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The Development of Skills

Kenneth Kaye

We use the word *skill* to describe any systematic action that an organism is capable of producing under particular circumstances. When we say that an organism possesses a skill, we mean that a model we might construct can account for the organism's behavior. Whatever we find necessary to include in our model—that is, in the inferred skill—can be considered a property of the skill itself. Some models, however, come closer than others to the actual processes we believe occur in a skilled organism, step by step; these I shall call functional models, or P-models. Other models are more abstract and analyze the products rather than the processes of skill; these I call formal, or C-models.

We sometimes use the word *skill* to refer to the functional model and sometimes to the actual thing it represents, the systematicity. Since functional models are the closest we can come to describing the processes themselves, this slight ambiguity in the meaning of skill is not a serious problem. The same kind of equivalence does not exist, however, between skills and formal models.

Because both types of models are used by psychologists in the study of skills—for different purposes—a discussion of skill itself necessarily involves discussion of how the models relate to various phenomena of concern to us. I will begin with some conclusions from the literature on skilled behavior, treating skill as a functional model of the regularity underlying action in real time—that is, as processes. This concept of skill turns out to be identical to Piaget's concept of schema.

A problem arises when we move from a consideration of skills at one period of time to their development over time. Stages have been described in terms of their formal properties rather than functionally. Although the abstraction is useful, I shall argue that we cannot then expect to explain transition from one stage to the next on the basis of changes in the formal models. The rest of the chapter, therefore, will return to the functional mode—analysis of action in time, in the real world, and in its social context—and discuss some considerations for a theory of skills and of cognitive development in general.

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Our discussion will touch upon many topics: how skills transfer or generalize to new situations; the use of feedback to control action and improve skills; disequilibrium and equilibration; sensorimotor compared with "higher" cognitive processes; differentiation and integration; the concept of an open system; indeterminacy in behavior; the social context through which skills develop; imitation; instruction; consciousness; self-concept and self-confidence as components of skills. All these topics, however, are related to a single theme. I shall try to clarify the issues and resolve them as far as I can in terms of the idea that a program for action is always constructed heirarchically by the embedding of schemata within schemata in the manner of subroutines in a computer program.

This theme is a dominant one throughout a very diverse literature on human skills. The reason for reiterating it here is that it offers a better explanatory model for how skills develop over time than any theory which focuses only upon the formal-structural properties of action. I shall argue the need for theories that attempt to account for the programmatic organization of action in real time and space.

A SKILL IS A SCHEMA

Theories of skill have been approached from at least four directions—by the fields of animal behavior, cognition, developmental psychology, and psychometrics. Within each field many different notions of skill distinguish different groups of investigators. Among "cognitive" psychologists in America and Great Britain (where the field encompasses "human performance"), some would talk of response chains, some of means-end relationships, some of coping strategies, some of information processing and communication. However, the lack of precision with which skill has been defined may have masked four essential points of agreement among all of the approaches. These are (*a*) that a skill is a unified structure, and the distinction between perception and action is false (to perceive is to respond, and conversely, action entails decision, categorization, and perception) (Piaget, 1951; Skinner, 1938; Tolman, 1933; Welford, 1968); (*b*) that a skill is purposive, and that this is not inconsistent with behaviorism if we accept the goal or intention as simply one aspect of the context in which a particular set of responses occurs (Tolman, 1925, among others); (*c*) that a skill is generic, a relation not between a stimulus and a response but between classes of stimuli or contexts and classes of equivalent responses (Skinner, 1935, among others); and (*d*) that a skill is hierarchically organized.

Of these points of agreement, the first three are clear and need not be belabored here. It will help to illustrate their importance, however, if we quote two authors who come to the same conclusion from very different approaches:

> It is not that a perception *begins* by being interesting or meaningful and *later* acquires a motor power through association with a movement: it is interesting or meaningful *just because* it intervenes in the performance of an action and is thus assimilated to a sensory-motor schema. The first datum is therefore neither the perception, nor the movement, nor the association of the two, but the assimilation of the perceived object to a schema of action, which is *at the same time* motor reproduction and perceptive recognition [Piaget, J., *Play, Dreams, and Imitation in Childhood,* New York, W. W. Norton, 1951, p. 17].

> The functional unit of performance does not typically consist merely of perceptual processes leading to motor responses, but of attempts by the organism to bring about modifications in the situation in which it finds itself. To put this in signal-response terms, we should have to say that the unit of performance extends from a signal to a modified signal and that response or action is merely the link between these two. This way of looking at skilled action has two important consequences. First, it places the main emphasis on perception and decision and thus makes the essential matrix of behavior cognitive. Secondly, since actions merely bridge the gap between one perceptual situation and another, they can vary substantially without the *functional* unit of performance having to be regarded as different: the central mechanisms are capable of producing a range of actions the details of which are matched to the precise requirements of the occasion so that the same end may be achieved in slightly different ways [Welford, 1968, p. 196].

