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Upstaging the Stage Model

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Marie Jahoda once remarked that after 40 years of research on Freud's model of psychological development with few concrete results, "Freud will still not go away." This is because Freud asked the fundamental questions that psychology has so far failed to answer. There is a direct parallel between Freud's puzzle over psychosocial behavior and Piaget's concern with the development of human cognitive capacities, for despite all the criticism that has been aired concerning Piaget's methods and his stage model, we have no more sophisticated model to put in its place. No one has as yet answered the fundamental question that Piaget raised: What is the nature of the cognitive process that leads to competence in complex problem solving? Not only did both men pose the key questions, but they worked in a very similar style, building a model from painstaking and meticulous observations. Although both inductive thinking and their subjective methodology are currently unfashionable, their contribution looms large.

In this chapter we attempt to bring Piaget's insights in line with new data from psychology and the brain sciences. Our fundamental premise is that Piagetian "stages" are not unidimensional, applying globally to every cognitive ability. However, *each* unique cognitive domain will require the *same* progression from sensorimotor to symbolic or logical transformations. In addition, age must be factored separately from these cognitive progressions. Children and adults undertaking a completely novel task must begin with its sensorimotor properties, though to some extent the facility with which a sensorimotor process can be attained will be different, depending upon age and experience. Therefore, what exists beyond logical operations is both a lateral extension of existing cognitive structures through the refinement of skills and increasing knowledge *and* the possibility of acquiring completely new cognitive abilities, by running through the stages from the beginning.

One of the more intriguing aspects of Piaget's work is that both his genetic epistemology and his stage model were formulated in terms of biological systems. Despite the evidence that has accrued over the past 40 years, he only began to attempt to specify the biological processes for his "logical" mechanisms toward the end of his life. This beginning has proved extremely valuable, because it highlights the similarities and the distinction between his epistemology and his stage model that are so often obscured.

First and foremost, although Piaget has been credited with developing a philosophical system of epistemology, his theory of knowledge is a biological theory, not a philosophical one. Piaget never really inquires into the central philosophical question of what a knower knows, the *contents* of knowledge. He asks instead, "*How* do organisms know?"—a question more related to the mechanics of knowing. His genetic epistemology appears philosophical because of his extraordinary capacity for logical analysis, and it is powerful because it is logically consistent, rather than because it is "scientific." It suggests the way things must "go" if they are to make any sense at all, and it leads the way to a search for mechanism.

By contrast, Piaget's stage model is derived from observational data. It is not a biological model, but an inductive theory based on a set of phenomena. What is puzzling about Piaget's stage theory is that it seems to have so little in common with his epistemology. There is no way one could predict the nature of his genetic epistemology from his stage model, or predict stages from his epistemology. In fact, one of Piaget's frequent assertions is that the acquisition of knowledge is continuous: "knowledge is a continuous construction" (1970a), which appears on its face to contradict the notion of age-related abrupt changes in "state."

To address the question of whether or not a stage model can continue to apply at levels beyond logical operations, we will attempt to reassess Piaget in three ways. First, we will discuss his genetic epistemology in the light of our interpretation of recent data. Second, we will explore the evidence for an age-related theory of stage. Finally, we will attempt to show how "stages" become redeployed as context-dependent "states" invoked in every new learning experience irrespective of the age of the subject.

Genetic Epistemology

Equilibration

The central concept in Piaget's epistemology is that of equilibration. In Piaget's description of this concept he refers to two fundamental issues. The first is the question of biological versus environmental determinism, the quintessence of the nature–nurture debate. In dealing with this issue he refers to the process of environment–structure *interaction*. Here the organism serves as the field for multiple interactions or *transformations*, while maintaining stability in overall form through a set of invariant relationships, through what he terms *conservation*. Whereas "transformations" represent his solution to a biological–environmental interaction, "conservation" is much more akin to Cannon's notion of homeostasis. The purpose of equilibration is to achieve a stable state in an open environment–organism interaction.

Equilibration is a "process," a cycle of approximations to a state that is never totally satisfied. In common language, equilibration has three characteristics: (1) It entails active compensations to environmental change; (2) it operates to maintain internal coherence; and (3) it represents an ongoing search beyond the current status quo (an aspect that makes equilibration a misnomer). Piaget has stated that the process of equilibration can take place by means of these three "mechanisms," which he names (1) *autoregulation,* which ensures that the organism remains stable while adapting to the environment; (2) a mechanism for *action,* which is both a condition for and a consequence of behavior and which operates on the environment to adapt it to the organism; and (3) *decentration,* which operates to extend behavior away from stability.

Cognition enters the picture as the result of the transformations and constructions that occur in the cycles of "assimilation" (determined by autoregulation) and "accommodation" (determined by action) by which the organism interacts with the environment (1936, 1952c). The relationship between assimilation and accommodation and neural systems has been discussed in detail (Pribram, 1969; Pribram & Melges, 1969).

Autoregulation

In his writing from the mid-1960s to the early 1970s, Piaget began to specify in more detail exactly how he conceived the mechanism of autoregulation. He saw this as a set of dynamic, endogenously organized processes rather than as static endogenous "structures" as he believed Chomsky and Lorenz conceived them. The notion of autoregulation is much more in keeping with Waddington's (1975) idea of homeorhesis, which is a continuously changing self-organizing process. And although Piaget uses the term *equilibration,* his meaning is closer to that of Prigogine and Stengers (1984), who have identified processes characterized by temporary stabilities "far from equilibrium," which depend on fluxes constrained by initial conditions and the context in which they occur.

