in the gadget, and thus he will have developed the skill for conservation of length without ever having gone through Level 6 for that particular skill. He will have effectively skipped Level 6 in the developmental sequence for conservation of length.

Many of these irregularities and variations in developmental sequences will be reduced or eliminated by repeated testing with similar tasks. Suppose, for example, that an 8-year-old child has many other Level 6 skills but has not been induced to develop conservation of length. Exposure to the task for conservation of length with the gadget will normally induce him to develop conservation of length (Hooper, Goldman, Storck, & Burke, 1971). Because of effects like this, performance in later testing sessions will commonly fit a sequence better than performance in the initial session (Tucker, 1979).

The effects of specific tasks and testing procedures may explain many of the disagreements in the developmental literature about sequences in a given skill domain. For example, different investigators, using different procedures, have found different

microdevelopmental sequences for object permanence (compare for example, Corrigan, 1977, 1978; Opaluch, 1979; Uzgiris & Hunt, 1975; Wise, Wise, & Zimmerman, 1974).

These effects of testing procedures on variations in sequences and on synchronies across sequences are more than a mere methodological nuisance. They are a reflection of the general importance of environmental factors as determinants of cognitive development.

#### *Why Unevenness Must be The Rule*

If environmental factors are as important as I have argued in determining sequence and synchrony, then indeed unevenness must be the rule in development. The level, or step within a level, that an individual attains on a task is affected by so many environmental factors that he or she could not possibly perform at the same level or step on all tasks. Jackson et al. (1978), in their study of object permanence, examined three different potential sources of unevenness: practice, task, and content. All three sources produced unevenness. As described earlier, the difference between the longitudinal and cross-sectional groups showed strong unevenness due to practice: two to three steps in an eight-step sequence. Similarly, the specific task used to assess object permanence created substantial unevenness: two steps in the eight-step sequence. Finally, the content (the type of stimulus searched for) often produced small but reliable unevenness, especially with the cross-sectional procedure: Both the type of object and the familiarity of the object produced unevenness ranging up to one step in the eight-step sequence.

#### *Individual Differences*

Just as environmental factors make unevenness the rule within an individual, so they ensure that different individuals will show different patterns of cognitive development. Of course, hereditary factors also contribute to individual differences in development (as well as to unevenness); but even without those hereditary differ-

ences, the environment would induce large individual differences in development.

Individual differences can take several forms. People differ in rate of development: Some move through the hierarchy of levels much faster than others. People differ in their profiles of cognitive skills—catalogues of which skills have attained which levels. And most interestingly, people differ in the paths through which they develop.

Many cognitive-developmental psychologists have assumed that all people normally develop through the same developmental path in any single domain, but recently a large number of researchers have begun to argue that individual differences in some or all developmental paths are the norm (e.g., Braine, 1976; Nelson, 1973; Rest, 1976).

Skill theory predicts that individuals will frequently follow different paths of development and that these differences will take at least two forms. First, different individuals will develop in different skill domains. One person will develop basket-making skills but not reading skills; another will develop both basket-making skills and reading skills, but not skills for drawing maps.

Second, different individuals will follow different developmental paths in the same skill domain (Fischer & Corrigan, in press). The developmental transformation rules predict a large number of different possible paths in any single domain. The spring-and-cord gadget illustrates how individuals can take different paths within the same domain. The way that an individual moves from Level 6 skills for the gadget to a Level 7 skill integrating all four variables of the gadget (weight, length of spring, vertical length of cord, and horizontal length) will vary depending upon the particular Level 6 skills that he combines. The results of two possible alternative paths are shown in Table 5. In the first path, an individual begins with two Level 6 skills: the system relating weight,  ${}^6W$ , to the length of the spring,  ${}^6L$ , and the system for conservation, relating total length of the cord at two different times,  ${}^6C_{V,H}$  and  ${}^6C_{V,H}$ . As shown in Table 5, the individual forms a Level 7 skill for the entire gadget by intercoordinating these two Level 6 skills.

In the second path, a different individual begins with a different group of Level 6 systems, each involving weight  ${}^6W$ ; weight and length of the spring,  ${}^6L$ ; weight and vertical length of the cord,  ${}^6C_V$ ; and weight and horizontal length of the cord,  ${}^6C_H$ . He too combines these skills to form a Level 7 skill for the entire gadget; but to do so, he must go through more developmental transformations, as shown in Table 5, and he ends up with a different skill from the individual who followed the first path.

The first path is more efficient than the second one: It requires fewer transformations, and the final skill (Step 2 of Path 1 in Table 5) relates the four variables together without redundancy. The second path not only goes through more transformations but also produces a skill (Step 3 of Path 2 in Table 5) that is full of redundancy, with the weight variable reappearing in every representational system. The skills also differ somewhat in the behaviors that they control. For example, the first skill

allows direct access to the concept of conservation of the total length of the cord, whereas the second skill requires that the conservation be inferred from the coordination of two representational systems.

On the other hand, the two final Level 7 skills are equivalent for most purposes. Both of them interrelate the same four variables, and both of them reflect accurately the relations among the variables in the real gadget. Individuals using the two skills will come to mostly the same conclusions about the variables in the gadget.