The "unit of performance" described by Welford and others who have analyzed skill—the link between input and output or between signal and modified signal or, if we like, between stimulus and response—is exactly what Piaget means by "a sensorimotor schema." It is a model of the regularity underlying action: a model generalizing how the organism performs in real time, as opposed to a model characterizing the formal or logical relations among properties of the organism's behavior.

Hierarchical Organization

When Miller, Galanter, and Pribram (1960) set out their model of plans as essential units of behavior, they were concerned with several levels of description. In the broadest sense, plans are not skills. We would hardly speak of someone engaged, for example, in a murder plan as practicing a skill. Yet Miller *et al.* noted a basic structural quality in plans and strategies of the broadest type, which is found also in the more specific acts from which we infer skill. This is their hierarchical quality, the fourth point of agreement in the literature on skill. While engaged in Plan X, we initiate Subplan Y (which in turn may require Subsubplan Z), and when Subplan Y has been completed we continue with Plan X. To demonstrate this point Miller *et al.* (1960) postulated a feedback control sequence called test–operate–test–exit (TOTE). Basic to the notion of a TOTE unit was the fact that it was recursive; that is, the "operate" phase could consist of another TOTE unit. This is an important though perhaps obvious statement about behavior. When we reach for an object, for example, many different component acts are involved: raising the upper arm, extending the forearm, opening the hand, orienting the fingers, etc. Instead of happening all at once or in random order, the component responses and the sensory control monitoring the responses are organized hierarchically like a computer program whose subroutines are embedded within it at appropriate points.

The sequence test–operate–test–exit is purely a superficial one, functions inferred from a series of acts as they might be observed in real time. What is specified in the nervous system is not a sequence of tests or a sequence of movements. Its result, as manifest in observed behavior, is a series of acts but is more parsimoniously described in terms of a hierarchical organization with embedded subroutines. A theory of skill therefore has to account for the relation between skills and subskills, not just the relation between acts in sequence.

This basic point is implicit or explicit in all current work on skilled behavior (Welford, 1968). It refers to the hierarchical or programmatic organization of the movements that comprise a skill. This meaning of the word *hierarchy* needs to be distinguished from the hierarchy in which skills or responses may be organized in the brain.

Questions about organization in the brain have to do with the structural organization of whatever circuits encode and govern brain activity. This activity, like external behavior, no doubt needs to be modeled in terms of real-time processes as well as more formally. But a skill or schema is not a model for such brain activity: It is a model of action. We can assign a place to a "subroutine" or "operation" or "test" in a functional model only if its place can be inferred in relation to other subroutines, on the basis of observed behavior.

Still another meaning of hierarchy has to do with the choice of alternative responses. One can think of a hierarchy of response thresholds, or probabilities with which some particular response will occur. There may or may not be a systematic order with which the alternative subroutines are tried, one after another, as possible means toward an end. However, what I mean by the hierarchical organization of skills is that whatever subskills are activated will be activated as subroutines—as means towards ends—embedded in the main program as described above.

There is a kind of mystery here, in the fact that serially ordered responses must be organized not serially but hierarchically. Unfortunately, we have made little progress in solving the mystery since Lashley's (1951) classic statement of the problem nearly 30 years ago. He pointed out that serially ordered responses occur too quickly and too smoothly, in comparison to the "response time" of the nervous system. For example, a pianist, instead of playing each note in a musical run as an individual note, must conceive of and practice the whole phrase as a unit, inserted in its place in the whole piece. Furthermore, the preparation for subsequent phrases, as for subsequent notes in a phrase, must be going on well before the fingers are through with the preceding phrase. If the pianist is performing from written music, the ear may be on one measure, the fingers ahead, the brain farther ahead, and the eye still farther ahead. The phenomenon is familiar in many areas of skilled action, and though it has never been explained other than in these general terms, it is still a fundamental demonstration of the programmatic complexity of skill.

There is a relation (though not a simple one) between the subskills in performance and the subskills that must be learned as units, then combined. The skill–subskill relation has to do with both the execution of a series of movements and the learning of a series as a unitary act. Bryan and Harter (1899) used the learning of telegraphy codes as one of the earliest experimental proofs of an idea whose emphasis in the literature survives from William James (1890) to Bruner (1973): that practice frees attention (a limited resource of the brain) from the component movements and makes it available to their higher-level coordination. The more proficient a pianist is and the better he knows the piece, the farther his eyes move ahead of his fingers. The idea of "chunking" of information in perception and memory (Miller, 1956) has a parallel on the motor side.

Piaget's Sensorimotor Theory

In the same sense in which a skill is hierarchical, Piaget's notion of the schema is hierarchical. Although the schema itself is in no sense a series of movements or muscle discharges, the result of having a schema is a programmatic action sequence. Just as the organization of a skill is such that other skills can be embedded within it, the substructures that Piaget calls schemata are embedded within one another (1951, 1952, 1954). The schema for reaching for objects, for example, includes a schema for hand orientation. Piaget uses the word *coordinated* instead of *hierarchical*. Particular schemata can serve many different ends; in a given action sequence the relation between involved schemata is likely to be different from the relation they bear in the course of some other action sequence. On both occasions, however, the schemata will be coordinated hierarchically. The schemata do not come into play sequentially, but like the TOTE unit that forms the "operate" phase of another TOTE unit, the second schema comes in service of the first.