Autoregulatory mechanisms are involved at all levels of the system and include cognitive operations. These mechanisms set the overall pattern of constraints on the whole that operate downward in the system on its parts. This is true both at the level of the cell, where as Paul Weiss (1969) had noted, the totality of the cell is more stable than the activity of its elements, and in higher levels of organization, where there is a continuing balance between the open program of parts of a system and the more closed and stable properties of the whole. Piaget's view of the autoregulatory process is more related to cybernetics, with interlocking feedback systems, than to a balance of "forces" as conceived in classical physics. Ashby (1960) and Pribram (1971, Chaps. 5 and 14) have proposed formal models of such self-organizing autoregulatory processes based on the ubiquitous parallel processing connectivities of the nervous system. These have the property of integrating feedback closed-loop processes, which gives rise to open-loop feed-forward mechanisms that make voluntary action possible. An example of a feed-forward process is the temperature regulator on a thermostat. A thermostat ordinarily acts as a negative feedback mechanism, entirely regulated by the changes in the room temperature effecting the expansion and contraction of two metal tips. However, by adding an external regulator that controls the position of the metal tips, the circuit can be manipulated independently and in parallel with the effects produced by the temperature in the room. The system, in other words, comes under "feed-forward" voluntary control.

The internal neural organization of organisms imposes constraints on this assimilative process. Piaget quotes Waddington (see also Pribram, 1971) to the effect that, just as tissue must be "competent" to respond to an inductor in embryonic development, neural systems must be "competent" to process signals from the environment. It will not be lost on some readers that in the example of tissue competence in induction, Piaget has one possible mechanism for his stage model in the concept of "critical periods." This issue will be taken up below, but Piaget's failure to seize on this idea is a puzzling example of how his epistemology and stage model have not been brought into harmony.[1]

Piaget in 1972 also refers to Pribram's work on the central regulation of input to the senses in the context of autoregulation, suggesting that he saw autoregulation as governed by two sets of constraints. The first represents the competencies of the sensorimotor systems to respond to events in the environment (an information processing system), and the second, the competencies of control systems to filter out unwanted events (an attentional mechanism). Piaget saw these as two parts of a single process, whereas we have come to view them as independent processes originating in different neural systems (Pribram & McGuinness, 1975).

Action

So far we have discussed autoregulation only in terms of its impact on sensory and attentional processing, but one of the key aspects of Piaget's epistemology is the great importance he places on action as a critical variable in the development of cognitive systems. In 1967 he states that the most manifest characteristic of life is that it is the "creator of forms"; it is "invention." Action accommodates the environment in the sense that the environment can provide constraints or "totalities," within which the organism behaves. Action is the essence of creation and invention because it is an operator by which a self-organizing system changes its environment. At the same time, action is integral in the formation of competencies, in that competence is demonstrated by its response-ability, the ability of a system to "respond" (i.e., to be challenged and changed). Competencies regulate both the range of possibilities and the actual configuration of a response.

At the most primitive level actions are generated by neurobehavioral rhythmicities and emerge in reflexes, which are the earliest observable actions. A major turning point in the development of acts is the onset of coordinations. Both ontogenetically and phylogenetically, the connection between stimulus and response weakens with time and with evolution. In the most primitive systems the response is temporally bound to the stimulus. The S–R connection is truly reflexive. In higher organisms, control systems make it possible to impose a *delay* between the input and the reaction. The delay allows the organism to block reflex action either by stopping the behavior entirely or by the substitution of a new response. In other words, control systems allow for *reflection* instead of reflexion. (The similarity to Freud's concept of ego functions is striking; see Pribram & Gill, 1976, Chap. 2.) Intentional acts, in particular, depend upon the coordination of means and ends. Means are determined by intentions, but intentions must be in accord with possible action. Piaget discusses two mechanisms that are necessary for coordinated action. The first is an energizing element; the second is the existence of structure in both neural and physical systems that allow the action to occur. How structures become energized is developed in the concept of decentration.

Decentration

Decentration involves the coordination of autoregulation with action. Decentration is invoked to account for the fact that the boundaries of action continue to increase. That is, although the organism retains an essential stability or "integrity," action can go beyond this stability and need not function solely to bring the organism back to equilibrium. The capacity of action systems to go beyond stability means that new problem-solving capabilities can emerge. Had Prigogine's insights into the creation of stabilities far from equilibrium been available to Piaget, the concept of decentration would undoubtedly have had a greater mathematical and biological foundation. Nevertheless, Piaget was able to see the importance of the coordination of autoregulation and action as the critical factors initiating the process of intentionality, or the awareness of self. In the same sense, action (including speech and thought) forms the basis for new stages of development.

