How Cognitive Processes and Environmental Conditions Organize Discontinuities in the Development of Abstractions

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How Cognitive Processes and Environmental Conditions Organize Discontinuities in the Development of Abstractions

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There is a major contradiction in the literature on adult cognitive development. Most studies seem to show that adults cannot perform the complex abstract tasks that Inhelder and Piaget (1955/1958) and others use to measure advanced thinking (Flavell, 1970; Horn, 1976; Neimark, 1975). Yet everyday beliefs suggest that many adults can reason in sophisticated ways about abstract concepts. In recent years, evidence has accumulated contradicting the findings of low-level thinking in adolescents and adults. In later adolescence and early adulthood, people seem to show major cognitive-developmental advances (Commons, Richards, & Armon, 1984; Fischer & Lamborn, 1989; Kitchener, 1982; Kitchener & King, 1990; see Richards & Commons chapter).¹

The contradiction between these two sets of findings can be readily explained. What is needed is a theory that treats cognitive development as arising from the collaboration of person and environment. That is, both organismic and environmental components must be included in the central constructs of the theory. Then cognitive development is seen to involve both the great heights of abstractions and normal variations below those heights. That is, the two sets of findings not only are both correct but are fully compatible with each other. On the one hand, adolescents and young adults develop new levels of abilities to understand abstract concepts and relations. On the other hand, most behavior during this period does not show these cognitive advances.

Within the collaborative framework called skill theory (Fischer, 1980b), these apparently contradictory findings are explained by the systematic variations in people's level of performance. Under ordinary environmental conditions, people routinely function below their highest capacity. Yet high-level performance—and true cognitive-developmental levels—are strikingly evident under specific environmental conditions that optimize performance.
Cognitive-Developmental Levels as Discontinuities

One of the central problems in cognitive-developmental research has been that the criteria for what constitutes a stage have been unclearly specified. Piaget (1957) argued that the fundamental criterion for a stage is synchronous change across domains: The child's abilities in diverse domains should move nearly simultaneously into a new logical stage, such as concrete operations (Broughton, 1981b). Yet research has shown overwhelmingly that such synchrony does not obtain (Fischer & Bullock, 1981; Flavell, 1971b, 1983), as Piaget himself gradually acknowledged (e.g., Piaget, 1941, 1972). With the failure of this straightforward criterion, investigators have fallen back on a loose, poorly articulated criterion: Some sort of qualitative change indicates a new stage or level (Fischer & Silvern, 1985). As a result, ways of detecting stages or levels have remained unclear. Indeed, if observers were to happen upon a genuine stage or level, how would they know they had found it?

One straightforward criterion for a cognitive-developmental level is a discontinuity or sudden alteration in the pattern of developmental change. The simplest form of discontinuity is a spurt in performance during a limited age period, as shown in Figure 7.1: A person shows a sudden improvement in performance during a relatively short time interval. To test for such a spurt, a number of methods are available, as outlined by Fischer, Pipp, and Bullock (1984). The fundamental requirements of all the methods are the use of a ruler and a clock. The ruler can be any scale that provides an approximately continuous measure of the ability hypoth-

![Figure 7.1](image-url)

*Figure 7.1* Spurts in three hypothetical behavioral domains as a result of the emergence of a new developmental level. Note: A, B, and C are different behavioral domains. The spurts were chosen to represent the emergence of Level 8 abstract mappings. (Reprinted with permission from Fischer, Hand, & Russell [1984]. Copyright Dare Association and Praeger Publishers.)
esized to change. The clock can be age or any other measure that can specify the length of the interval during which change takes place. A discontinuity is evident when a large change in performance occurs in a short time.

According to skill theory (Fischer, 1980b; Fischer & Farrar, 1987), the emergence of a new cognitive-developmental level produces a cluster of such spurts in performance. Within some limited age period, spurts can be detected in a wide range of different domains. For example, one level hypothesized by skill theory typically appears between 14 and 16 years of age, as shown for three hypothetical domains in Figure 7.1. The spurts do not all occur at exactly the same age, nor do they take exactly the same form. Adolescents do not suddenly metamorphose on their fifteenth birthday. Instead, the change is only relatively rapid, occupying a small interval of time.

For such spurts to occur reliably, people must be performing at or near their optimal level, the most complex skill that they can control. Complexity is defined in terms of a developmental scale of hierarchically ordered skill structures involving the coordination of sources of variation in behavior. For the cognitive levels that develop in adolescence and adulthood, the sources of variation are based in a structure called an abstraction, which typically specifies an intangible characteristic for coordinating some of the sources of variation in representations (concrete characteristics of people, objects, or events). Examples of abstractions include concepts such as justice, honesty, law, and responsibility, as well as arithmetic operations such as addition and division (Fischer & Lamborn, 1989).

Environmental conditions determine when people perform at their optimal level. Only with practiced skills in familiar domains and with environmental support for high-level performance will most people perform at optimum and thereby show a spurt in performance with the emergence of a new level. Most of the time, people do not encounter such environmental circumstances, and so they do not usually show spurts in performance. Levels are therefore evident only under special environmental conditions. Most conditions are likely to produce slow, gradual, continuous improvements in performance, even when people are performing exactly the same tasks that show discontinuities under optimal conditions.

Evidence for Continuous, Gradual Change

The typical pattern of slow, gradual change is evident in most developmental and educational research. Study after study demonstrates that with age, children, adolescents, and young adults typically show small improvements in performance or no change at all (Brown, Bransford, Ferrara, & Campione, 1983; Chi, 1978; Fischer & Silvern, 1985; McCall, Meyers, Kartman, & Roche, 1983). However, it could be argued that many of these studies do not provide appropriate tests for stagelike change because they do not assess developmental sequences. Colby, Kohlberg, and their colleagues (1983) carried out a longitudinal study that does not suffer from these problems and so provides a particularly clear test of the hypothesis that most cognitive development is slow and gradual (see Kohlberg & Rynearz chapter).

Kohlberg (1969) devised a structured interview comprised of a series of moral dilemmas for assessing ideal types that were found to form a sequence of stages in
the development of moral judgment. The stages were formulated within the Piagetian tradition to reflect changes in thinking about morality and were hypothesized to form what Piaget (1957) called structured wholes. Consequently, they should emerge in a stagelike manner, appearing relatively suddenly and permeating the child's moral thinking.

According to the optimal-level hypothesis from skill theory, on the other hand, performance on Kohlberg's interview should demonstrate slow, gradual, continuous improvement over many years rather than abrupt, stagelike emergence. Gradual change is predicted because the interview is administered in such a way that it does not encourage optimal performance: Each dilemma is given only once, subjects are never told what is a good answer, and no contextual support for high-level performance is provided.