The means–end differentiation of schemata and their coordinated use begin slowly over the course of the first two years. Piaget (1952) considers that coordination can first be seen at the end of the first year, in the fourth stage of sensorimotor development. It is, in fact, the ability of schemata to become coordinated on the basis of their common factors that allows us to attribute meaning to the schemata, and meaning to the child's experience of objects and space. The coordination and integration of schemata with one another, either in parallel or in series (which includes embedding as well as chaining), depend upon the activation of both schemata by some common contextual feature that they share. In other words, schemata accommodate (change to fit the environment) for the same reason they assimilate (interpret the environment as fitted by particular existing schemata), and for the same reason we say more generally that skills transfer to new situations. The assimilation and accommodation of schemata hinge upon the correspondence between certain features of objects in the world and certain features of particular schemata, and also between the features of one schema and another. A conception of reality is constructed through action, or more specifically, through changes in the schemata underlying action. This means literally that what we call meaning only arises through the reciprocal assimilation and coordination of schemata.

There are three points crucial to my reading of Piaget. Assimilation is the fundamental function, from which accommodation necessarily results just because the fit is never perfect. Second, even more important than assimilating an object to a schema is the assimilation of schemata to one another: important, that is, to the explanation of how a conception of reality and an organized intelligence develop. Third, the correspondence between features of schemata is rooted in the physical features of objects, the similarity between one stimulus and another, one context and another, one goal and another, one social object and another.[1]

Thus the programmatic organization of schemata

[1]The physical properties of objects do not, ot course, translate into continuous psychological dimensions. Categorization occurs even at the perceptual (preattentive) level (Neisser, 1967) and can thus be assumed to influence the process of assimilation.

depends upon the generic nature of experience, the third point of agreement I listed with respect to the skill literature. If each event were entirely novel for the child, there could be no assimilation or accommodation of schemata, no hierarchical coordination of schemata, no progressive organization, no development at all. It is only because new events and objects are always more or less novel, never absolutely novel, that they can be assimilated to particular existing schemata and these schemata in turn accommodated to them. Having reduced this adaptation process to assimilation and accommodation, and having implicitly postulated a law of similarity, Piaget's model inevitably describes the progressive hierarchical coordination of sensorimotor schemata. The ultimate forms of these substructures, the operations of intelligence, obey the formalized laws of the logical grouping (Piaget, 1950). In particular, the conditions of associativity and transitivity are expressions of the same hierarchical, recursive quality we found in the TOTE unit and the sensorimotor schema.

The hierarchical organization of skills or schemata is also consistent with their structural unity, the first of the four points of agreement about skill. The whole changes as the parts change and are linked in new ways. Everyone who has learned to play an instrument, swing a racquet, speak a language, eat with chopsticks, or behave as a member of a group has experienced the fact that the learning of subskills forces many changes in the ways they are coordinated with one another, and thus with the organization of the whole.

Most importantly, hierarchical organization results from purposiveness, the second point of agreement. For what is it that maintains Plan X after the execution of Subplan Y? What keeps the infant reaching, even when he has activated a schema for hand orientation or for grasping, which we might expect to distract him from his reach? This is the function of intention, or purpose.

Piaget's interest, of course, is not merely in the nature of sensorimotor skills. Like Mead (1934), he sees in sensorimotor activity the origins of Mind. I am arguing here that the way Piaget uses the notion of schema provides an explanation for Mind, or "the child's conception of reality," only because it embodies purposiveness and hierarchical organization on the basis of the assimilated "common features" I referred to above. A schema is fundamentally different from the Skinnerian operant (Skinner, 1938). In this I disagree strongly with Hunt (1969) and Fischer (1978): The latter sees no difference at all between schemata and operants. A schema is defined by its intention as well as by its organization. An operant is a unit of behavior, not an underlying construct, and is defined only by its outward manifestation and the environmental conditions that affect its probability of being emitted. Despite Skinner's contribution to our understanding of the generic nature of the concepts stimulus and response (1935), operant learning utterly fails to account for the development of Mind.

FORMAL STRUCTURES DO NOT DEVELOP

Let me repeat the definition of a skill or schema: a model of the regularity underlying action; a model generalizing how the organism performs in real time, as opposed to a model characterizing the formal relations among properties of the organism's behavior. The preceding sections discussed some properties of skills (i.e., some properties of human behavior represented by such models). Reasons for regarding the terms *skill* and *schema* as synonymous were also discussed. This section will deal with the distinctions and relations between two fundamentally different kinds of model. Those we have been discussing will be called P-models (P for *process*), as opposed to C-models representing the *competence* or *formal structure* of knowledge. It is meaningful to use the word *skill* either to refer to a P-model or to refer to the programmaticity in someone's behavior, which the P-model represents. A C-model, on the other hand, is only a statement of some formal properties of a skill; it does not represent the skill itself.