Neural Mechanisms of Control

Neither Piaget nor neuropsychologists working on brain models have, until recently, had access to Prigogine's discoveries. As noted earlier, Piaget used the concept of "equilibration" incorrectly. Similarly, neuroscientists studying cognitive brain function have generally used the concept of "control," rather than framing their theories in terms of extensions away from equilibrium to new stabilities. Prigogine's solutions could provide a far more powerful explanation of how hierarchical cognitive processes come to be established. Not only this, but viewing novel organizations of subsystems as new "stabilities" could help to explain how certain of these organizations take on a life of their own and appear as "abrupt changes in state."

It is not appropriate here to present a detailed account of the neural structures involved in autoregulation, action, and decentration. However, it has been possible from research using animal models to distinguish three major systems that operate as controls on attention and learning (Pribram & McGuinness, 1975). These are systems anchored in corebrain systems and operate outward onto cortical systems. One system, centered on the amygdala, responds to changes or shifts in recurrent regularities of input, often thought of as "novelty." This is called an "orienting-habituation" system or an "arousal" system and has many of the properties of Piaget's autoregulation mechanism. A second system, which has a brain stem reflex component, comes to be centered on the basal ganglia of the forebrain. This system regulates action, in Piaget's sense of the word, by establishing a set or bias to respond and is called a "readiness" or "activation" system. These two systems act reciprocally on the functions of the primary sensorimotor projection systems (Spinelli & Pribram, 1966, 1967; Lassonde, Ptito, & Pribram, 1981), and in young infants, when most stimuli are "novel," they work more or less in tandem.

Over time the primary sensorimotor systems come to regulate habitual behavior without the intervention of these two control mechanisms. Instead, a third system, the hippocampus, comes to operate as a high-level override on the reciprocal relationship between the orienting and the activation systems. This third system, called an "effort" system, increases flexibility by biasing behavior toward risk (Spevak & Pribram, 1973). This system shares the properties Piaget attributes to decentration.

Cognitive Development

It can be seen from this brief overview that the mechanisms Piaget sought do exist and that they fulfill his requirements of how the processes must operate. However, for Piaget, as for most cognitive neuropsychologists, the problem of how these separate systems effect the development of complex cognitive organizations has not been solved. This seems to be the central problem in the schism between the neurosciences and cognitive psychology per se, as it is between Piaget's *own* difficulties in reconciling his genetic epistemology with his stage model.

Before we move on to a discussion of this issue, it is of interest to consider the role that development played in Piaget's epistemological theory. He was very specific in his view that the affective domain was anchored in an energy concept, or in his terminology: "energetics." About this domain Piaget had little to say (in contrast to Freud and his followers). It was a shortcoming in his model that he acknowledged. Cognitive development, on the other hand, received much more careful attention and was conceived of as largely due to structures that developed during an interaction with the environment. As noted, Piaget's definition of structure differed from that of Chomsky and Lorenz. For Piaget, structure or schema simply embodied a *system of transformations.* These transformations constituted "wholes" in which various elements are organized according to laws. However, the laws are never specified. During cognitive development, three categories of schemata play a predominant role.

The first he called *inversions,* which are structures arising from rhythmic or repetitious movement, based largely upon autoregulatory processes. These movements subsequently lead to "habit schemata" involving coordinated actions. Ultimately, the child is able to gain conscious control over these actions in what Piaget calls secondary or tertiary circular reactions. These are "procedures which make interesting things last." In other words, Piaget is describing the point at which the child achieves voluntary control over reflexive movement.

Second are *inventions,* or "action schemata," wherein an action arising from reflex organization moves through voluntary control of repetitive movement to the initiation of a completely novel act. Experimentation, defined as employing a variety of means to the same end, is one way that secondary and tertiary circular reactions are accomplished. For Piaget the concept of an "act" always included the totality of the action schema, that is, the stimulus to be operated upon, the behavior, and the outcome. This need not always involve physical movements. As Piaget noted (1936, 1952c) "operations" are "acts" that are carried out symbolically. They are "mental inventions." In 1972 he made the distinction between an operation and an object schema: "An operation is not the representation of a transformation, it is in itself an object transformation, but one that can be done symbolically, which is by no means the same thing. Thus an operation remains an action and is reduced neither to a figure nor to a symbol."

Finally there is *reality construction,* which arises from decentration. This leads to the separation of self from objects in the world and ultimately to abstract schemes such as object permanence, schemes of space–time, and schemes of causality. Piaget makes it very clear that abstract schema develop from the capacity to *distance* oneself from events, rather than by being incorporated into them. It might be noted that this idea has interesting philosophical implications, especially as it has become popular to view modern man as overly "distanced" or "alienated" from his environment. Piaget would consider this "distance" or "objectivity" to be a sign of a higher cognitive level.

The Stage Model

From the preceding discussion it can be seen that current evidence is compatible with Piaget's biological epistemology, and we have no quarrel with his approach. A problem does arise, however, when one uses his genetic epistemology to predict how age-dependent stages might be organized or indeed whether they even exist. In addition, apart from the fact that his epistemology and his stage model of development have an uneasy fit, there are further problems with Piaget's stages. First, Piaget employs the notions of cognitive development, intellectual development, and development of logico-mathematical operations interchangeably throughout his writings. In general his stage model is based upon his observations of logical operations, and this is too limited to have broad implications. As he himself points out:

> The states of intellectual development form a privileged case and we cannot generalize them to other fields. If, for example, we take the development of a child's perception or the development of language, we observe a completely different and much greater continuity, than in the field of logico-mathematical operations [1972, p. 49].