Groups of normal boys were originally tested on Kohlberg's interview at 10, 13, or 16 years of age, and they were retested on the same interview several times over the ensuing 20 years. Results showed that the stages did indeed form a developmental sequence, such that people consistently demonstrated later stages after they had first shown earlier ones. Because Kohlberg's research was designed to detect Piagetian-type cognitive—structural stages and because the stages have been shown empirically to form a developmental sequence, the study provides a strong test of the two competing hypotheses: Will the stages show abrupt emergence, or will their development be slow and gradual because the subjects were tested under nonoptimal conditions? With the longitudinal design, it is possible to determine not only whether the group as a whole showed spurts or gradual change in moral stage but also whether individual subjects demonstrated such spurts.

We analyzed the published data (Colby et al., 1983) to test for spurts versus gradual change in performance. The results were clear. Movement from stage to stage was continuous—slow and gradual. There was no evidence at all for relatively sudden change from one stage to the next. The development of Stage 4 offered a particularly good case, because no Stage 4 moral reasoning was evident at the youngest age in the study and virtually all subjects produced extensive Stage 4 reasoning by the end of the study. As shown in Figure 7.2, Stage 4 moral reasoning

![Figure 7.2](image)

*Figure 7.2* The development of stage 4 reasoning in Kohlberg's longitudinal study. Based on data in Colby et al. (1983).
first appeared at approximately 13 years of age, and the frequency of Stage 4 reasoning increased very slowly throughout the entire course of the study. Most subjects did not produce a preponderance of Stage 4 reasoning until they reached their 30s. The pattern was the same for individual subjects—a slow, gradual increase in Stage 4 moral reasoning over many years.

This study of Kohlberg's stages clearly demonstrated continuous change, not discontinuous, and the pattern of continuous change is typical of most other research. Nevertheless, a few studies do provide evidence of developmental spurts during adolescence and early adulthood (e.g., Martarano, 1977; O'Brien & Overton, 1982). We propose that the optimal-level hypothesis will predict how spurts appear and disappear as a function of environmental conditions and will thus explain the cases in which spurts have been found. To show how this explanation will operate, we first need to elaborate our skill-theory analysis.

Building and Using Skills: The Importance of Practice and Environmental Support

It takes work to build a skill. When a person develops a general capacity to build skills at a new developmental level, there is no automatic transformation of all skills to the new level. The human information-processing system follows what might be called a Calvinist principle: The person must actively construct every new skill. Skills do not emerge for free, without effort.

In general, at least two circumstances are necessary for a person to build a new skill. First, the environment must provide a context that induces and supports performance of the behaviors that comprise the skill. Second, the person must practice the skill until he or she has mastered it.

When stated so directly, the Calvinist principle about skill building may seem sensible and obvious; yet it has not been included in the central principles of traditional cognitive-developmental theories such as Piaget's (1970b). Once it is included, stagelike change can no longer be expected across all domains of behavior. Even if Piaget could magically touch the head of an 11-year-old and instantaneously transform him or her to formal operations, the child would have to take time and effort to use the new capacity to build specific formal-operational skills. Only with time, then, would the new capacity become evident. And while the child was expending time and effort on building new skills in one domain, such as arithmetic, little progress would be made in building skills in other domains, such as morality. Consequently, even an instantaneous transformation of capacity would result in a gradual transformation of skills occurring during some interval of time. Relatively, this transformation would involve spurts in performance, but absolutely, it would still take time.

Furthermore, if the environment must induce and support the building of a new skill, then the levels of a person's skills will inevitably vary across domains. After a new capacity emerges, the environment will happen to induce the building of skills at the new level in certain domains and not in others. The person will experience the environmental contexts necessary for inducing the building of some
skills, such as those for arithmetic reasoning, and not for the building of others, such as those for moral reasoning. It is physically impossible within a limited time period to encounter the contexts needed to induce all possible skills. Consequently, even if capacity were transformed instantaneously, the actual skills a person possesses would vary across domains.

According to skill theory, the environment not only induces the transformation of a skill to a new level but also affects the level of performance of a skill more directly. The environmental context provides varying degrees of support for high-level performance (Fischer & Bullock, 1984). A skill is not simply present or absent, but it is internalized to a certain degree. The more it is internalized, the less environmental support is required for a person to perform it. Conversely, the less it is internalized, the more environmental support is required for performance. The gap between the person's optimal level and his or her level of functioning with low support is called the developmental range (Lamborn & Fischer, 1988).

In Kohlberg's moral judgment interview, little support was provided for high-level performance: Subjects were not shown a good answer or given any other aids for high-level performance, nor were they allowed to work out an answer over a period of time. Without environmental support or the opportunity to work out a high-level skill, people do not typically function at or near optimum. They function at the bottom of their developmental range.

Detection of the discontinuities predicted to appear with a new developmental level, then, requires the following sort of skill assessment: People must be tested (1) in familiar domains, where they have had the opportunity to construct high-level skills; (2) under environmental conditions that provide contextual support for high-level performance; and (3) with the opportunity to practice the tasks they must perform. In familiar domains, relatively short periods of practice will suffice, such as hours, days, or weeks. But in unfamiliar domains, optimal performance will be possible only after long time periods for practice and instruction.

Traditionally, developmental and educational researchers have not assessed behavior under conditions for optimal performance (Feuerstein, 1979). As in Kohlberg's study, testing conditions have provided little contextual support for high-level performance, and there has been little opportunity for practice. Also in some cases, the domains tested have not been familiar. Inevitably, performance under such conditions will show slow, gradual, continuous change.

In a study of the development of arithmetic skills, we have tested this interpretation by varying both degree of contextual support and opportunity for practice (Fischer et al., 1984; Fischer, Kenny, & Rose, 1987). Subjects were tested individually in two sessions, with two conditions in each session. In the first session, a series of arithmetic tasks was administered to them with no support or practice. The subjects were shown each task for the first time, and they were encouraged to give an immediate answer. Later in the same session, they were given each task again, but now environmental support was provided. The experimenter first showed them a sample good answer and allowed them time to read it over and ask questions about it. Then the sample answer was taken away, and they provided their own answer. At the end of this session, they were reminded that they would be tested on the same tasks in two weeks and that they should think about them.
during the interim. In the second session, the two conditions from the first session were repeated—first, assessment with no support, and then assessment with the support of first seeing a good answer.

Eight subjects were assessed in each grade between third grade and college. The tasks in the arithmetic study were designed to test several of the levels of abstract skills that are predicted by skill theory to develop during adolescence and early adulthood.

Four Levels of Abstract Skills

According to skill theory, abstractions first develop at about 10–12 years of age, the period when formal operations are said to begin (Inhelder & Piaget, 1955/1958). This new capacity for abstractions is built upon a series of earlier levels involving first reflexes, next sensorimotor actions, and then representations. First, young infants come to control reflexes at successively more complex levels until they can ultimately control single sensorimotor actions. Next, older infants build sensorimotor actions at successively more complex levels, until eventually they can control single representations. Children in turn build more complex representations, moving through a series of levels that culminate in the control of single abstractions at 10–12 years. The developmental levels involving actions, representations, and abstractions are presented in Table 7.1, along with the simplest algebraic representation of the skill structure for each of the 10 levels. All the developmental levels are described in detail in Fischer (1980b).