Producing explanatory theories of cognitive behavior—either simple motor skills or higher thought processes—would be a difficult enough task for psychologists, but it is made much more difficult by our need to explain cognitive *development*. The "transition problem" poses an enormous challenge to every theory of cognition. How does the child develop from Stage A of cognitive ability to Stage B, and then from B to C? In other words, how does he get from a stage in which a certain formal structure A characterizes his thinking or his language or his problem solving, to a stage in which formal structure B does a better job of characterizing him? Usually B is presented as a better, more elegant, more parsimonious, more powerful, or more complex stage than A, and there is something plausible about the sequence A to B to C. But does this plausibility constitute an *explanation* of development? This is where the controversy lies (Hamlyn, 1971; Mischel, 1971; Toulmin, 1969, 1971).

Leave aside, for purposes of this chapter, three related issues that have occupied the attention of philosophers in this area: first, whether one has to understand the development of knowledge before one can understand the knowledge itself; second, whether the notion of a stage has any meaning; and third, what the criteria are by which a stage or a structure or a scientific theory may be said to be more advanced than the one that preceded it. For the sake of our argument, it will be all right if we accept the notion that cognitive development proceeds through stages of one type or another. Furthermore, if A, B, and C represent abstractions from the behavior of typical children as they grow older, I have no objection to using the word *change* in connection with these stages. For example, "The formal structure of a child's thought changes from A to B to C." I would interpret such a statement as meaning that the formal structure chosen by a psychologist to characterize children's thought changes as they grow older: It changes in the sense that the psychologist's choice of a structure changes. Take another example: "The sensorimotor stages of the infant change from simple reflexes to primary circular reactions to secondary circular reactions." The stages can be said to change because our model of the underlying regularity in an infant's behavior is replaced by a different model as the infant grows older.

But can we substitute for *change* the word *develop?* In the case of the whole organism, we can. The child develops; that is what the word *develop* means. Even in the case of particular organs, the changes are developmental; though there are discontinuities in rate and direction, it is still the case that what the organ was before and how it behaved were critical factors in the processes by which it changed into what it is today, and its morphology and physiology today will affect its further development.

It is an easy step, and an appropriate abstraction, to be willing to say of *skills* that they develop. It is not just change in the sense of having one skill at one age and another skill later, but really development: A skill affects the experiences a child will have and thus affects its own gradual transformation into something else.

It is not the case, however, that the *formal structure* of some set of skills develops. It may change from Stage A to Stage B to Stage C, but there is not necessarily anything inherent in the model that can explain those changes. Although the formal structures most often used to represent behavioral systems may very well be adequate for a theory of how these systems behave at some period in their development, it does not follow that changes from one model to the next will constitute an adequate model for a theory of developmental processes. In particular, where the models are atemporal, dealing with the properties any system would have to have in order to behave as the observed system does, but without regard for real-time processes, I will argue that such models can never supply a sufficient explanation for the changes from one to the next. The reason, quite simply, is that such models do not represent what develops.

Suppose we attempt to display the formal structure of the reaching-and-grasping skill in 6-month-old infants (Figure 2.1). The basic observations are that if you place a small object within the arm's length of an infant at that age, he will reach for it with whichever hand happens to be closest to it. If

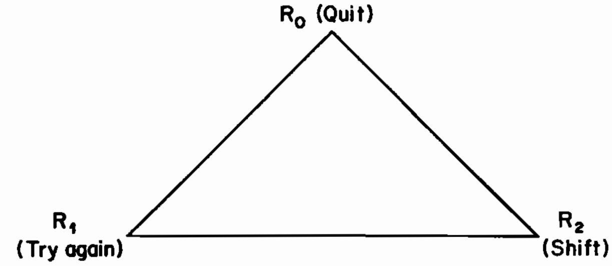

Figure 2.1. Model of the reaching skill in 6-month-old infants

you move it away or conceal it, he will stop reaching. If you place a transparent barrier in front of the object so as to foil his reach, he will switch to the other hand (provided the object is not very far to one side of his visual field). Other than repeating his direct reach with one hand, switching to the other hand, and choosing not to reach at all, he has no other way of obtaining the object without help.

By the age of 8 or 9 months, the reaching skill has developed. From that age until well after the first birthday, the most striking thing about the infant's behavior is that in the face of failure, rather than being limited to a repetition of his unsuccessful movements or the mobilization of the other hand (an alternative that is already part of his reaching skill), he now shifts to exploratory movements such as feeling for the edge of the screen, scratching the table surface, and leaning off to the side (Figure 2.2). These movements, though they take him away from the direct line-of-sight approach to the toy, are definitely not to be interpreted as abandonment of the task. The infant's eye movements show that he is periodically checking back to the toy, and when one of these exploratory movements takes his hand around the edge of the screen, he reaches toward the toy and grasps it.