Similarly, for virtually every skill at every one of the levels, different individuals can take different developmental paths within a skill domain, and usually the end products of the different paths will be skills that are equivalent for most purposes. That is not to say, however, that individual differences are minimal. The different paths within a domain are often significant; and more important, individuals normally develop in different skill domains and to different skill

Table 5  
Alternative Developmental Paths to a Level 7 Skill for All Four Variables in the Gadget

Cognitive level	Path 1	Path 2 <sup>a</sup>
6: Representational systems	<b>Step 1:</b> [ ${}^6W \leftrightarrow {}^6L$ ] and [ ${}^6C_{V,H} \leftrightarrow {}^6C_{V,H}$ ]	<b>Step 1:</b> [ ${}^6W \leftrightarrow {}^6L$ ], [ ${}^6W \leftrightarrow {}^6C_V$ ], and [ ${}^6W \leftrightarrow {}^6C_H$ ]
7: Systems of representational systems	<b>Transformation:</b> [ ${}^6W \leftrightarrow {}^6L$ ] · [ ${}^6C_{V,H} \leftrightarrow {}^6C_{V,H}$ ] = Step 2  <b>Step 2:</b> [ ${}^7W \leftrightarrow {}^7L$ ] $\updownarrow$ [ ${}^7C_{V,H} \leftrightarrow {}^7C_{V,H}$ ]	<b>Transformation:</b> [ ${}^6W \leftrightarrow {}^6L$ ] · [ ${}^6W \leftrightarrow {}^6C_V$ ] = Step 2a  <b>Step 2a:</b> [ ${}^7W \leftrightarrow {}^7L$ ] $\updownarrow$ [ ${}^7W \leftrightarrow {}^7C_V$ ]  <b>Transformation:</b> [ ${}^6W \leftrightarrow {}^6C_V$ ] · [ ${}^6W \leftrightarrow {}^6C_H$ ] = Step 2b  <b>Step 2b:</b> [ ${}^7W \leftrightarrow {}^7C_V$ ] $\updownarrow$ [ ${}^7W \leftrightarrow {}^7C_H$ ]  <b>Transformation:</b> [ ${}^7W \leftrightarrow {}^7L$ ] $\updownarrow$ [ ${}^7W \leftrightarrow {}^7C_V$ ] + [ ${}^7W \leftrightarrow {}^7C_V$ ] $\updownarrow$ [ ${}^7W \leftrightarrow {}^7C_H$ ] = Step 3  <b>Step 3:</b> [ ${}^7W \leftrightarrow {}^7L$ ] $\updownarrow$ [ ${}^7W \leftrightarrow {}^7C_V$ ] $\updownarrow$ [ ${}^7W \leftrightarrow {}^7C_H$ ]

<sup>a</sup> Steps 2a and 2b form separate skills, but they do not develop in sequence with respect to each other, according to this skill analysis.

levels in the same domains. The environmental diversity of human experience, as well as the genetic diversity of the human species, ensures the occurrence of major individual differences in development.

Skill theory thus makes several general predictions about the effects of environmental factors on sequence and synchrony in development and provides tools for analyzing some of these effects. In addition, the structures defined by the theory suggest a number of general corollaries about structural relations and how they determine sequence and synchrony.

### *Structural Corollaries*

I shall not attempt to provide an exhaustive list of structural corollaries but instead will present a few illustrations of potentially useful ones.

#### *Consistent Decalage Within a Task Domain*

Unevenness in skills across domains seems to be a fact of development. But according to the theory, many phenomena that are commonly classified as instances of unevenness are in fact microdevelopmental sequences: The unevenness follows the same pattern in virtually all children in a given social group, and it seems actually to arise from differences in the complexity of the skills. Most of the instances of horizontal decalage (unevenness within a stage or period) studied by Piaget and his colleagues show such microdevelopmental sequences. The skill theory explanation is simplest in cases where the skills belong to the same task domain. The skill that develops later can be derived by the transformation rules from the skill that develops earlier.

Among the best documented cases of consistent decalage within a task domain is the development of conservation of substance and conservation of weight. Research has repeatedly shown that school children develop conservation of substance 1 to 3 years before conservation of weight (e.g., Hooper et al., 1971; Piaget & Inhelder, 1941/1974, especially in the introduction to the 2nd edition; Uzgiris, 1964). In conservation of substance,<sup>14</sup> children understand,

usually by 7 or 8 years of age, that the amount of clay does not change when a ball of clay is elongated into a sausage, flattened into a pancake, or changed into some other shape. At the same age, however, they still believe that the *weight* of the clay ball does change when the shape changes. Typically, they will not develop the skill for conservation of weight until 9 or 10 years of age. Within Piaget's framework, this consistent sequence is puzzling because both types of conservation are said to require exactly the same kind of concrete operational scheme: Two factors (height and length) covary in such a way that changes in one compensate for changes in the other.

According to skill theory, conservation of weight develops after conservation of substance because it requires a compounded Level 6 skill that subsumes the skill for conservation of substance. In conservation of substance, the child must coordinate the length and width of the original piece of clay,  $\frac{1}{2}B_{L,W}$ , with the length and width of the transformed piece,  $\frac{1}{2}B_{L,W}$  (Halford, 1970; Peill, 1975; Verge & Bogartz, 1978).<sup>15</sup> In conservation of weight, on the other hand, the child must go beyond mere amount of clay and think about weight of clay. That is, he must relate the changes in the length and width of the clay to a third factor, such as the weight readings on a scale or the amount of force that he feels when he holds the clay in his hand,  ${}^6F$ . To coordinate all three sets together in a single skill, he must compound the skill for conservation of the substance clay with a skill involving the weight of the clay, such as the skill in which the child relates the length of pieces of clay (for instance, sausage-shaped pieces) to their

<sup>14</sup> Note that this type of conservation is properly called conservation of *substance*. It has often been erroneously translated as conservation of matter or conservation of volume. Both matter and volume are much more abstract and difficult concepts than amount of a substance such as clay, and they develop at later ages.