The first level of abstractions (Level 7) involves only the simplest level of abstract skills. Three additional, more complex levels (Levels 8–10) develop over the next 15 years. These four levels of abstractions continue the hierarchical series of levels that started in early infancy. The cycle of the four levels of abstractions is the focus of the present section.

Each level is defined in terms of a skill structure that is specified algebraically. For Level 7, the structure is a single abstraction, which arises from the intercoordination of two or more representational systems. To avoid having to elaborate upon the structural definitions for each abstract skill level in this chapter, we will define these levels in terms of one type of abstraction, the intangible category. Many instances of abstractions involve intangible categories and the relations between them, and they seem to have been investigated more than any other type, not only in our laboratory but in most research on cognitive development in adolescence and early adulthood. In describing the levels, we will focus on our arithmetic study as well as several other studies from the literature dealing with the following intangible categories: intention and responsibility (Fischer, Hand, & Russell, 1984; Hand & Fischer, 1981), political concepts (Adelson, 1972), moral concepts (Kohlberg, 1969; Rest, 1983), and reflective judgment about knowledge (Kitchener, 1982; Kitchener & Brenner, 1990).

In the arithmetic study, tasks were designed to assess each of the four levels of abstractions, although thus far we have collected data only for the first two levels. All the tasks involved using, defining, and relating the four basic arithmetic operations—addition, subtraction, multiplication, and division. For each task, the sub-
Table 7.1 Ten Levels of Skill Structures$

<table>
<thead>
<tr>
<th>Level</th>
<th>Name of Structure</th>
<th>Sensorimotor† Tier</th>
<th>Representational† Tier</th>
<th>Abstract Tier</th>
<th>Estimated Age Region of Emergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Single sensorimotor set</td>
<td>[A] or [B]††</td>
<td></td>
<td></td>
<td>3–4 mos.</td>
</tr>
<tr>
<td>2</td>
<td>Sensorimotor mapping</td>
<td>[A → B]</td>
<td></td>
<td></td>
<td>7–8 mos.</td>
</tr>
<tr>
<td>3</td>
<td>Sensorimotor system</td>
<td>[A₀,₁,H → B₀,₁,H]</td>
<td></td>
<td></td>
<td>11–13 mos.</td>
</tr>
</tbody>
</table>
| 4     | System of sensorimotor systems, equivalent to a single representational set | \[
\begin{align*}
A &\rightarrow B \\
\downarrow &
\end{align*}
\] \Rightarrow \[R\] |                        |              | 20–24 mos.                         |
| 5     | Representational mapping | \[R → T\]          |                        |              | 4–5 yrs.                           |
| 6     | Representational system | \[R_{i,k} → T_{i,k}\] |                        |              | 6–78 yrs.                          |
| 7     | System of representational systems, equivalent to a single abstract set | \[
\begin{align*}
R &\rightarrow T \\
\downarrow &
\end{align*}
\] \Rightarrow \[\delta\] |                        |              | 10–12 yrs.                         |
| 8     | Abstract mapping    | \[\delta → \theta\] |                        |              | 14–15 yrs.                         |
| 9     | Abstract system     | \[\delta_{x,y} → \theta_{x,y}\] |                        |              | 19–21 yrs.                         |
| 10    | System of abstract systems, equivalent to a single principle | \[
\begin{align*}
\delta &\rightarrow \theta \\
\downarrow &
\end{align*}
\] \Rightarrow \[\gamma \rightarrow \eta\] |                        |              | 24–26 yrs.‡                        |

*Boldface capital letters designate sensorimotor sets; italic capital letters designate representational sets, and script capital letters designate abstract sets. Multiple subscripts designate differentiated components of a set; whenever there is a horizontal arrow, two or more subsets exist by definition, even when they are not expressly shown. Long straight lines and arrows designate a relation between sets or systems. Brackets designate a single skill.

†Sensorimotor structures continue after Level 4, and representational structures after Level 7, but the formulas become so complex that they have been omitted. To fill in the sensorimotor structures, simply copy the pattern in the representational tier, replacing each representational set with the sensorimotor formula for Level 4. Similarly, to fill in the representational structures, copy the pattern in the abstract tier, replacing each abstract set with the representational formula for Level 7.

‡Since little research has been done on development at this level, this age range must be considered highly tentative.

ject calculates a simple arithmetic problem or two, such as 7 + 3 = ?. Then he or she answers a general question about the operations used, such as “Explain what addition is, and show how the definition applies to this problem.” In all cases, the problems dealt only with positive whole numbers. Each type of task was given in two different forms, one involving general verbal explanation without any visual props and one involving an explanation using the number line for positive whole numbers (a line along which the numbers are displayed at equal intervals). Table 7.2 provides an example for each of the four abstract levels taken from the arithmetic study.

In Level 7 single abstractions, which first appear as early as 10 or 11 years of age, the child controls individual intangible categories, such as intention and responsibility, law, society, and justice. Children with single abstractions can coordinate two or more concrete instances to form an intangible category, but they can-
Table 7.2 Arithmetic Examples for Four Developmental Levels of Abstract Skills

<table>
<thead>
<tr>
<th>Level</th>
<th>Name of Structure</th>
<th>Skill Structure</th>
<th>Examples from Arithmetic Study*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>“Addition is when you put together two numbers, and you end up with a bigger number called the sum. Like you put together the numbers 5 and 7, and you get the bigger number 12.”</td>
</tr>
<tr>
<td>8</td>
<td>Abstract Mappings</td>
<td>[E − E]</td>
<td>General Relations of Two Closely Related Arithmetic Operations and Application to Problems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“Addition and multiplication are similar operations. Both put numbers together to get a larger number, but the numbers are put together in different ways—by single numbers in addition and by groups of numbers in multiplication. Multiplication is really addition repeated a specific number of times. In 5 times 7, the first number, 5, tells you how many times to do the second number, 7, so you have a group of five sevens. In addition, you take the single number 7 and put it together with another 7, and another, and another, and another.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>“Addition and division are opposite operations in two ways. Addition increases by single numbers, while division decreases by groups of numbers. The fact that one increases and the other decreases is one way they are different, and the way they increase or decrease by single numbers or groups is the other way. Repeated addition can be used to express a division problem like $35 ÷ 5 = 7$. Five added seven times yields 35, so we know there are seven fives in 35.”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[E ↔ H]</td>
<td>“Addition, subtraction, multiplication, and division are all operations, which means that they all transform numbers by either combining or separating them and doing so either in groups or one number at a time. There are relations between all possible pairs of operations. Some pairs are closely related, and others are more distantly related . . . (Elaboration explaining the pairs, as diagramed in the table below, and applying them to concrete arithmetic problems, such as $5 + 7 = 12$, $12 - 7 = 5$, $5 \times 7 = 35$, and $35 ÷ 5 = 7$.)”</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number</th>
<th>Group of Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase</td>
<td>Addition</td>
</tr>
<tr>
<td>Decrease</td>
<td>Subtraction</td>
</tr>
</tbody>
</table>

Note: Script capital letters designate abstract sets. Subscripts designate differentiated components of the respective set. Long straight lines and arrows designate a relationship between sets of systems. Brackets designate a single skill.