This of course raises the immediate problem of whether or not logico-mathematical thinking can be separated from other forms of thought and if it can, how one would draw the appropriate boundaries. But the major difficulty here is that in using the terms *cognitive* or *intellectual* rather than *logico-mathematical,* Piaget has misled many scholars into believing that his stages were representative of all cognitive development.

A second problem arises from the results of research that seriously challenges the sequence of the landmarks that Piaget adopts for his stages and substages. Not only this, but research findings have also challenged the characteristics of the schemes that Piaget claims to have identified (see Flavell, 1985). Recall that the sensorimotor period consists of six stages that follow one another in a specific order. Object permanence is expected to arise at stage 4 and imitation at stage 6. Studies by Bower (1966, 1982) and by Charlesworth (1966), however, show that object permanence is established as early as stage 3. Meltzoff and Moore (1977) have evidence that imitation, presumed to require "symbolic representation," can be demonstrated shortly after birth at 12–21 days.

Furthermore, in a summary of studies on psychotic children performing Piagetian tasks, Cowan (1978) points out that a re-examination of the "notion of necessary sequence" is essential to explain how "older psychotic children and adults achieve beginning conservations (concrete operations) without having established schemes of object permanence (sensory-motor period)" (p. 337).

Some of this confusion is due to the fact that object permanence has at least two meanings. One refers to "object constancy," or identification, and the other to "permanence" in memory during distraction. Thus, Bower and Wishart (1972) found that infants who failed the standard version of the object permanence test did reach for the vanished object when the room lights were off. This suggests that one of the problems children face in learning about the world is their high distractibility (i.e., failure to habituate an orienting reaction) and that failure in Piaget's task occurs for entirely different reasons than the ones he specified (see also Anderson et al., 1976). Also, Uzgiris and Hunt (1975) report a different and larger set of landmarks in the sensorimotor stage when they were constructing scales for infant assessment. It does not appear possible at this point to determine whether landmarks or stages of development (other than perhaps reaching, walking, and talking) are *real*, or merely a product of the investigator's own categorizing system and imagination. In all the various ways of demonstrating object permanence (pulling away the cloth, showing surprise, or reaching in the dark) are we measuring distractibility, motor skills, emotionality, or visual short-term memory? That is, does object permanence arise not because of achieving some higher-order abstraction, but because of the development of some lower-level capacity?

Finally, even when a particular skill is investigated, regardless of the sequence in which it appears, it has been observed many times that the demonstration of the scheme may not be simultaneous with its construction. This is an old problem in developmental psychology and is especially familiar to psycholinguists. It has been suggested by one of us (Pirnazar) that as differentiation between qualities of objects (object constancy) begins at birth, this differentiation process may ultimately underpin object permanence. For example, an infant comes to discriminate the sensory and motor distinctions he experiences when sucking at his mother's nipple and on his thumb. After several repetitions of finding the thumb and sucking it, it soon becomes a fixed habit. The images of the thumb in terms of sensations of movement, taste, comfort, and so on, remain when the sensations are absent (permanence), and the real experience can be reinstated. The fact that he can voluntarily locate his thumb and bring it to his mouth indicates that he has a sense of the permanence of an object. It does not guarantee, however, that he will be able to pass any test designed to measure this aptitude.

This example suggests that object constancy and resistance to distractibility are not related to one another in a linear progression, but develop in parallel. This suggestion is supported by neurophysiological data that clearly dissociate constancy, the extraction of invariances in the formation of object percepts, from permanence, the maintenance in awareness of these percepts. Distractibility during the performance of an object permanence task (temporarily hiding a piece of food) is increased by lesions of the far frontal cortex (Anderson et al., 1976), whereas constancy (e.g., of size) is impaired by posterior lesions to the peristriate cortex (Ungerleider et al., 1977). The developmental "sequence" of performance based upon these competencies occurs as follows: The function of neural systems of the posterior cortical convexity enters in the formation of percepts of three-dimensional objects, irrespective of the angle of view, by means of automatic cross-correlations of a large number of visual images. In other words, this part of the brain extracts invariances (Pribram, 1990). Once the brain has coded these invariances (thumbs do not turn into nipples), object permanence is a necessary consequence. But object permanence is also affected by distraction, and the ability to resist distraction develops more slowly, because the frontal lobes are late to mature in comparison with the posterior visual systems (see review article by Pribram, 1986b). This maturation process is more in accord with a stage model. Object categorization, on the other hand, is dependent upon the *amount* of exposure to stimulus patterns and their reinforcement history.

Cognitive Operators

Because of the problems with Piaget's Stage Model, we wish to develop a somewhat different approach to "stages," one that is more akin to Piaget's genetic epistemology. A central difficulty with the term *stage*, as used in Piaget's theories of behavioral development, is that it confounds two distinct aspects of development. First, developmental changes that occur as a function of age cannot simply be dismissed. The slow maturation of the frontal lobes is matched by the finding that certain problems are solved with different strategies at different ages. At the same time this effect is dependent upon the sequential nature of development in which each stage of a sequence is contingent upon a prior stage of processing.