<sup>15</sup> A precise measure of the amount of clay, of course, requires three dimensions (height, length, and thickness), not just two; but with early Level 6 skills the child does not yet understand true volume—that is, three-dimensional volume. His understanding of amount of clay is based on a relatively crude coordination of just two dimensions.

Table 6  
A Few Examples of Mimicking

Actual cognitive levels	Mimicking skill at Level L	Mimicked skill at Level L + 1
Levels 2 and 3	$[{}^2S_2 - {}^2M_2 - {}^2G_2 - {}^2M_1 - {}^2S_1]$	$[{}^3S \leftrightarrow {}^3M \leftrightarrow {}^3G]$
Levels 2 and 3	$[{}^2S_2 - {}^2M_2 - {}^2G_2] > [{}^2G_1 - {}^2M_1 - {}^2S_1]$	$[{}^3S \leftrightarrow {}^3M \leftrightarrow {}^3G]$
Levels 6 and 7	$[{}^6M \leftrightarrow {}^6N \leftrightarrow {}^6P \leftrightarrow {}^6Q]$	$\begin{bmatrix} {}^7M \leftrightarrow {}^7N \\ \updownarrow \\ {}^7P \leftrightarrow {}^7Q \end{bmatrix}$

weight:

$$[{}^6B_{L,W} \leftrightarrow {}^6B_{L,W}] + [{}^6B_L \leftrightarrow {}^6F] = [{}^6B_{L,W} \leftrightarrow {}^6B_{L,W} \leftrightarrow {}^6F]. \quad (23)$$

Consequently, the child will develop conservation of the weight of clay after conservation of the substance of clay.

This same kind of analysis should be able to explain most cases of consistent decalage within a skill domain, including cases where the differences in complexity are not obvious, as when differences in stimulus salience produce decalage (Odom, 1978; Fischer & Roberts, Note 3). The skills in each case actually differ in complexity, but psychologists have previously categorized them as showing unevenness simply because there has been no tool for analyzing the skills and thus recognizing the differences in complexity.

### Mimicking

Besides explaining phenomena like the lag between the development of conservation of substance and conservation of weight, microdevelopmental transformations also predict another phenomenon: mimicking, in which a complex skill or series of skills at Level L produces behavior that seems at first to require a skill at Level L + 1.

A person can mimic a skill at Level L + 1 by acquiring a complex skill or series of skills at Level L that includes all the sets that comprise the higher-level skill. The mimicking skill will usually result from the transformations of compounding or focusing (or both), as illustrated in Table 6. I use the word *mimic* intentionally because the

mimicking skill at Level L is by no means identical with the mimicked skill at Level L + 1. In general, the skill at Level L + 1 will be much more flexible and differentiated than the skill at Level L, and the child will have much better control over the relations among sets. But there will still be many similarities between the mimicking skill and the higher-level skill.

An example from the sensory-motor tier will illustrate how mimicking occurs. By compounding Level 2 mappings, the child can mimic the flexibility and complexity of a Level 3 system, as shown in Table 6. Consider the actions of grasping a doll, G, looking at the doll, S, and moving the arm, M. When a child has a Level 3 system controlling all three of these actions, he can combine several aspects of each of the three actions in a great variety of ways. For example, he can look at the doll and use what he sees to guide the movement of his arms to grasp the doll, and then once he has grasped it, he can move it in front of his face and visually examine it. More generally, he can carry out plans that require him to consider the relations among several aspects of all three actions simultaneously. He can use his looking to guide his moving all along the path of movement; he can place the doll at any point in space within his reach; he can remember where he saw the doll a few seconds before and reach there to grasp it. And he can do all these complex things smoothly and planfully, without trial and error.

At Level 2, the infant can mimic this Level 3 system by compounding the three actions (Table 6). First suppose that he has a sensory-motor mapping relating grasping



the doll,  ${}^2G$ , moving it,  ${}^2M$ , and looking at it,  ${}^2S$ : When he happens to grasp the doll, he can move it in front of his eyes and look at it. He also has the related mapping of looking, moving, and grasping: When he happens to look at the doll, he can move his hand to where he sees it and then grasp it. By compounding these two skills, he can construct a complex Level 2 skill that mimics the Level 3 skill, as follows:

$$[{}^2S_2 - {}^2M_2 - {}^2G_2] + [{}^2G_1 - {}^2M_1 - {}^2S_1] \\ = [{}^2S_2 - {}^2M_2 - {}^2G_2 - {}^2M_1 - {}^2S_1]. \quad (24)$$

With this mimicking skill, the child can demonstrate a complexity and recombination in his actions that mimics the complexity and recombination of Level 3. When he happens to look at the doll, he can move his hand to it, grasp it, move his hand in front of his body, and look at the doll there. The sequence of actions is thus physically reversed and looks superficially like the recombination of looking, moving, and grasping that occurs so fluidly in the Level 3 skill. But in fact it is still only a chaining of actions. The infant can carry out the sequence, but he cannot reorder it into the many flexible combinations that typify Level 3.