*The arithmetic concepts deal only with positive whole numbers.
not relate one intangible category to another. There were eight arithmetic tasks for assessing Level 7 skills. All tasks required providing a general definition of one of the four operations, as illustrated in Table 7.2, and showing how it applied to an arithmetic problem the child had calculated.

With Level 8 abstract mappings emerging at about 14–16 years of age, adolescents relate one intangible category to another in a simple way. Examples include the relation of intention to responsibility, of liberal to conservative, and of one type of knowledge to another type. What is not possible at Level 8 is dealing simultaneously with several components or varieties of each intangible category, such as relating two types of intention to two types of responsibility. There were eight arithmetic tasks for assessing Level 8 skills, two each for the four following pairs of closely related operations: addition and subtraction, multiplication and division, multiplication and addition, and division and subtraction. To pass each task, the person had to explain in general terms how the two operations in the pair relate to each other (how they are similar and different) and how that relation is evident in specific arithmetic problems, such as $7 + 3 = 10$ and $10 - 3 = 7$.

The findings from a number of studies support the emergence of the new capacities described by Levels 7 and 8, but there are not many studies relevant to Levels 9 and 10 (Fischer, Hand, & Russell, 1984). Nevertheless, a few studies do suggest the emergence of the hypothesized capacities of Levels 9 and 10 in early adulthood (see Broughton, 1978; Commons et al., 1984; Fischer & Lamborn, 1989; Jaques, Gibson, & Isaac, 1978; Kitchener, 1982). Also, the theories of Case (1980) and Biggs and Collis (1982) predict levels of abstraction similar to those of skill theory. Because of the dearth of data, the description of the nature of these two levels and the ages associated with them should be considered tentative.

**Level 9 abstract systems**, developing initially at approximately 20 years of age, introduce more complex relations between intangible categories. The young adult can relate several components or varieties of one abstraction, such as intention, to several components or varieties of another, such as responsibility. For example, systems relating several types of intention to several types of responsibility seem to be common in the legal system, where intention and responsibility are two of the essential components for determining guilt and punishment. In arithmetic, one such system for relating several types of arithmetic operations involves the two pairs of distantly related operations: addition and division, subtraction and multiplication. The relation of each pair constitutes a Level 9 skill, in which the pair is related by variations in two distinct components—direction of change and type of unit (see Table 7.2). We devised a series of arithmetic tasks for assessing Level 9 skills based on these two distantly related pairs of operations.

The final reorganization, **Level 10 general principles**, involves the integration of two or more Level 9 abstract systems in terms of some general theory, ideology, or framework. A reasonable estimate is that this level first appears at approximately 25 years of age. Examples include an epistemological framework for coordinating variations in knowledge systems, such as the reflective-judgment framework outlined by Kitchener (1982), and Darwin's principle of evolution by natural selection (Gruber, 1981). More modest principles also occur at Level 10, including the one integrating the relations among the four arithmetic operations: The four operations involve the possible combinations of the two different types of transformations of
numbers implied by the components in the distantly related pairs assessed at Level 9: direction of change (increase or decrease) and type of unit (single numbers or groups of numbers), as outlined in Table 7.2. At Level 10 the person can fluidly use this principle relating these transformations to analyze how the four operations relate to each other.

Empirical Criteria for Levels

With the arithmetic tasks devised for testing the four levels of abstractions, it is possible to test the skill-theory analysis of the effects of environmental conditions on the pattern of developmental change. Under optimal conditions, performance on these tasks should demonstrate discontinuities upon the emergence of each new level. Under ordinary (nonoptimal) conditions, performance should demonstrate slow, gradual, continuous improvement. This hypothesis specifies several empirical criteria for levels.

Spurt in Tasks for a Particular Level

The most obvious empirical criterion for the emergence of a new level is a spurt in optimal performance. In the arithmetic study, such a spurt occurred for both Level 7 and Level 8.

Between third and fifth grades, Level 7 performance under optimal conditions spurted from near zero to over 50 percent correct. Figure 7.3 shows the data for the two extreme conditions: no support or practice (the first condition in the first session) and both support and practice (the second condition in the second session). The latter, the optimal condition (practice and support), produced the spurt in per-

![Figure 7.3](image-url)  
*Figure 7.3* Development of level 7 arithmetic skills under ordinary and optimal conditions of support.
performance, whereas the former, the nonoptimal ordinary (spontaneous) condition, produced slow, gradual improvement on the same tasks. The nonoptimal condition is like most standard cognitive and educational assessments, which employ similar testing procedures. Under each condition, children performed eight tasks assessing Level 7 skills, but two of the tasks dealt with division, which is not taught until late in elementary school. Consequently, only the six tasks for addition, subtraction, and multiplication are included in the analysis for Level 7.

Between ninth and tenth grades, Level 8 performance under the optimal condition spat from near zero to over 80 percent correct. Figure 7.4 includes all four assessment conditions, ranging from spontaneous to optimal. For every condition, each subject performed eight tasks assessing Level 8 skills, as described earlier.

For both Levels 7 and 8, the spurt was closely tied to age and grade: In the optimal condition, Level 7 was marked by a spurt that occurred for all subjects between third and fifth grades (approximately 9 and 11 years of age), and Level 8, by a spurt for all subjects between ninth and tenth grades (approximately 15 and 16 years).

To meet the criterion for a discontinuity, however, such a close tie to age and grade is not necessary. All that is required is that every subject show a spurt in the tasks for a given level at some point; different people can demonstrate the spurt at different ages. To test for such a spurt, the researcher can use either a longitudinal or a cross-sectional design: The fundamental pattern of data predicted is that under...
optimal conditions most subjects will either fail all or most tasks at a given level or pass all or most of them. In a cross-sectional design, this pattern will produce a bimodal distribution of scores for each level. In a longitudinal design, it will produce not only the bimodal distribution but also a relatively abrupt change at some age for each subject from failing most tasks to passing most of them (Fischer, Pipp, & Bullock, 1984).

The spurt criterion applies to performance in a single domain, such as the understanding of arithmetic operations. When tested across domains, people's optimal performance will demonstrate a cluster of spurts in a given age region, as shown in Figure 7.1 for Level 8. According to skill theory, every person will produce the spurts, although they will occur only for optimal performance in familiar domains (Fischer & Pipp, 1984). It is possible that all normal people will show the cluster of spurts within the same age region, such as 13 to 16 years for Level 8, or there may be substantial variation across people. If there is substantial variation, however, what will vary is (1) the exact age interval when the cluster of spurts occurs and (2) the specific domains that show spurts. Across these variations, there will be a universal phenomenon, the cluster of spurts itself. That is, every individual will show such a cluster for each level at some limited age interval. For example, one person might spurt to Level 8 at 13–15 years, and another might do so at 18–20 years.