These observations come from a study of more than 100 infants between the ages of 6 and 18 months, which I did some years ago in collaboration with Jerome Bruner and Karlen Lyons (Bruner, 1971). One striking observation we made of infants in this second "stage" was that if their exploratory fingering did take them around the edge of the screen and enable them to grasp the toy, they usually failed to bring it out along the reverse path, around the edge. Instead they tried to go directly toward their mouths and thus banged into the barrier and had to rediscover the detour on the way out.

Infants over a year of age did not have this problem; once they had made a detour to get in, they automatically reversed the procedure to get out. I have tried to depict these properties of their behavior in Figure 2.3. Depending upon the outcome of exploratory movements, the child has the capacity to organize them as alternative means toward the original goal.

By 18 months most infants do not have to do any exploring with their hands at all in this task; they are able to size up the situation visually and reach right around the screen without even touching it. Figure 2.4 is a model incorporating this change.

My four models are perhaps rather silly-looking, and they fail to satisfy some criteria for formal models (I have not specified what relations among the terms are symbolized by the connecting lines). No doubt the formal structure of each stage could be represented better, but I have chosen these representations in order to illustrate a point. However we represent them, these four successively better solutions to the detour problem have every right to be called stages since they differ in the basic properties a system would have to have if that system were to behave as babies typically do behave in each of the four age periods. But it would be

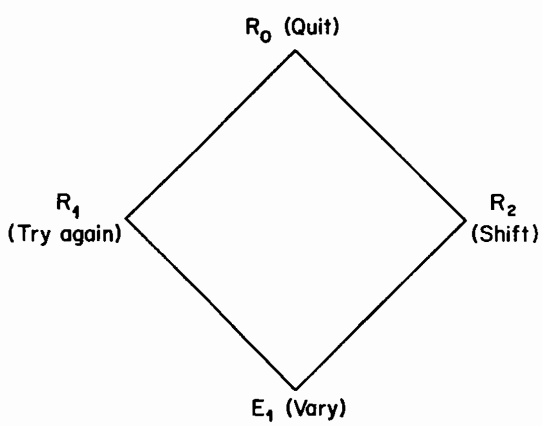

Figure 2.2. Model of the reaching skill at age 9 months

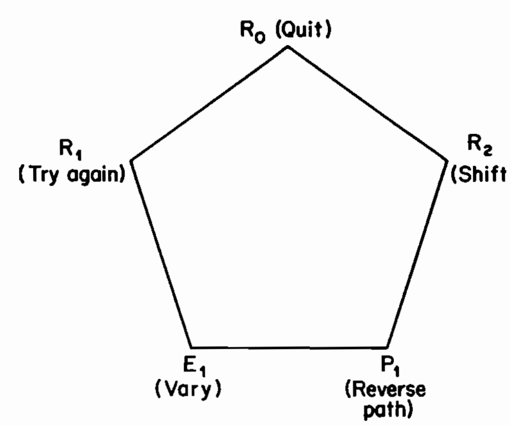

Figure 2.3. Model of the reaching skill at age 12 months

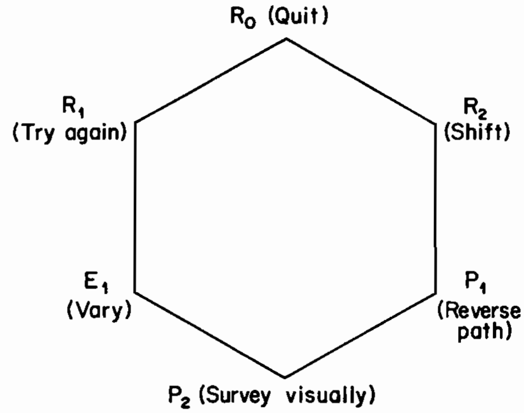

Figure 2.4. Model of the reaching skill at age 18 months

absurd for me to suggest that I had explained the transition from each stage to the next by pointing out that there is a lovely mathematical progression from triangular to quadrilateral to pentagonal to hexagonal structure.

It is equally absurd to suggest that the development of conservation or classification skills in the child is explained simply by the transition from a grouping to group structure. It is also absurd to suggest that the development of language in the child is explained by logical progression in the grammatical rules accounting for the sentences produced by children at each age. The grammar may change, but it does not develop. Progressive grammars provide a description of the stages but no explanation of the transition from one stage to another.