In addressing cognitive development, we would like to suggest that all cognitive processes, or some subsets, such as problem-solving routines, undergo "stages" and that these occur independently of maturation. An example might be the development of software for a computer system. "Machine language" could be thought of as analogous to a sensorimotor stage; the creation of "assemblers," as involving operational processes; and the creation of high-level languages, as akin to transformational structures.

The dissociation of cognitive stages from age-related developmental stages has several consequences. First, it allows for the fact that as children become skilled processors, they can run through stages more rapidly and in certain contexts can even skip a stage. For example, an adult "dyslexic" remediated for sensorimotor deficiencies could advance immediately to an adult reading vocabulary. A second and related fact is that the utilization of an appropriate stage depends as much on context as on age. Finally, only the *elements* of classes of cognitive skills would be expected to show plateaus. This would result in the failure to find support for fixed stages when the elements essential to successful performance on any task had not been correctly identified by the investigator.

In short, we are suggesting that *in addition* to age-related developmental stages apply in some circumstances, such as tangible real-world situations, but not in others; otherwise "Piagetian Stages" would apply only to Piagetian tasks, and a general theory of invariant stages would collapse.

More pertinent is the example of the failure of many college women to find the correct solution to Piaget's water level task, in which subjects are expected to draw a line representing water in a tilted pitcher. The solution is supposed to emerge between the ages of 7 and 11 years, during the stage of concrete operations. This failure is not due to a misunderstanding of the "concrete" aspects of the task, because even after the principle has been thoroughly explained, and the women appear to understand, they still cannot perform accurately (Thomas et al., 1973; Liben & Golbeck, 1984). So far, the only evidence that can account for this sex difference comes from two sets of data. First, there is a high correlation between tests of visuospatial ability (exemplified by 2-D drawings of 3-D shapes) and Piaget's water-level problem. Females from the ages of about 12–14 years tend to score between one half to one standard deviation below the males on these visuospatial tests. Second, females score below males on tests requiring the construction of three-dimensional objects from about four years of age (McGuinness, 1985), despite the fact that they perform equally well on two-dimensional constructions.

Our explanation of this sex difference is that there is a failure on the part of females to create the appropriate sensorimotor scheme of object movement in three dimensions, initially. That this is due to the lack of sensorimotor *integration* seems more likely, as no tests of primary visual processing (acuity, convergence, stereopsis, depth perception, etc.) have been found to correlate with visuospatial ability (McGuinness & Brabyn, 1984; McGuinness & Pribram, 1978).

Finally, hyperactive children, whose main problem appears to be that they continue to want to learn by putting their hands into the world, show by this behavior an extreme tendency to remain in the sensorimotor stage. Yet these children have no deficit in Piagetian tasks or any other cognitive tasks, and in some studies they have actually been found to be superior to their controls on abstract reasoning (Kroener, 1975).

We would suggest that in learning *any* cognitive operation a new sensorimotor scheme must be evolved. First, the relevant invariant units essential to the solution of the task must be discriminated through repetition or interest. Second, the appropriate action patterns or skills must be acquired. Third, these perceptions and actions must be coordinated and integrated to the point where a transformation has been achieved. This transformation is initiated through decentration, which allows a higher level of abstraction (hierarchical) to emerge in which the sensorimotor components of the task become one integrated unit, or chunk, and the process runs off automatically without conscious effort. This is the essence of what Piaget describes as "autoregulation."

Over time these higher-order abstractions can be integrated into further abstractions, so that the initial operations required by the scheme are lost to immediate awareness or even to memory. If you ask mathematicians "how" they think when they are solving problems in algebra or geometry, they will usually be unable to tell you. This may seem like typical behavior on the part of inarticulate mathematicians, until one considers questions closer to home, such as, "How did you learn (critical periods, and the timing of maturation of specific brain systems), there are also cognitive stages that are specific to certain problem sets. These stages are so intertwined in each culture's educational process that they appear inseparable.

Identifying Elements

Several examples will illustrate how a difficulty in any specific domain is independent of other cognitive operations and will spell failure whatever the age of the subject. The most cogent example is that of reading failure in subjects who are well beyond the level of logical operations. In fact, studies have shown that in families with a predisposition to dyslexia across several generations, visuospatial reasoning (concrete and logical operations) is actually *superior* to that in control subjects who show normal reading skills (Decker & DeFries, 1980; Smith, 1982). Clearly, the predisposition to dyslexia cannot be accounted for by a failure to achieve the appropriate cognitive stage for learning to read—for example, the misapprehension of symbolic representation or some related cognitive deficit. The evidence is now conclusive that reading failure is in large part due to a deficiency in sensorimotor processing. Poor readers of all ages consistently fail in tasks that measure phonemic discrimination in both written and spoken language (Calfee et al., 1973; Liberman & Mann, 1981; McGuinness, 1981; Blachman, 1982; Smith, 1982). Moreover, these same subjects show a deficiency in sequential motor fluency both in purely manual operations and in speech and decoding (Smith, 1982; Badian, 1982).