Note that the cluster of spurts is predicted only for optimal performance in familiar domains. Spurts will not occur consistently for ordinary, nonoptimal performance, or for performance in unfamiliar domains. Except for optimal performance, the norm for development is slow, gradual change, with discontinuities occurring only under limited circumstances.

**Spurt upon Emergence of the Next Level**

The data from the arithmetic study allow a partial test of the cluster hypothesis. Different tasks were used to assess each level, and the tasks for one level can in some cases be used to test not only for a spurt at that level but also for one at the succeeding level. When two such spurts occur, they should cluster within an age region.

For example, with the spurt in optimal performance upon the emergence of a given level, such as Level 7 in Figure 7.3, performance may not reach 100 percent. In that case, the opportunity still exists for substantial improvement in performance, and so a second spurt can be predicted upon emergence of the next level. When Level 8 emerges, performance on the Level 7 tasks will spurt again as the new capacity produces consolidation and differentiation of the Level 7 skills. The findings in Figure 7.3 support the second-spurt hypothesis. After the initial spurt in Level 7 performance, performance leveled off at 50–60 percent correct. Level 7 performance then showed a second spurt beginning at 13 years. Performance reached 100 percent by age 16, the age at which the spurt in Level 8 occurred (Fig. 7.4). According to these results, the age region for the two spurts indexing the emergence of Level 8 was 13–16 years.

For performance on Level 8 tasks, a similar second spurt can be predicted at approximately 18–20 years, when Level 9 emerges. The data in Figure 7.4 suggest
such a spurt, although performance in the optimal condition was already so high that the magnitude of the increase is necessarily small.

In general, then, the arithmetic study supports the skill-theory hypothesis that development shows spurts in optimal performance with the emergence of each new cognitive level while showing gradual, continuous change in performance under ordinary, nonoptimal conditions. Further tests of the hypothesis seem warranted by these initial encouraging results.

In addition to investigating the effects of different testing conditions on the form of developmental change, researchers also need to assess the relation of change across domains. The spurts found in the arithmetic study were simple first-order discontinuities. More complex discontinuities should also occur, such as second-order discontinuities involving an abrupt change in the relation between performance in different domains. There are straightforward empirical criteria for detecting these second-order discontinuities, based on measures of the relation between performance in different domains (Fischer, Pipp, & Bullock, 1984; McCall, Eichorn, & Hogarty, 1977).

The Brain-Growth Hypothesis

The emphasis on the environmental conditions for detecting developmental levels highlights the environmental side of skill development, but the organismic side needs to be taken seriously as well. Optimal level is a property of a specific combination of organism and environment—a person under specific environmental conditions. Several researchers have suggested that the emergence of developmental levels may be accompanied by major biological changes in the child, including changes in brain waves and neural networks (Emde et al., 1976; Epstein, 1980; Kagan, 1982; White, 1970). Indeed, a number of these changes involve developmental spurts in biological variables, spurts that seem generally to parallel the spurts in behavior documented in psychological research.

Despite the paucity of knowledge about how brain functioning relates to cognitive-developmental changes, we have put forth a simple hypothesis about a possible neural basis for the change in levels—the brain-growth hypothesis (Fischer, 1987). Each level is hypothesized to correlate with a spurt in the formation of a new type of neural network. That is, with each level, the brain grows a large number of new networks that facilitate performance at that level. The networks are then gradually pruned to form efficient neural systems.

Early Development

Synapses are a fundamental component of neural networks, since they are the primary junction between neurons. Consequently, a straightforward interpretation of the neural network is that a spurt in synaptic growth will be associated with the emergence of each cognitive-developmental level. The existing evidence is limited, but it provides enough data to allow us to begin to articulate what these spurts might look like.
In early infancy, there is evidence for a dramatic long-term growth surge in synaptic density throughout all major areas of the cortex. The surge lasts over many months, reaches a peak at approximately twice the density level of adult cortexes, and then gradually decreases over a very long period to the adult level. The decrease indicates that “excess” synapses are gradually being pruned away.

The most extensive data are from infant macaque monkeys (Goldman-Rakic, 1987; Rakic, Bourgeois, Eckenhoff, Zecovic, & Goldman-Rakic, 1986). For human beings the data are more sparse, but they indicate the same sort of surge: Synaptic density in the visual cortex seems to increase throughout the first year of life to approximately 200 percent of its eventual adult level (Huttenlocher, de Courten, Garey, & van der Loos, 1982). After the peak at one year of age, it gradually decreases over several years until it reaches the adult level during the grade school years. In the frontal area, which is associated with high-level cognitive functioning, the growth surge seems to last even longer: Synaptic density seems to sustain its peak to five or six years of age and then begins gradually to drop down to the adult level (Huttenlocher, 1979).

The general surge in synaptic growth does not mark the emergence of a cognitive level, because it occurs over a long period when a number of levels are emerging. It is analogous to the familiar general increasing curve for cognitive skills, like that in Figure 7.2. Where levels will be evident is in discontinuities in the general curve, points where the curve shows short-term spurts or drops (Fischer, Pipp, & Bullock, 1984).

Since synapses play such a crucial role in neural networks, discontinuities in the synaptic-growth curves can be hypothesized for each emerging cognitive level. During the period of the general surge in synaptic growth in infancy, several cognitive levels develop. For each of them, discontinuities in the growth curve are predicted at the approximate age of emergence of the new cognitive capacity. Unfortunately, existing data do not allow reliable detection of the predicted sudden changes in the growth function, although there are some suggestions of such discontinuities in the data for monkeys (Fischer, 1987). The apparently long-growth period for synapses in the human frontal area suggests that synaptic spurts could be correlated with the emergence of all cognitive levels before those involving abstractions.

Development of Abstractions

The synaptic growth curves make it unlikely that there are spurts in synaptic density in adolescence, when the levels of abstractions develop. However, other changes in networks could still produce discontinuous increases in the formation of networks during these ages. Factors that increase the speed of neural transmission are likely candidates, because speed is a crucial determinant of neural network functioning (Grossberg, 1980). For example, myelin, the insulation around neural axons, not only grows in infancy and childhood but also continues to grow into early adulthood (Yakovlev & Lecours, 1967). Spurts in myelin formation or in other factors contributing to effective neural-network functioning could produce the hypothesized spurts in network formation during adolescence and early adulthood.
Changes in Brain Electrical Activity

Although it is not yet possible to test the brain-growth hypothesis directly, it is possible to test for changes in brain activity associated with the ages of emergence of the developmental levels. Data are available for both the electroencephalogram (EEG) and the evoked potential, two measures of brain electrical activity. These data, collected by independent researchers, were analyzed to determine whether spurts appeared at appropriate ages for each level.

Brain activity does seem to spurt in the appropriate age region for every level for which we could find relevant data (nine levels—from single sensorimotor actions through abstract systems in Table 7.1). The most extensive data are available for the EEG. Global measures reflecting the entire spectrum of activity waves typically show a discontinuity (spurt or drop) for each new developmental level. Figure 7.5, illustrating one such measure based on data collected by the Swedish neuroscientists Matousek and Petersen (1973; John, 1977), shows statistically significant spurts for Levels 4, 5, 6, 7, and 8, starting at approximately ages 2, 4, 8, 12, and 15. There is also a possible spurt for Level 9 at about 19 years, but because of the great variability of the measure during that age period, the spurt is not statistically reliable.