A more primitive form of mimicking can also occur in this situation, as shown in Table 6. When the child has only the two simpler Level 2 skills shown in Equation 24, the stimulus context can lead him to change focus from the first skill to the second: He happens to look at the doll, moves his hand to where he sees it, and grasps it. As he holds it in his hand, he then loses sight of it and so changes focus to the second skill: He maintains his grasp on the doll, moves his hand in front of his face, and looks. Thus, the context produces behavior that superficially appears to show the mimicking Level 2 skill or the mimicked Level 3 skill, but the child cannot actually control either of these complex skills.

Mimicking has been produced in the laboratory by a number of ingenious experimental psychologists (e.g., Case, 1974; Harris & Bassett, 1975; Siegler, 1976), and some of these studies nicely support the skill-theory argument that the mimicking skill is different from the higher-level skill

that it mimics. For example, Bryant and Trabasso (1971) carefully trained preschool children to correctly judge the larger of every pair of sticks in a five-stick series. When the children were asked about non-adjacent parts from the series without being shown the specific lengths again, many of them correctly inferred the longer stick—thus apparently demonstrating transitive inference, which for their series of sticks would seem to be a Level 6 skill. However, the training procedure was perfectly designed to teach a compounded Level 5 skill that would mimic the Level 6 skill for transitive inference.

If the children had only been taught a mimicking skill, their correct performance should have been limited. For example, they should not have been able to solve a transitivity problem that required them to organize the needed information about non-adjacent sticks on their own. In a follow-up study, Bryant (1974, pp. 54–56; 1977) found exactly that: Children who after training could consistently solve the original transitivity problems could not solve similar new transitivity problems that required them to seek out the needed information on their own. According to the mimicking corollary, all instances of mimicking should show similar kinds of limitations.

When one uses skill theory to analyze behaviors that Piaget has studied, it is important to be aware of mimicking, especially for many of his infant observations. Most cases of primary, secondary, and tertiary circular reactions, for instance, seem at first to require sensory-motor skills at Levels 1, 2, and 3, respectively. But closer examination shows that many of these reactions are probably complex skills at the previous levels.

Mimicking is not just a laboratory curiosity or a measurement problem, however. It occurs normally when the child constructs transitional steps in the spontaneous development of a skill. Indeed, mimicking skills probably lay the foundation for the child's development to the next level.

#### *Parallels Between Tiers*

A third corollary involves the relations between tiers. Because the general Levels I

to IV (Table 1) repeat at every tier, behavior should show structural parallels between tiers. If a specific developmental sequence occurs at the sensory-motor tier, for example, then in the proper environment a similar sequence should appear at the representational tier, but it should of course involve changes in the structure of representations rather than changes in the structure of sensory-motor actions.

I know of only two sets of studies that provide data relating to precise parallels between tiers. One shows a parallel in the representational tier to a sensory-motor sequence; conversely, the other shows a parallel in the sensory-motor tier to a representational sequence.

In the sensory-motor tier, the infant develops skills for finding hidden objects. By Level III of the sensory-motor tier, he can follow the visible displacements of an object and look for it where it last disappeared (see Piaget, 1937/1954, Stage 5 in chapter 1). Because of the parallel between tiers, a similar skill for search should develop at Level III of the representational tier. Drozdal and Flavell (1975) have described exactly such a behavior, which they call "logical search behavior." By 7 or 8 years of age, most children could represent the probable displacements of a lost object and so look for it where it had probably been lost. (See also Wellman, Somerville, & Haake, 1979.)

Mounoud and Bower (1974/1975) report a parallel in the opposite direction: from the representational tier to the sensory-motor tier. At Level III of the sensory-motor tier, infants developed a skill that was apparently parallel to the skill for conservation of weight at Level III of the representational tier: When a familiar object made of a malleable substance like clay was altered from its usual shape, the infants grasped it as if its weight remained the same, even though in other situations they routinely adjusted their grasp to fit the differing weights of various objects. That is, they seemed to assume that the familiar object's weight remained the same even though its shape had changed. This sensory-motor conservation was not present in young infants and emerged by about 18 months of age.

More tests of the predicted parallel between Levels 1 to 4 and Levels 4 to 7 are clearly necessary, but besides generating tests of skill theory, the parallel serves another important function in research. It offers a source for new hypotheses. For every phenomenon that is discovered in sensory-motor development, a similar phenomenon can be searched for in representational development, and vice versa. Likewise, developments at the sensory-motor and representational tiers suggest similar developments at the abstract tier.

Other investigators have proposed a general parallel between sensory-motor development and later development (Piaget, 1937/1954, 1967/1971; Mounoud, 1976; Siegel & White, 1975; Werner, 1948). Piaget (1941) even gave a special name to parallels across his developmental periods: vertical decalages (distinguished from horizontal decalages, which are "parallel" developments within the same period). Greenfield and her colleagues have searched for structural parallels between language and manipulative play (Goodson & Greenfield, 1975; Greenfield, Saltzman, & Nelson, 1972; Greenfield & Schneider, 1977). None of these investigators, however, has provided a system for analyzing and predicting the parallel structures, and consequently it has been impossible to test the validity of suggested parallels. Skill theory, with its system for analyzing the structure of skills, may allow more precise tests of proposed structural parallels.

Besides specific structural parallels between tiers, skill theory also predicts new tiers, because Level IV of each tier produces a new kind of set. Both before and after the three specified tiers, the cycle of four levels can occur again with different types of sets. There must, of course, be some limit on the recurrence of the cycle, since it cannot go on infinitely; but that limit will have to be determined by future research.