Training programs designed to improve phonemic decoding, especially in conjunction with training in articulatory regulation, have been uniformly successful in teaching subjects to read (see McGuinness, 1981, 1985). The most dramatic results have come from those programs that *integrate* the perceptual and motor tasks. This allows for the development of new transformations and enhances the fluency with which the operations can be executed, thus reducing the load on short-term memory. The result is a change in competency that allows larger units, or "chunks," to be encoded into short-term or working memory. Pribram (1971) has argued that, once developed, attention span or the *capacity* of working memory remains relatively fixed and that what appears as a change in capacity is in actuality a change in competence, or the ability to chunk the operations into more complex units. This is supported by the fact that short-term memory studies reveal that the absolute number of items retained in a sequence varies between modalities *within* each individual, depending upon their competence to process information in that mode (Tallal & Stark, 1982).

Of course, what we are saying is not incompatible with an age-related stage model in the sense that no advanced stage can be achieved prior to the more primitive stage, in this case sensorimotor coding. It could be argued that this is merely another example verifying Piaget's theory of "invariant sequences." Yet one has a very uncomfortable feeling about a stage model in which adults, after years of schooling, have bypassed the sensorimotor period but nevertheless are fully aware of the "logical" properties of a writing system, that it is symbolic, phonemic, and so forth. A writing system is a *code* and belongs in Piaget's category of logical-mathematical operations. Nor is it any more convincing to argue that Piaget's stages only children were equal to Scottish children in accuracy. Yet when asked to build a replica from a 2-D pictorial representation, many of the Ghanaian children could not complete the task (Jahoda, 1979). This illustrates that the capacity to perform at the level of concrete operations can be demonstrated to be equivalent cross-culturally under one set of stimulus conditions but nonequivalent in another. Obviously, the Ghanaian children had had less exposure to pictorial representations. But the same argument might be applied to the 3-D blocks, which were equally novel to these children. How, then, does one determine which "stage" the Ghanaian children had reached? Quite apart from these data, lengthy exposure to specific materials does not guarantee that higher stages will automatically be reached, if the initial sensorimotor programs are not developed. We have already discussed severe reading delays, and the same problem arises in mathematics. College students often begin geometry or calculus with no understanding of the *concrete* principles involved. The most efficient and lasting teaching method, as pioneered by Davidson at the University of Massachusetts (see McGuinness, 1985), is to teach the entire course in the concrete mode, or, in other words, at the sensorimotor level.

Second, we have a good deal of evidence of the importance of "critical periods" in the developmental progression. Critical periods for visual perception have been worked out in detail in the rat and the cat and are found to be extremely reliable. Furthermore, unit recordings in cat visual cortex have shown that each cell in the brain has specific innate sensitivities to certain properties in the environment, such as velocity of movement and orientation, and that with use the "tuning" in these cells becomes sharper and sharper (discrimination). In highly constrained environments, or freak environments, these cells either lose their original sensitivity or set up new sensitivities. In extreme conditions, such as the absence of light, the cells stop functioning, and if this occurs at certain periods of time, the animal becomes functionally blind (Hubel & Wiesel, 1963).

Not only this, but complex cognitive functions in humans show the effect of extreme environments. Perhaps the best example is Genie, who when found at the age of 12 years in a Los Angeles bedroom had no language and had heard no one speak. After several years of training, Genie's language skills were identical to those of the great apes, with a severely restricted vocabulary employed in two- to three-word strings (Curtiss et al., 1974). The "critical period" for language development appeared to have passed, and although she had spent as much if not more time in language training than the ordinary five-year-old, she could not even come close to a five-year-old in language skills.

Piaget tended to avoid an emphasis on maturational theories, because he wished to promote his central thesis of a biological–environmental interaction. Perhaps Piaget, like Freud, although trained in biology, wished to avoid the problems inherent in a strict biological or genetic determinism that underpinned social Darwinism. Not only does such an extreme position have profound social consequences, but it negates the impact of the environment in shaping cognitive development. Yet both Piagetian and Freudian theories are essentially theories of "mechanism," and a truly "interactive" approach has to take into account the inbuilt constraints of the machine. One of these constraints is that neurons are primed for certain types of input. When this input does not materialize, aggregates of these cells are adopted into other neural networks.

to read?" "What is it that you *see* when you look at that word?" The fact is that good readers don't actually "see" the word at all; they are only aware of its meaning.

It is important to note that we have not been describing minute pockets of the population. About 15 percent of all boys are diagnosed as dyslexic. Approximately 50 percent of college women fail Piaget's water-level test. We have cited these extreme examples rather than using the cross-cultural data that show large discrepancies between the ages at which children of different cultural backgrounds reach various Piagetian stages. The Geneva counterargument has always been that the necessary experience had not taken place for the various schemes essential to each stage to emerge. This is taken to indicate that the same sequence of stages would be found irrespective of the large delays in children of some cultures. This argument becomes less valid when applied to adults who have been raised in the same culture, attended the same schools, and had identical educational bgackgrounds. In fact, an across-the-board theory of invariant sequences determined merely by exposure becomes completely untenable, and such a stage model must collapse. When using Piaget's epistemological model, however, we find no contradiction. As interpreted by us in the suggestions of cognitive specific stages, this model is sufficiently flexible to allow for failure to arise in any one component of a particular process at any age.