Measures of relations between electrical activity in different parts of the cortex seem to be especially promising because they may relate directly to the functioning of neural networks. For example, links between activity in the frontal and occipital area of the cortex are likely candidates for detecting neural-network changes associated with the later developmental levels. A recent study with an American sample by Robert Thatcher and his colleagues found spurts and drops in several measures of such links. These discontinuities occurred at the approximate ages for Levels 5, 6, 7, and possibly 8 (Thatcher, Walker, & Guidice, 1987). The data did not allow tests of the other levels.

![Graph showing annual increase in energy in alpha waves as a function of age.](image)

*Figure 7.5* Increase in percentage of energy in alpha waves of the electroencephalogram as a function of age. The electroencephalogram was measured in the occipital-parietal area, and the percentage of energy was calculated by dividing the amount of energy in alpha waves by the total amount of energy in all waves.
Studies of evoked potentials also show discontinuities at the expected ages. When people were exposed to flashes of light, the brain electrical potential that resulted showed discontinuities at the ages for Levels 6 and 7 (Dustman & Beck, 1969). It was not possible to test for the other levels.

Of course, these data can only be taken as suggestive, since there have been no studies systematically examining both brain electrical activity and cognitive changes in the same people. Nevertheless, the evidence is strong enough to indicate that the brain-growth hypothesis is worth pursuing further. It at least provides a basis for beginning to investigate relations between cognitive levels and brain development. In our opinion, the major danger to avoid in developing the hypothesis further is thinking of the biological changes as prerequisites in any simple sense for the cognitive changes (Fischer & Silvern, 1985). Just as it is necessary to avoid neglecting organismic influences when testing environmental hypotheses, so is it necessary to avoid simplistic biological hypotheses that neglect environmental influences.

How Optimal Level Functions

According to the optimal-level hypothesis, then, development is both stagelike and gradual at the same time. When people are functioning at their upper limit, development spurs in a relatively short period to a new level of skill, and correlated brain changes may spurt roughly simultaneously. When people are not performing at their limit, change occurs gradually over a longer period. Most of the time, people do not perform at their optimal level; consequently, most development is gradual.

During periods in which a new optimal level is emerging, developmental changes in familiar domains can occur at a rapid rate. After the optimal level has emerged, skills in those same domains will show slower, less dramatic change in complexity and generalization. The periods of slow change in optimal performance do not indicate developmental stasis, however. The person never lacks additional skills to learn, because there are always new domains to master. The emergent capacity must be extended to many diverse domains, and it must be internalized to the point that the individual can use it even when there is little environmental support. This extension and internalization of the capacity both consolidates the person’s skills and prepares for the emergence of the next optimal level.

The way that a new optimal-level capacity is extended to diverse domains highlights a major difference between skill theory and competence–performance models such as those of Piaget (1957, 1971b) and Chomsky (1965). In the latter approaches, a general structure is present in the mind and can be straightforwardly applied to new domains. For instance, Piaget’s structure d’ensemble (structure of the whole) for concrete operations emerges at six or seven years and is said to be automatically applicable to any content. The reason that it does not generalize to all contents immediately is that objects and events differentially resist application of the structure. The competence is thus present, but sometimes the child cannot demonstrate it in performance (Bullock, 1981; Stone & Day, 1980).

Optimal level functions very differently. When people develop a new optimal
level, they have the capacity to construct skills at the new level, but they do not actually have any competences at the level until those skills are built. An individual must always work to construct particular skills in specific domains. There are no powerful competences that are somehow being prevented from eventuating in performance.

In summary, although much research remains to be done, a number of independent strands of evidence do support the optimal-level hypothesis, including the particular levels postulated in skill theory. The upper limit on the complexity of skills that a person can construct seems to develop through a series of qualitatively different levels, each of which is characterized by a cluster of spurts in optimal performance. Most of the systematic changes in behavior that constitute development, learning, and problem solving, however, are affected only modestly by this upper bound. Optimal level, after all, specifies only a limit on skills that can be mastered. To explain the many systematic changes in skills below the upper limit, another set of developmental processes must be invoked—processes of skill acquisition.

Transformation Rules for Analyzing Skill Acquisition

Skill theory gambles that thought and behavior can be fruitfully described structurally and that development, learning, and problem solving can be explained by transformations of these structures (Fischer, 1980a). The transformations can be characterized in terms of a limited set of rewrite rules, which specify how given skill structures can be transformed to produce new skill structures.

The transformation rules constitute one of the most important mechanisms by which skill theory predicts and explains sequences in development. New skills are mastered in a succession of many small steps, each of which is specified by a transformation rule. The sequence of skill acquisition within a domain can thus be described by reference to the initial skill structure and the series of transformation rules used. Development, learning, and problem solving all involve these same basic transformations.

Five different transformation rules have been specified, and we suspect more will be discovered. There are four rules for predicting steps within a developmental level: substitution, focusing, compounding, and differentiation. The fifth rule, intercoordination, deals with movement to a new level—how skills at one level are combined to produce a new skill at the next level. All the rules have been formally defined as algebraic rewrite rules for skill structures, and principles for ordering the results of the transformations have also been explicated (Fischer, 1980b).

A Developmental Sequence Involving the Transformations

To illustrate four of the transformation rules, we will analyze a developmental sequence for the two levels of representations that immediately precede abstractions. Three Level 5 representational-mapping skills for social roles are rewritten by the four transformations, and the results are ordered according to skill-theory principles to produce the sequence shown in Table 7.3. This sequence has
<table>
<thead>
<tr>
<th>Step</th>
<th>Type of Transformation</th>
<th>Cognitive Level</th>
<th>Role-Playing Skill</th>
<th>Example of Behavior</th>
<th>Formula for Transformation</th>
<th>Skill Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initial skills</td>
<td>5: Representa-</td>
<td>Social role of</td>
<td>The child pretends</td>
<td>[R₀ − S₀]</td>
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<td></td>
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<td>tional mappings</td>
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<td>Social role of</td>
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<td>nurse</td>
<td>that a nurse doll</td>
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<td>Social role of</td>
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<td>[Rₚ − Sₗ]</td>
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<td>father</td>
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<td>child doll, who</td>
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<td>responds</td>
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<td>appropriately.</td>
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<td>2</td>
<td>Substitution</td>
<td></td>
<td>Doctor role with</td>
<td>The child pretends</td>
<td>Sub[R₀ − S₀] = [R₀ − Tₚ]</td>
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<td></td>
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<td>woman patient</td>
<td>that a doctor doll</td>
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<td>doll, who responds</td>
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<td>appropriately.</td>
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<td>3</td>
<td>Focusing</td>
<td></td>
<td>Shifting between</td>
<td>The child pretends</td>
<td>Foc([R₀ − S₀)(Tₙ − Sₚ)] =</td>
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<td></td>
<td></td>
<td>doctor and nurse</td>
<td>that a doctor doll</td>
<td>[R₀ − S₀] &gt; (Tₙ − Sₚ)]</td>
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<td>roles</td>
<td>examines a patient</td>
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<td>doll, who responds</td>
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</table>
4 Compounding

Social role of doctor with complementary roles of nurse and patient

appropriately; and then she switches to having the nurse doll examine a patient doll, who responds appropriately.