#### *Reflex Tier*

The tier before the sensory-motor tier could be called the reflex tier and might well provide the starting point for skill develop-

ment: The infantile reflexes seem to be reasonable candidates for the initial units from which skills are constructed. Unfortunately, almost no research has been done that can be used to test the existence of these levels, and consequently I have treated this tier as a corollary rather than as a more firmly established part of the theory.

The infant or fetus begins with single reflexes, combines the single reflexes into reflex mappings, then combines the mappings into reflex systems, and finally combines the reflex systems to form systems of reflex systems, which are single sensory-motor sets (Level 1 in Table 3).

The term *reflex* is used in a number of different ways in the psychological literature. Some psychologists reserve the term for behaviors that are not subject to operant control and that are often assumed to be controlled by the peripheral nervous system, like the knee-jerk reflex. I use the term instead in the sense that it is used by ethologists (e.g., Hinde, 1970) and many psychologists (e.g., Piaget, 1936/1952): It refers to what might be called preprogramed behavior—species-specific activities that seem to be biologically programed into the nervous system (Teitelbaum, 1977). For example, Zelazo, Zelazo, and Kolb (1972) have worked with the stepping reflex, a complex response that can be elicited in the newborn infant and that seems to be organically related to the voluntarily controlled walking that develops toward the end of the first year after birth. Other examples would be the sucking reflex, which is elicited by stimulation of the lips, and the tonic neck reflex, in which the infant turns his head to one side and raises his arm on the opposite side. Even complex behaviors like looking are reflexes within this meaning: The sophisticated rules for visual scanning described by Haith (1978) seem to be preprogramed properties of the looking reflex or reflexes. To distinguish these reflex behaviors from peripherally controlled reflexes like the knee jerk, I will call them reflex skills or sets, because skill theory predicts that they normally develop into sensory-motor skills.

I know of only one study that relates

directly to the prediction of a reflex tier—a study by Bullinger (1977, Note 8). Much of the large quantity of other research on the newborn (Haith & Campos, 1977) could be interpreted in terms of such a tier, but none of it seems to provide a direct test of the predicted four levels of reflex development. Bullinger describes how the tonic neck reflex becomes gradually coordinated with the looking reflex and eventually develops into a looking skill that is independent of the tonic neck reflex.

In a sense, there are really two tonic neck reflexes. In one, the infant turns his head to the right and raises his left hand, and in the other, he turns his head to the left and raises his right hand. The tonic neck reflexes and various looking reflexes show a significant physical dependency: When the young infant is producing a given tonic neck reflex, he can look only to the side of his midline where his head is turned. For example, when his head is turned to the right, he can look at stimuli within his visual field to the right of his midline, but he cannot look at stimuli to the left of midline. To look at stimuli to the left, he must produce the other tonic neck reflex, in which his head is turned to the left. Bullinger describes how the infant gains control of this relation. My description of Bullinger's results includes an interpretation in terms of the four reflex levels.

At Level I, *single reflex sets*, the infant produces single reflexes, like each of the tonic neck reflexes and each of the various looking reflexes; but he cannot control any relations between reflexes. Bullinger found that infants from 15 to 45 days of age produced the tonic neck reflexes and various looking reflexes, but usually could not control any relation between tonic neck reflex and looking.

At Level II, *reflex mappings*, the infant maps one reflex onto another and thus begins to control relations between reflexes. For example, he should be able to produce the head-right tonic neck reflex in order to look at a stimulus to his right. At Level III, *reflex systems*, the infant relates two mappings to each other, integrating the two tonic neck reflexes with the two looking reflexes (left and right) in a reflex system.

He should therefore be able to shift from one tonic neck reflex to the other as necessary to look anywhere within his left and right visual fields. Bullinger describes the development of control by the infant over the relation between the tonic neck reflexes and the looking reflexes, but he does not discriminate between the predicted Level II and Level III skills. Infants usually showed some control of relations between the two types of reflexes at 45 to 80 days of age.

At Level IV, *systems of reflex systems*, the infant coordinates two Level III systems into a higher-order system and thus generates a single sensory-motor set (sensory-motor Level 1). He should be able, for example, to relate the tonic-neck-reflex-and-looking system with another reflex system involving posture and looking, thus showing highly flexible looking behavior that is relatively independent of specific postures: He has generated a new kind of set, the single sensory-motor action of looking. Bullinger found such flexible looking behavior commonly in infants 80 to 120 days old.

In this way, development through the reflex tier produces a single sensory-motor set. Note, however, that such a set involves not only one reflex system but two or more, because a Level IV skill involves the coordination of at least two Level III systems. In the Bullinger example, the child coordinates the tonic-neck-reflex system with another postural system in such a way that the postural adjustments go almost unnoticed, but in other cases the two systems are more obvious. For example, an infant can coordinate a reflex system for sucking with a reflex system for looking, and thereby he can look while he is sucking. This kind of analysis can provide a mechanism for predicting and explaining the composition of sensory-motor sets, especially the types of co-occurring behaviors that can be globally combined in the single, poorly differentiated sensory-motor sets described earlier.