Covariation

We cannot construe any of the preceding to mean that we can ignore age changes as a factor in cognitive development. Too many talented and shrewd observers of behavior have independently come to the conception of stages—including Freud (1949), Sullivan (1953a), and Berne (1961)—to dismiss the concept entirely. Furthermore, these stages are remarkably similar in essential respects. For example, Freud's oral stage, Sullivan's prototaxic and Berne's "child" are essentially sensorimotor in character. Freud's anal, Berne's "parent," and Sullivan's parataxic stages are essentially devoted to developing voluntary control. Finally, Freud's sexual, Berne's "adult," and Sullivan's syntactic stages all involve communicative transformations. However, just as in the case of cognitive development, recent stage models, most especially Berne's, emphasize that these stages are really "states" that depend more upon context than upon age.

So far our account cannot explain the fact that by and large *most* children do appear to develop certain logical capacities at certain times. There are two ways that this characteristic of "stages" could be explained. The first is simply due to *concurrence*—that is, given similar cultural and educational backgrounds, children will begin to integrate (transform) certain types of sensory and motor experience at the same time. Once these transformations are sufficiently internalized and become automatic, they lead to a shift in logical thought that is qualitatively different. By this explanation, there would be periods of continuous development, followed by sudden shifts to a new level of understanding, a new "stage." This process would be largely independent of age but would entail "invariant" sequences.

For example, in a comparison of the performance of children in two cultures who were asked to construct a replica of a model built from 3-D blocks, Ghanaian ysis replaces the effortless and semiautomatic processing characteristic of childhood.

The second and related issue, that of the continuity of state-transformational processes, concerns the problem of sequential timing rather than absolute time dependent upon chronological age. One interesting facet of the research on this issue is that the results of such studies can shed considerable light on the question of sensitive periods. It has been suggested that failure in certain higher-order aptitudes is created initially by poor sensorimotor processing. If these skills can be *taught* at any age, by the process of exclusion, one can obtain a clearer picture of which cognitive abilities are more related to absolute time than to sequential time. Take for example, the problem discussed earlier on adult dyslexics. New techniques have revealed that the deficit is due almost entirely to the failure to develop the fine discrimination in both sensory and motor domains that is required during the initial learning stage. Unlike language-deprived children and those learning a second language, these adults learn to read once the missing subroutines are in place. Furthermore their reading rapidly catches up to normal limits if they are of normal intelligence in other respects (McGuinness, 1985).

Does this ability to catch up apply to other cognitive domains? What are the subroutines underpinning mathematical competence? That this also depends upon sensorimotor competencies that can be mastered in adulthood is suggested by Davidson's work. In addition, visuospatial problem solving is known to be highly correlated to ability in higher mathematics, yet despite a number of studies that have demonstrated this correlation, no programs have been established to discover how these visuomotor subroutines are set up initially. Such questions might lead to a more precise definition of cognition, one that relates more directly to some innate competence for abstract reasoning or problem solving that is independent of sensorimotor skills but that cannot be demonstrated unless these skills are in place. This definition would imply that there is some truth in the notion of Spearman's "G" factor, an inherent ability to find "intelligent" solutions, irrespective of the means by which these solutions are obtained.

Many of the examples cited earlier are negative cases that are intended to highlight those situations in which a stage model would be less viable than a continuous transformational model. However, most children proceed through their educational experience without deprivation, even of piano lessons! The question still remains, especially when dealing with Piaget's final stage of logical operations, what weight to place upon experience as opposed to neural maturation. Piaget and Inhelder were insistent that both were equally important in their discussion of logical operations. Yet they had considerable difficulty in reconciling these two domains. This struggle is highlighted in the following quotation.

> Given that in our society the 7–8 year old child (with very rare exceptions) cannot handle the structures which the 14–15 year old adolescent can handle easily, the reason must be that the child does not possess a certain number of coordinations whose dates of development are determined by stages of maturation. In a slightly different perspective, the lattice and group structures are probably isomorphic with neurological structures and are certainly isomorphic with the structures of the mechanical models devised by cybernetics in imitation of the brain. For these reasons, it seems clear that the development of formal structures in adolescence is

Conclusion

In conclusion, we would like to suggest that Piaget's genetic epistemology provides a compelling set of constructs to account for developmental change, especially in terms of our more continuous cognitive specific state–transformational model. Shifts that occur in any cognitive process are produced by the self-organizing and autoregulatory properties of sensorimotor schemes, which by virtue of action and decentration come to function as subsets in a new whole. Furthermore, biological data indicate that critical periods must be factored separately from concurrent covariation among these self-organizing properties. It is likely that both multiple transformational and multiple maturational processes are operating simultaneously and that this has been one of the reasons the data from studies on Piaget's tasks have been so difficult to disentangle. What is clear, however, is that the continuous and recurring state-transformational process, cast in the framework of genetic epistemology, applies at all ages and can account for cognitive growth.

The implications for human cognition beyond logical operations lead to a restructuring of our thinking and research goals. First, are there critical or sensitive periods after childhood and what operations would they entail? So far the most compelling evidence for early critical periods comes from extreme cases. We know that permanent amblyopia can result from a sufficient absence of patterned light in infancy and that language not only will fail to develop in the absence of another species member, but cannot develop fully after a specific time period has elapsed. From the limited number of cases that have been observed, it is possible that logical operations, involving advanced analytical thought, may not function in the absence of language. However, we know neither the timing parameters nor the precise critical period during which such profound effects can be produced. Furthermore, we cannot set up any research programs on humans that could answer such questions. The importance of these abnormal phenomena is to alert us to the possibility that the efficiency of certain psychological processes may be dependent upon the right input at the right time. This is not a new problem in educational psychology, but the approach has been more by trial and error than by any rigorous assessment of sensitive periods, and no one has explored the possibility of critical or sensitive periods past puberty.