The child pretends that a doctor doll examines a patient doll and is aided by a nurse doll. Both patient and nurse respond appropriately.

\[ [R_D - S_D] + [T_N - S_T] = [R_D - T_N - S_T] \]

5 Intercoordination

6: Representational systems

Intersection of doctor and father roles and their complements

The child pretends that a doctor doll examines a patient doll and simultaneously acts as a father to the patient, who is his son or daughter. The patient doll acts appropriately as both patient and offspring.

\[ [R_D - S_D] \cdot [R_F - S_C] = [R_D \cdot F - S_F] \]

Note. In the formulas, the italicized capital letters stand for the child's representation of a particular doll as an independent agent: \( R \) for a man doll, \( S \) for a child doll, and \( T \) for a woman doll. The subscripts designate the role or roles that the child represents for each doll, as follows: \( C = \) child; \( D = \) doctor; \( F = \) father; \( N = \) nurse; \( P = \) patient. See Fischer (1980) for elaboration of the notation. The sequence has been tested and confirmed in several studies (Watson 1981; Watson & Fischer 1980).
been tested and confirmed in several studies (Watson, 1981; Watson & Fischer, 1980).

The initial Level 5 mappings deal with the social roles of doctor–patient, nurse–patient, and father–child as shown for step 1 in Table 7.3. A social role always involves a relation between a primary role, such as doctor, and a complementary role, such as patient. For the doctor–patient role, for example, a girl pretends that a doctor doll examines a patient doll, who interacts appropriately. For the nurse–patient role she pretends that a nurse doll examines a patient doll, who interacts appropriately. For the father–child role she makes a man doll treat a child doll as his daughter, who interacts appropriately.

The simplest of the within-level transformation rules is substitution, a type of generalization in which a skill is mastered through one task and then transferred to another, similar task. An individual may show such transfer when all but one of the components in the second skill structure are the same as those in the first structure, and when the single different component can be generalized to the second task. The Level 5 skill for doctor/patient shows an instance of such transfer when the type of patient is changed, as shown in step 2 of Table 7.3. The child first learns to make a doctor interact with a girl patient and then transfers that skill to the interactions of a doctor with a woman patient.

In the transformation called focusing, a person uses two related skills in succession, shifting from one to the other within a single task or situation (Gottlieb, Taylor, & Ruderman, 1977; Hand, 1982; Harter, 1983b; Watson, 1981). The example in step 3 of Table 7.3 uses the two skills of doctor–patient and nurse–patient. The child first has the doctor doll examine the patient doll, who interacts appropriately. Then the child simply shifts her focus from the doctor to the nurse: The nurse doll examines the patient doll, who interacts appropriately. There is no integration between the two types of social roles: They are simply strung together.

Like all transformations, focusing arises from the collaboration of person and environment. The person possesses two or more related skills for a given situation but can apply only one of the skills at a time. Nevertheless, the situation tends to elicit both skills. The result is that the person effectively links the two skills together by focusing on first one skill and then the other.

The two Level 5 skills can be integrated by another type of within-level transformation, compounding. Two skills at a given level are combined to form a more complex skill at the same level that unifies the components. With the play example, the child may combine the two role skills, doctor–patient and nurse–patient, to form a new compounded structure, doctor–nurse–patient, as shown for step 4 in Table 7.3. With this new structure the child makes the doctor doll and the nurse doll jointly examine the patient doll, who responds appropriately to both of them. Note how this skill is different from the one based on focusing. In compounding, the three actors are made to carry out an integrated interaction, but in focusing, the two initial skills remain separate and are only linked temporally.

The final transformation, intercoordination, is the one rule that describes how combination moves behavior to a higher level. In conjunction with optimal level, it specifies how a person's skills at one level are transformed to the next level. At the beginning of the process, the child has two well-formed skills at a given level. The two skills function separately from each other until some object or event in
the world induces the child to relate the two skills. If at this point the child is capable of the next developmental level, she will unravel the relationship between the two skills, gradually intercoordinating them.

For example, two Level 5 social roles can be intercoordinated into a Level 6 understanding of the intersection between social roles. In one Level 5 skill, a child pretends that a doctor doll examines a patient doll, who interacts appropriately. In another Level 5 skill, the child pretends that a father doll interacts with a daughter doll, who responds appropriately. By intercoordinating these two social roles, the child constructs a Level 6 role intersection (step 5) in which a doctor who is also a father interacts appropriately with a patient who is also a daughter. As a result of the intercoordination, the child can control the relations between the several social roles and so can understand that two people interacting can fulfill two complementary roles at the same time. Once this simple Level 6 role intersection has been mastered, more complex intersections can be built by means of the other transformations, such as the addition by compounding of a nurse who is also the patient’s mother.

These four transformation rules specify different ways of rewriting skills. Within a domain the rules can be used to analyze and predict sequences of skill acquisition, including both steps that must be ordered in a sequence and steps that cannot be consistently ordered with respect to one another. It is no trivial matter to predict developmental sequences (Bertenthal, 1981; Flavell, 1972; Fischer & Bullock, 1981; Siegler, 1981), and the transformation rules seem to provide a useful framework for doing so.

Many Paths from a Few Transformations

Cognitive developmentalists, especially Piagetians, commonly assume that there is one and only one path for development in any domain (e.g., Piaget, 1970a,b). That is, all children are believed to pass through the same steps or stages of development. Skill theory postulates, to the contrary, that when specific skills are considered, different people follow different developmental paths (Fischer & Corrigan, 1981; Fischer & Farrar, 1987; see also Bullock, 1983; Flavell, 1982; Kuhn & Phelps, 1982). The steps that people move through in mastering a domain may vary enormously in detail from one person to the next.

Variations in the environment alone will produce such differences, because every person’s specific experiences are different from every other person’s. For example, the types of dolls available to a preschool child will influence the types of social roles the child will construct when playing with those dolls. The child who plays with a baby doll and a mommy doll is likely at an early age to construct a skill for acting out a mother–child relationship, whereas the child who plays with a doctor doll and a nurse doll will construct different role skills. Likewise, various nine-year-olds will master the skills of addition through different paths, depending on their experiences with numbers and arithmetic tasks (see Lawler, 1981).

Similarly, variations in the person alone will produce differences in developmental paths. People seem to differ widely in the facility with which they can master certain kinds of materials, as illustrated by wide variations in verbal, spatial, and mathematical abilities (Horn, 1976; Sternberg, 1980). When variations in other
person factors such as motivation and activity level are considered, it is evident that individuals will demonstrate important differences in developmental paths.