Skill theory produces, then, at least these four structural corollaries: the reflex tier, parallels between tiers, mimicking, and consistent decalage within a task domain. The theory should also be able to predict other

structural corollaries, as well as other general effects of the environment on skill development and, of course, many other specific developmental sequences and synchronies. Rather than enumerating more such predictions, however, I would like to turn to some general implications of skill theory for conceptions of cognition, learning, and development.

#### A Few Implications of the Theory

Any theory worth its salt should do more than answer the original questions it was devised to answer. It should have implications for other important questions. Several of the most interesting implications of skill theory involve central topics in cognitive psychology: the nature of the big picture of cognitive development, the analysis of cognitive development and learning across skills, and the relation between behavior and thought.

#### *The Big Picture of Development*

Skill theory emphasizes careful analyses of specific tasks and predictions of specific sequences and synchronies in circumscribed task domains. But it also goes beyond these specifics to predict the general nature of major shifts in cognitive development—how skills are changing across the board as the person develops.

Although particular skills do not show abrupt or discontinuous change, major statistical shifts in populations of skills do occur (Feldman & Toulmin, 1975). In skill theory, the child's optimal level increases with age, and the speed of the increase is faster when the child is moving into a new level (Fischer & Bullock, in press; Fischer, Note 7). Together with environmental induction, these spurts at each level will produce major changes in the profile of skill levels. Transition periods between "stages" can therefore be defined as times when an increase in optimal level is producing a major shift in the population of skills, with many skills gradually moving to the new optimal level. To the extent that the new optimal level applies broadly across a wide range of skills, the shift in the skill profile should be dramatic and easy to detect.

The study by McCall et al. (1977) on shifts in the profiles of infant skills shows one method for inferring such transition points. These researchers found instabilities in the correlation patterns of infant tests that correspond generally to what is predicted by skill theory. When a shift to a new optimal level occurs, an increased unevenness in the levels of performance will appear in the individual child. The reason for this greater unevenness is that the speed of increase in optimal level becomes larger at these times and the child can initially apply this new capacity to only a few skill domains. Consequently, many correlations across domains decrease. The periods of correlational instability thus reflect times of maximal change. McCall et al. found four such periods of instability during the first 2 years of life, exactly as is predicted from the four sensory-motor levels. (They found these periods of instability before they knew about skill theory.)

Presumably, similar instabilities could be found for all the higher levels as well. For example, Kuhn (1976) finds instabilities in ability-test correlations in early adolescence, when people are presumably moving to optimal Level 7, single abstractions. Epstein (1974a, 1974b, 1978) reports spurts in mental age and brain growth that seem to correspond with the emergence of Levels 5, 6, 7, and 8.

There is a difficulty, however, with using age as the dimension along which one looks for instability. After infancy, developmental canalization decreases (McCall, 1979; Scarr-Salapatek, 1976), and consequently people probably no longer change to a new optimal level at the same approximate age. This variability in the age of shifting should increase dramatically at higher levels. Also, at higher levels, the prevalence of unevenness within an individual should become much greater. This problem with age can be eliminated if good measures of skill levels are used. Then people can be grouped not by age but by their optimal level, and the distribution of optimal levels within a sample will demonstrate whether spurts and instabilities exist (Fischer & Bullock, in press; Fischer, Note 7).

Skill theory thus predicts general types of

shifts in patterns of skills with development. These general shifts allow one to predict not only broad statistical changes but also many other general skill patterns, such as the probability of possession of a specific skill in all people in a large, culturally homogeneous population. One can predict, for example, the average age at which virtually all children of a given culture will have attained a specific level of a skill that is important for that culture: Virtually all American middle-class children will have attained an understanding of the social role of doctor (Level 5: Step 2 in Table 4) by 5 years of age. One can specify the normal range in which American middle-class children will normally be moving onto a new cognitive level for skills that are important to them, as shown in Table 7. Also, tests can be made of the levels predicted by skill theory versus those predicted by other theories (e.g., Bickhard, 1978; Case, 1978; Halford & Wilson, 1980; Isaac & O'Connor, 1975; Mounoud, 1980; Mounoud & Hauert, Note 9).

#### *Application to Other Skill Domains*

As the social-role example implies, the "big picture" to which skill theory applies is not limited to the standard cognitive-developmental tasks (mostly Piagetian tasks and IQ-type tasks). It has the promise of applicability across many different skill domains and consequently the potential for integrating theoretical analyses in areas that have usually been treated as theoretically distinct. Skill theory may be applicable to areas as diverse as language development, social development, and learning.

The skill levels should apply to any skills that develop, since they characterize the general information-processing system of human beings. Applying the theory to a new skill domain will not be an easy matter, of course, because it will require careful descriptive analysis of the specific skills that develop in that domain. This kind of careful analytic research has only recently become common in cognitive-developmental psychology.

The first step in applying skill theory to new spheres such as language develop-

Table 7  
*Age Periods at Which Levels First Develop*

Cognitive level	Age period <sup>a</sup>
1: Single sensory-motor sets	Several months after birth
2: Sensory-motor mappings	Middle of first year
3: Sensory-motor systems	End of first year and start of second year
4: Systems of sensory-motor systems, which are single representational sets	Early preschool years
5: Representational mappings	Late preschool years
6: Representational systems	Grade school years
7: Systems of representational systems, which are single abstract sets	Early high school years
8: Abstract mappings	Late high school years
9: Abstract systems	Early adulthood
10: Systems of abstract systems	Early adulthood

<sup>a</sup> These periods are merely estimates for middle-class Americans. For Levels 9 and 10, existing data do not allow accurate estimation.

ment or social development must therefore be an analysis of some of the specific skills that develop in language and in social relationships (see, e.g., Harter, 1977). Starting with these specific skills, the theory can be used to predict how they will develop through the skill levels, as was demonstrated earlier by the prediction of a developmental sequence for social-role skills (Table 4).