C-models and P-models

The diagrams above are what I am going to call C-models. They represent formal, correlational, or logical properties of a system; properties any system could be said to possess if its information-processing outputs were, at some level of generalization, like those we observe in the system we are investigating. The C stands for *competence,* in the sense used by Chomsky (1965, 1968) for linguistic knowledge. Competence models can be of the kind that specify rules, even sequential rules, for combining elements of behavior. (Chomsky indeed did just that, and one of his major points was that the rule structure for language must involve recursiveness, the same kind of hierarchical structure we described for skills in general.) However, even a C-model that specifies an ordered series of steps (as I did not bother to do in the examples above) is not a description of the steps the system actually goes through in producing its utterances or other behavior. The rules in the C-model are just those which are postulated as logically necessary to produce all and only the "grammatical utterances" of a language or the idealized instances of a particular skill. Whether those rules correspond to the actual processes of the system, and in what ways they correspond, are left for psychological research.

A very different kind of model is a P-model. P-models represent processes in real time, processes any system could be said to possess if it behaved as the observed system seems to behave in real time. A C-model tells us what someone knows; a P-model tells us what someone does.

To return to the example of reaching skills, Figure 2.5 is my P-model for the 6-month-old. Actually this P-model is an oversimplification—depicting an idealized infant who would keep trying to reach through the plexiglass barrier some number of times depending upon his level of arousal, then try the other hand once, and then avert his gaze. Figure 2.6 is a P-model of the same idealized infant at the next stage, after he has developed the ability to try new and varied means, but before he is able to organize those means as efficient alternative paths. I have not ventured to draw the even more complex P-models corresponding to Figures 2.3 and 2.4, the next two stages, but will ask the reader to imagine them.

Although the P-models are cumbersome and specific to the particular task in which we placed the infant, they do have one important property: The reservations just expressed about C-models do not apply to P-models. Although it is still true that the model itself is not the thing that develops, still the change from Figure 2.5 (P-model Stage A) to Figure 2.6 (P-model Stage B) usefully represents a development in the infant's skill. Rather than simply telling us that the infant now tries exploratory acts, it tells us that he tries exploratory acts when his reach has been obstructed for the xth time and where formerly he would have averted his gaze.

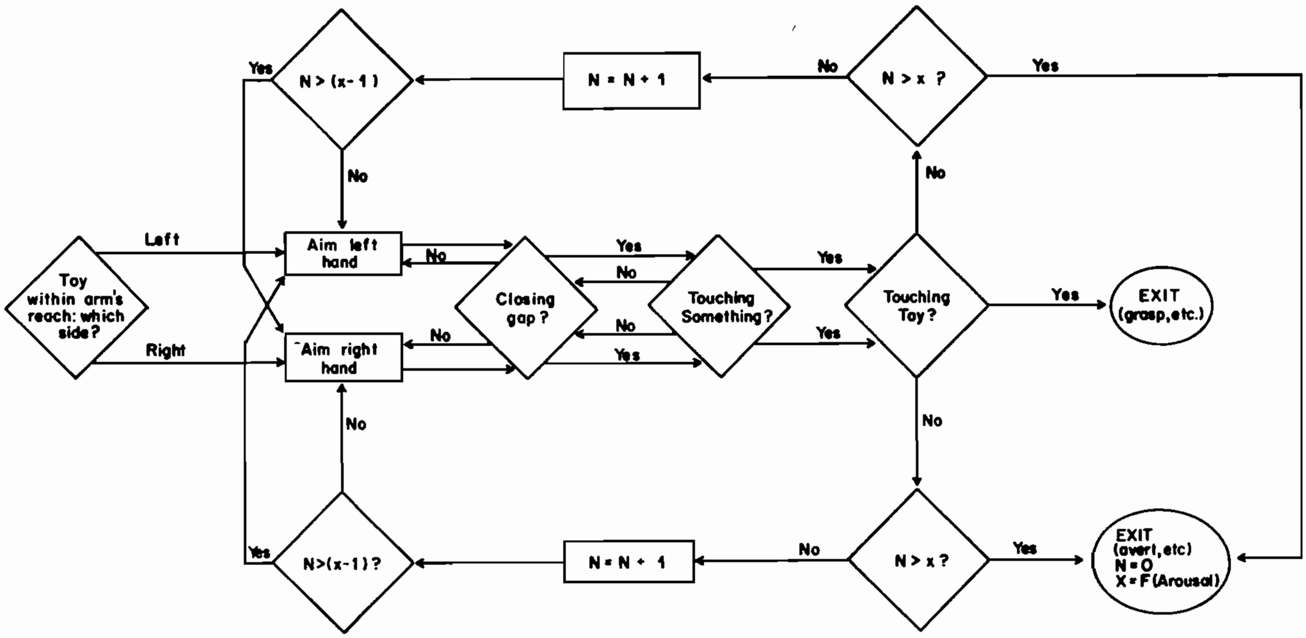

Figure 2.5. Idealized reaching schema for 6-month-olds who would keep trying to reach through a Plexiglas screen X-1 times (where X depends upon their level of arousal), then try the other hand once, then avert their gaze