A less dramatic illustration of the impact of sensitive periods relates to skilled performance. Certain high-level skills that we might consider indicative of cognitive ability, such as musical performance, are closely tied to early critical periods. It appears from a long history of training musicians that aptitude in performance depends to a large degree upon an early commitment of certain neural structures to specific motor routines (habits). If these skills are not acquired before the neural networks are committed, then a facility in performance can rarely be obtained, no matter how long practice continues. This might occur despite a high musical intelligence. The same situation applies to second-language learning, where early critical periods play a role in the degree to which accuracy in perception and production of speech can be developed. This ability declines rapidly after the age of six to eight years, when the phonemic structure of the primary language appears to coopt most of the neural networks engaged in linguistic processing. Learning a second language later in life appears to be more of an intellectual exercise, wherein conscious anal-

> linked to maturation of cerebral structures. However, the exact form of linkage is far from simple, since the organization of formal structures must depend on the social milieu as well.—Moreover the history of formal structures is linked to the evolution of culture and collective representations as well as their ontogenetic history.—Thus the age of 11–12 years may be, beyond the neurological factors, a product of a progressive acceleration of individual development under the influence of education and perhaps nothing stands in the way of a further reduction of the average age in a more or less distant future.
>
> In sum, far from being a source of fully elaborated "innate ideas," the maturation of the nervous system can do no more than determine the totality of possibilities and impossibilities at a given stage. A particular social environment remains indispensable for the realization of these possibilities. It follows that their realization can be accelerated or retarded as a function of cultural and educational conditions. This is why the growth of formal thinking as well as the age at which adolescence itself occurs—i.e., the age at which the individual starts to assume adult roles—remain dependent on social as much as and more than on neurological factors.
>
> For, if the social milieu is really to influence individual brains, they have to be in a state of readiness to assimilate its contributions. So we come back to the need for some degree of maturation of individual cerebral mechanisms (Inhelder & Piaget, 1958, pp. 336–338).

Unless one were to assume that, following adolescence, which Inhelder and Piaget have characterized as extending from puberty to the late teens, a new neurological departure took place, one must conclude that at the point of logical operations, the ultimate structure of cognitive operations is in place. In fact, their description of the final form of logical operations as the capacity for deductive and inductive reasoning is scarcely a commonly applied aptitude even in the adult members of any society. Indeed, whenever a totally novel problem is encountered, this inductive reasoning is brought to bear *only* at the conclusion of a sequence of prior operations, such as discrimination, categorization, and so forth, which constitute the application of sensorimotor strategies and concrete operations. The greater the amount of information acquired through past experience, the faster and more flexibly this sequence will be performed.

Therefore, it appears that what is beyond logical operations are processes of lateral extension rather than forward extension in terms of the available intellectual tools. Such a lateral extension makes possible greater powers of reasoning by virtue of a larger matrix of available skills and knowledge. In short, what is beyond logical operations is simply more of the same.

Appendix

Baerbel Inhelder was kind enough to read our chapter in two versions. She made three specific comments, which support the theme we are developing:

1. Piaget wrote in 1975 a major book titled *The Equilibration of Cognitive Struc-* [illegible] (translated by T. Brown and K. Thampy. Chicago: University of Chicago [illegible] which he developed a dynamic conception of equilibration through [illegible] three compensatory mechanisms (labeled as Alpha, Beta,

Gamma). Thus, the shift towards a view closer to that of Prigogine (i.e., stability far from equilibrium) comes more easily. In fact, on his 80th birthday in 1976 Piaget's thinking was related to that of Prigogine, Paul Weiss, and others. This set of interchanges was published in *Epistémologie Génétique et Equilibration* edited by Inhelder (Neufchâtel and Paris: Delachaux et Niestlé, 1977).

2. Inhelder states that her epigenetic model is clearly an interactive one: both biology *and* culture interweave to form stages in development:

> In sum, cognitive progress as observed in our learning research, cannot be interpreted according to a maturationist model or according to an empiricist theory. Since neither external factors nor purely internal factors are sufficient by themselves to explain the dynamics of acquisition of knowledge, and since there is no absolute beginning, only a model that reflects the continuity between the biological genesis and the development of the cognitive functions is appropriate. Such a model is provided by the concept of an epigenetic system where each new state incorporates the preceding ones, and where the influence of environment becomes progressively more important.

3. ". . . according to my [Inhelder's] still unpublished results it seems questionable as to whether microgenesis (the completion of a cognitive act) is in some [nontrivial] sense simply a foreshortened macrogenesis."

We look forward to the publication of Inhelder's results on the process of microgenesis.

Note

1. The example remains puzzling. One of the most interesting results in Inhelder's experiments is that a task given at one age and solved at that age with a cognitive strategy appropriate to that age, when given at a later age with no intervening practice, is immediately solved with a "more advanced" strategy. Is this the result of a change in age or of concurrent experience? Piaget and Inhelder both felt that it is age related but failed to make a good case for this.