Notice that language skills, social skills, and skills in Piagetian tasks are all "equal" in skill theory (as they are in the approach of Vygotsky, 1962). Many recent approaches to language development and social development have postulated that cognitive skills are somehow more fundamental than language skills or social skills. For example, the development of some Piagetian measure of cognitive development, such as object permanence, is hypothesized to be the one prerequisite for the appearance of language (see Corrigan, 1979; Fischer & Corrigan, in press). Similarly, researchers in social development use conservation or some other Piagetian measure to explain the emergence of important social skills, such as perspective-taking and morality. The Piagetian skill is again elevated to a special status, as if it were more fundamental than the social skills.

According to skill theory, there is nothing particularly fundamental about object permanence, conservation, or any other Piagetian measure of development. The

only thing special about these Piagetian cognitive skills is that their development was investigated first—before the development of the language skills or social skills that they are supposed to explain. Interactions between some Piagetian skills and some language skills or some social skills will undoubtedly occur in development, but they will be highly specific interactions, not general relationships in which one type of skill will be a general prerequisite for the other. And interactions will occur in both directions, not just from Piagetian skills to language or social skills, but also vice versa. The earlier discussion of synchrony explained the kinds of relationships that should be expected: (a) a low general synchrony across domains, (b) high general synchrony only when the skills in the specific domains being tested are all maintained at the children's optimal level, and (c) specific interactions only when a particular skill in one domain becomes a component of a particular skill in the other domain. Note that the kind of specific interaction to be expected is what behavioral analyses of transfer have always predicted: Specific components of one skill become components of a second skill (e.g., Baron, 1973; Mandler, 1962; Reed, Ernst, & Banerji, 1974).

In addition to large-scale developmental changes, skill theory is also applicable to changes in behavioral organization that are usually categorized under learning or prob-

lem solving. These changes should be predictable by the microdevelopmental transformation rules of the theory. For example, in the microdevelopmental sequence in which children pretend about going to sleep, the successive steps in the sequence are essentially steps in the generalization of an action: Children pretend to go to sleep, then pretend to put a doll to sleep, then pretend to put a block to sleep, and so forth (Watson & Fischer, 1977). Similarly, many microdevelopmental sequences typically categorized under cognitive development could equally well be categorized under learning or problem solving (e.g., Fischer & Roberts, Note 3).

Likewise, adults solving a complex problem or rats learning to run a maze show systematic changes in the organization of their behavior (Duncker, 1935/1945; Fischer, 1975; Siegel & White, 1975). These changes can be treated as microdevelopmental sequences, and therefore skill theory should be able to predict and explain them (Fischer, 1974, 1980).

Skill theory, then, may help to integrate such apparently diverse research areas as learning, problem solving, social development, language development, and cognitive development. It also has important implications for another major research problem—the relation between behavior and thought.

### *Behavior and Thought*

A classic problem for most cognitive approaches has been that their constructs typically do not explain how thought is turned into action (see Hebb, 1974). As some wit said, they leave the organism sitting in a corner thinking.

Skill theory provides a possible way out of this dilemma. Thought (representation and abstraction) develops out of behavior (sensory-motor action), and the skills of thought hierarchically incorporate the skills of action that they have developed from. That is, representational skills are actually composed of sensory-motor skills; and likewise, abstract skills are actually composed of representational skills and therefore sensory-motor skills. Consequently, there is no separation between thought and

action, since thought is literally built from sensory-motor skills. Also, sensory-motor development does not cease at the end of the sensory-motor tier but continues at higher levels.<sup>16</sup>

Representational and abstract skills produce and direct sensory-motor actions. This relation between representation and action is illustrated by the example of the child's understanding of the spring-and-cord gadget at Level 5. When the child understands the mapping of weight (representational set <sup>5</sup>W) onto the length of the spring (representational set <sup>5</sup>L), her control of each representational set is based on sensory-motor sets. With her Level 5 skill, she can therefore directly control the various weights to manipulate the length of the spring. She is not left sitting in a corner merely thinking about how weight relates to length. Behaviors studied in our laboratory also illustrate this relationship between representational and sensory-motor sets (Bertenthal & Fischer, 1978; Watson & Fischer, 1977, 1980; Fischer & Roberts, Note 3).

The inclusion of sensory-motor skills in representational skills is especially evident in language. Speech and gesture, which are both sensory-motor skills, are essential components of the representational skills of language (e.g., Fischer & Corrigan, in press; MacWhinney, 1977).

In addition, the control of sensory-motor skills by representational skills extends beyond the direction of sensory-motor skills that are already present. Higher-level skills also direct the acquisition of new lower-level skills. Jacqueline's "bimbam" skill, described earlier, provides an example (Piaget, 1946/1951, Observation 64). When she first combined two Level 3 sensory-motor systems into the Level 4 bimbam representation for fluttering, her skill controlled just two things that fluttered: herself, when she rocked back and forth on a piece of wood, and leaves, when she made them

<sup>16</sup> In Piaget's theory, the nature of the relation between sensory-motor action and representation is less clear, but it seems that sensory-motor development stops at the end of the sensory-motor period (e.g., Piaget, 1946/1951, p. 75).

flutter. Then, through compounding and substitution, she extended the skill to new objects, such as curtains, that she could make flutter or that fluttered in the breeze. For each object to which she extended the skill, she constructed or included a new Level 3 sensory-motor system involving the fluttering of the new object, and this skill thus became a new sensory-motor component of the Level 4 "bimbam" skill.