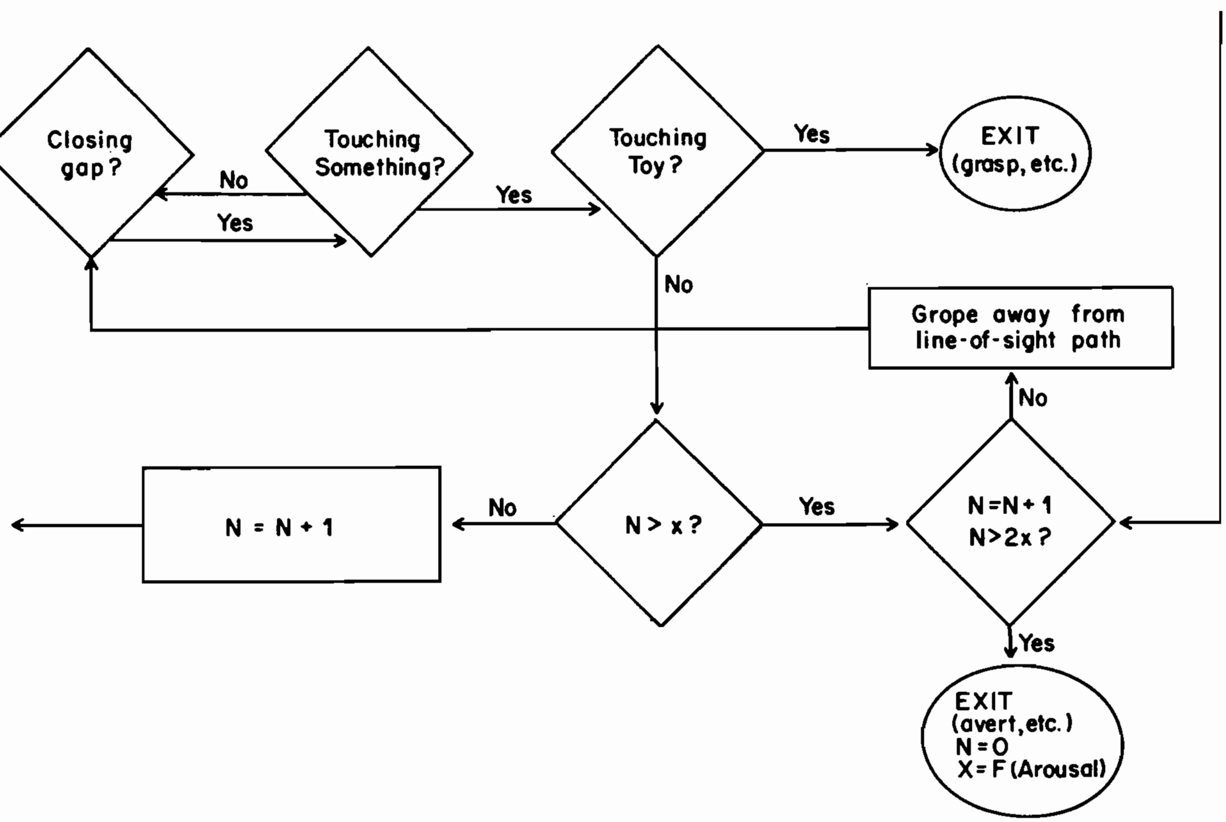

Figure 2.6. The lower right-hand section of Figure 2.5, with a new subroutine added (age 9 months)

This in its own right does not constitute a sufficient explanation, but it points us toward one: the subroutine that will eventually be used to scan the possible alternatives before reaching, inhabiting a place somewhere in the left half of the P-model for the fourth stage, has its origins in the repertoire of competing responses that can be elicited whenever the infant averts his eyes from the immediate goal. Furthermore, the infant's aversion of his gaze from the task has an important effect upon the behavior of his mother (Figure 2.7), who usually intervenes at that time and elicits alternative responses in a number of different ways (Barker, 1977; Kaye, 1970, 1977). Thus the structure of the infant's skill at Stage A affects the way his experiences subsequently provide information, and opportunities for accommodation, in the transition to Stage B. The P-models capture this developmental property of the skill, whereas the C-models do not.

In this instance at least, we can say that the P-models of the infant's behavior at the two stages represent the kind of hypothesis about developmental processes that can be tested and potentially disproved. The C-models in Figures 2.1 and 2.2 represent hypotheses about properties of the infant's behavior at the two stages; but as long as both are found to be adequate representations, we can neither prove nor disprove that the cause for development from one stage to the next has anything to do with transformations that appear in the models as they have been formally represented. The similarity between the P-models in Figures 2.5 and 2.6, on the other hand, is nontrivial. It might not have been possible to represent the process similarly at the second stage to the way it was represented at the first stage. The precise difference between the two P-models, at a particular place in the process, constitutes a fairly specific hypothesis about the frontier along which this schema for reaching obstructed objects apparently develops. The fact that further investigations revealed that mothers tend to intervene at just this point in their infants' efforts at reaching gives empirical support to the developmental hypothesis that was deduced from the P-models. C-models simply cannot be used in this way.