Since skills always involve influences from both person and environment, the degree of variation in developmental sequence will inevitably be large. It will be difficult to find two children who spontaneously develop through exactly the same steps in any domain.

There are, of course, important equivalences of skills across individuals, especially when those skills are analyzed globally. Various nine-year-olds, for example, have skills for addition that typically produce the same answers to simple addition problems. Likewise, in pretend play, preschoolers living in similar environments show many equivalences in the general types of developmental paths they demonstrate, as illustrated by the sequence outlined in Table 7.3.

The general developmental levels postulated by skill theory describe one highly general type of equivalence. When sequences are described in more detail, however, every child will show a different developmental path. In other words, people show wide variations in developmental paths because the specific skills they build are different. On the other hand, their skills all pass through the same general developmental levels.

Although developmental paths may vary widely, the transformation rules underlying them do not vary, according to skill theory. The many paths can all be characterized by the same small set of transformation rules. Both the skills that individuals start with and the way in which they use the transformation rules do vary, and therefore developmental paths vary. Yet all skill acquisitions at all ages involve the same limited group of transformation rules. This postulate of skill theory is similar to the position taken by many information-processing theorists that the same fundamental acquisition processes occur in development, learning, and problem solving at all ages (see Goodman, 1980; Klahr, 1984; Klahr & Wallace, 1976; McGuinness, Pribram, & Pinnazar chapter; MacWhinney, 1978; Sternberg, 1980, 1984).

How Optimal Level Limits Transformations

The transformation rules specify how skills can be changed and thereby predict which sequences of skill acquisition can occur, but there is an important limit on application of rules—the person’s optimal level. The type of transformation that can be applied to existing skills is restricted by the highest level of which the individual is capable.

The most basic form of this restriction involves the transformation rule for moving to a higher level, intercoordination. With two skills that are already at the person’s optimal level, intercoordination cannot occur because the person is not capable of building a skill beyond her upper limit. In the social role example, a four-and-one-half-year-old who has several Level 5 skills for social roles can make those skills more complex via the other transformations; but she cannot intercoordinate two of the skills to form a Level 6 role intersection.

Another form of limitation is hypothesized to occur when a new optimal level is first emerging: The person cannot yet apply the within-level transformations to
the simple skills just built at her new level. For focusing, the period of this limitation may be brief; but for compounding it is probably longer. Consider a six-year-old girl who has just begun to be capable of Level 6 and has constructed a simple role intersection such as the relation of doctor–father to patient–daughter. Because of the hypothesized limitation, she cannot extend that intersection by compounding, by adding, say, nurse–mother. For all within-level transformations, the duration of this limit is brief relative to the age interval between levels. By the time the girl becomes six and a half or seven years old, she will be able to compound her skill to include three role intersections.

For each optimal level, then, there is development of the limitations on transformation. As the level initially emerges, the person cannot apply the within-level transformation. This limitation gradually recedes, first for the simpler rules and finally for compounding. At that point the within-level limit no longer exists, and the only restriction is on moving to a higher level. This upper bound remains until the next optimal level begins to emerge.

Adult Functioning Below Optimal Level

Developmental research suggests that after the first few years of life, children typically function below optimal level (Fischer & Elmendorf, 1986). The size of this developmental range between functional and optimal levels seems to grow especially large during adolescence and adulthood (Fischer, Hand, & Russell, 1984). In the arithmetic study, for example, the ordinary or spontaneous testing conditions generally produced performance far below optimum.

This conclusion is supported by a vast array of research, including studies of Inhelder and Piaget’s (1955/1958) tasks for assessing formal operations. Many adolescents and adults can readily pass a few of the easiest of Piaget’s formal-operation tasks, but they fail the rest of them (Martarano, 1977; Neimark, 1975). Most of the tasks they fail seem to require the higher levels of abstractions, beyond Level 7 single abstractions (Fischer & Lamborn, 1989). Adults, it seems, routinely function at the lowest levels of abstraction. Only under special circumstances do they demonstrate abstractions at the highest levels.

Conclusion

Both data and theory indicate that cognitive development does not end with early adolescence but continues into adulthood. New capacities develop that allow the individual to relate abstractions in increasingly complex ways. These capacities are hypothesized to develop through four successive levels—single abstractions, abstract mappings, abstract systems, and principles integrating abstract systems.

Two different types of processes are involved in developmental transitions and in many other systematic changes in the organization of behavior. (1) Optimal level is the upper limit on the complexity of skills that the person can construct, and it develops through the series of hierarchically organized levels for abstractions. (2)
Skill acquisition processes are the rules by which a skill can be transformed into something more complex or advanced. Together these two types of processes account for both large and small changes in cognitive development.

Stagelike change to a new optimal level is most evident when a person is tested under environmental conditions that produce optimal performance. With the types of testing conditions typically used in psychological research, optimal performance is not assessed; consequently, developmental change appears to be slow and gradual. When environmental conditions such as practice, instruction, and support are thus taken into account, it becomes evident that stagelike and gradual changes can both occur in the same person.

Organismic factors contribute to the optimal levels too. According to the brain-growth hypothesis, each new optimal level is associated with spurts in the growth of neural networks in the cortex of the brain. Research evidence supports an association between cognitive levels and spurts in the growth of brain electrical activity.

The optimal-level effects for abstract capacities have powerful implications for education, as well as for any other enterprise involving adolescents or young adults. Apparently, there are certain kinds of concepts and relations between concepts that will pose great difficulty for students who have not yet reached the highest developmental levels. Of course, intelligent individuals will be able to learn parts of these concepts and thus mimic high-level functioning, but only at the highest levels will students be able to master such concepts in a straightforward manner.

When people develop a new optimal level, what changes is the most complex skill they can construct and control. Their general cognitive functioning does not change abruptly, because to function at the new level they must actually build specific skills at that level. The building of such skills takes time and effort and proceeds according to skill-transformation processes. Even when students have the capacity to function at a certain level, they cannot be expected to do so easily or automatically. They need both time for constructing the needed skills and environmental support to stimulate and guide the construction.

The environment plays an important role in supporting not only the construction of skills but also their internalization and use. The construction of an optimal-level skill in a specific domain is insufficient to lead to functioning at that level in that domain. There is a gap, called the developmental range, between people’s optimal level and the level at which they ordinarily function. This gap seems to grow larger at the highest levels. Although environmental support is required for optimal functioning at any developmental level, it seems to be especially important at the highest levels of abstraction. One of the most important roles of educational institutions may well be to provide the support that is necessary for functioning at high levels of abstraction.

Indeed, people may be virtually incapable of routinely using high-level skills without supportive environments like those provided by educational institutions such as high schools and colleges. At lower cognitive levels, the ordinary environment seems to provide infants and children with the support they need for functioning near optimum. At the highest levels, the ordinary environment will no longer suffice. Socially constructed environments designed to facilitate abstract thinking seem to be essential (Fischer & Bullock, 1984; Rest, 1983).
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