In the same way, representational skills at higher levels are constantly used to construct new sensory-motor skills. Development from Levels 4 to 7 produces skills that subsume more and more sensory-motor actions and at the same time control finer and finer differentiations of sensory-motor actions. Consequently, skill theory should be able to predict the development of complex sensory-motor skills like driving a car, using a lathe, or operating a balance scale—skills that develop after the first 2 years of life. Research does support the argument that orderly developmental changes occur in sensory-motor skills during both childhood (e.g., Greenfield & Schneider, 1977; Ninio & Liebllich, 1976) and adulthood (e.g., Hatano, Miyake, & Binks, 1977).

In addition to making numerous specific developmental predictions, then, skill theory has significant implications for the nature of changes in populations of skills in development, the integration of theoretical analyses of skill development and learning in spheres that have been traditionally treated as distinct, and the relation between behavior and thought. But skill theory also has several limitations.

#### Limitations of Skill Theory

Two limitations of skill theory are the need for a more powerful definition of skill domains and the need to deal with the processes by which skills are accessed.

#### *Defining Skill Domains*

Skill theory provides a mechanism for predicting and explaining the development of skills in specific task domains, and it also gives a general portrait of how populations of skills change with development. But

at this time it does not deal adequately with skill domains.

A task domain involves a series of tasks that are all very similar to each other, typically sharing a basic group of components but differing in the additional components that are required to perform the tasks. A skill domain, on the other hand, involves a number of task domains that share similar skills and therefore develop in approximate synchrony.

At present, skill theory determines skill domains in a primarily empirical way. When developments in two task domains show a degree of synchrony that cannot be accounted for by environmental factors such as practice effects, then the two task domains are said to belong to the same skill domain. To deal with skill domains in a more satisfactory way, skill theory will ultimately require concepts for specifying the glues that tie task domains together. These concepts will presumably lead to a graduated notion of skill domain rather than an all-or-none notion: Task domains will vary in terms of the proportions of skills that they share.

#### *Accessing Skills*

The second limitation involves a matter that skill theory says little about. No processes are designated to deal explicitly with the way in which skills are accessed. A person may have available the skill needed to perform a particular task or to show a specific behavior and yet in the appropriate context may fail to use that skill. Skill theory does not deal directly with phenomena of this type, which are commonly classed under the rubric of motivation. What makes a person do one thing instead of another when she is capable of doing either?

The omission of accessing also means that skill theory neglects many of the phenomena of memory and attention that are such central concerns within the information-processing framework (see Estes, 1976). Skill theory should be able to predict the development of memory skills, and it has already been used as a tool for uncovering some new memory phenomena, such as a



relation between recall success and skill level (see Watson & Fischer, 1977). It does not specify, however, how the process of accessing skills relates to individual differences and task differences in memory performance.

Skill theory in its present formulation does not use the information-processing framework. It is a structural theory that has its roots in the classical tradition of cognitive psychology (see Catania, 1973; Fischer, 1975). In recent years many psychologists have come to equate cognitive psychology with the information-processing approach. This equation ignores the fact that a long and venerable tradition of cognitive psychology existed decades before the information-processing approach was invented.

On the other hand, skill theory is not inconsistent with the information-processing approach. Indeed, I would hope that some parts of it could be reformulated in information-processing terms. Such a formulation might provide more precision in some parts of the theory and thereby help to overcome some of the theory's limitations, including the treatment of accessing skills.

Any attempt to provide an information-processing formulation, however, should avoid a major pitfall that has plagued many information-processing analyses of cognitive development: They neglect the adaptive process that is the very basis of cognition according to skill theory. The cognitive organism is constantly adapting skills to the world, and this adaptation provides the foundation for cognitive development and learning (see MacWhinney, 1978). Any information-processing formulation of the theory must include this adaptive process if it is to provide a fair representation of the entire theory.

A person should not be treated as a disembodied brain developing in a virtual environmental vacuum. In some cognitive theories that make sharp distinctions between competence and performance, the environment and the person's adaptation to it are effectively left out. The issue of the processes by which skills are accessed should not be confused with this issue of

competence versus performance. Although there is some overlap between the two issues, they are not the same. The extreme formulation of the competence-performance model assumes that a structure is present but that there is some performance limitation that prevents it from being fully realized in behavior (Chomsky, 1965). The access question, on the other hand, entails no such assumption, because skill theory does not posit powerful structures that have difficulty eventuating in behavior. The access question is simply: What are the processes that determine which skill an individual will use in a particular task at a given moment?

#### Concluding Comment

Whatever their form, theories are tools for thought (Hanson, 1961). The essential test of a theory is whether it is a good tool. This theory is intended to be a useful tool for understanding cognitive development and facilitating the process of theoretical integration that is essential to progress in psychology (Elkind & Sameroff, 1970; Haith & Campos, 1977). The theory promises to provide a system for predicting and explaining developmental sequences and synchronies in any skill domain throughout the life span, and it also promises to integrate analyses of development with treatments of learning and problem solving. Time and research will tell whether this promise becomes fact.

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