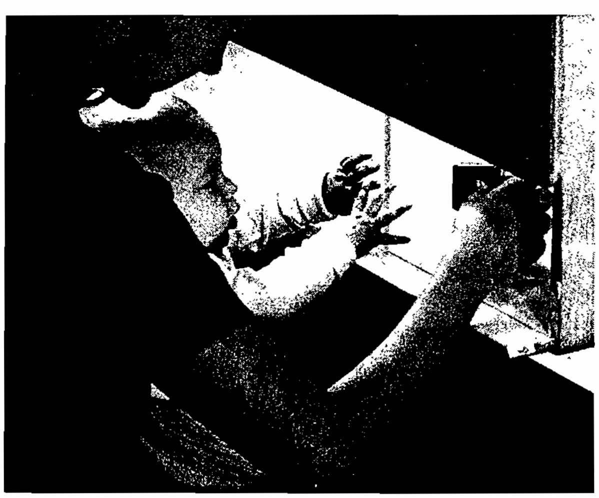

Figure 2.7. Detour-reaching situation

However, it would be a mistake to make too much of a dichotomy between the two types of model. Let me raise some points for further consideration.

A particular system may be represented by both C- and P-models. Both are abstractions; we must not regard the C-model as the idealized genotype and the P-model as the dusty phenotype. If P stands for something, it is performance *process*, not *phenotype*. Furthermore, the word *structure* applies to both models; if the structure of the C-model appears different from that of the corresponding P-model, it is only because each is a different way of representing the underlying structure of the observed system. What I said of generative grammars—that they are supposed to produce outputs like those produced by speakers of a language—is also true of P-models. Figure 2.5, for example, is supposed to generate outputs like those of a 6-month-old infant in one of our detour-reaching studies. The difference is that the steps in the P-model are hypothesized to be the actual processes by which the infant functions. That is not the case with generative grammars; psycholinguists have sometimes derived hypotheses from them, but when the hypotheses fail to be confirmed, the linguists are unperturbed (Chomsky, 1968).

The practice of psychology requires both kinds of models. One characteristic of a skillful psychologist is the ease and sophistication with which he or she slips back and forth between these fundamentally different modes of description. The modes (call them the C-mode and the P-mode) are different yet have mutual implications. The elements of each model have a correspondence with propositions of an axiomatic theory of the system in question, and the elements of each can be translated into those of the other. For example, my "triangular" diagram in Figure 2.1 was induced from Figure 2.5: the three properties of the system are manifest in various subsets of the boxes and arrows in that figure. The first property is an ability to recognize when there is no reasonable probability of success; this is manifested in the P-model by the decision points that ask "$N > x$?" or in other words, "Have I failed enough times to draw the conclusion that I am not going to succeed?" The second element of my C-model is the ability to repeat a subroutine if it is not successful. The third is the ability to switch from the subroutine initially tried to an alternative subroutine (reaching with the other hand) within the same skill. The three elements in my C-model are related to one another logically (where the logic is mine, of course, not the infant's), whereas the elements in the P-model are related to one another temporally.

Testing a theory usually requires the psychologist to translate hypotheses from one model to another. Sometimes the hypothesis or theorem that can be tested is the one regarding formal properties of a system. Sometimes it is the one regarding sequences of responses in real time. In a way the two types are not two different theories of the system, but a P-model of the C-model and a C-model of the P-model.

P-models contain C-models. The former have a tendency to be written as flow charts or actual computer programs. But what is each box or each diamond in Figure 2.5 if not a C-model listing relations without specifying their operation in real time? The use of an artificial intelligence as a model for human intelligence is essentially a substitution of logical processes for physiological or psychological ones, and therefore it reduces ultimately to a C-model. The label on any element of the P-model really implies a theory whose P-model is missing, such as "signal detector" or "superego," or "pattern recognizer." In principle the labeled element could be expanded to a P-model, but in practice the representation can only stop—even just long enough to be written on a blackboard—when we are satisfied to represent each element of the P-model as a C-model. How deeply a psychologist wishes to penetrate into this infinite regress depends upon his concern with process and mechanism as opposed to parsimony and abstraction. But even a fairly superficial and oversimplified P-model is isomorphic to the actual mechanisms of human behavior in at least one important respect: It preserves the temporal order of processes, allows us to analyze steps, decisions, the flow of information in time.

It is a mistake to attribute either kind of model to the child. His behavior may have structure, but he seldom has in his own mind the model which describes that structure. It is a mistake we consistently make, and it may seem a harmless figure of speech, but it gets us into a great deal of trouble. To say of an infant, for example, that he tests hypotheses about novel objects, or about the grammar of his parents' language, is to blind ourselves to most of what is interesting about the infant's cognitive processes. In fact, Piagetians distinguish a stage in which the child finally is able to formalize the operations of thought; before then he is incapable of having, in any meaningful sense, the models of his own behavior that the psychologist creates. We shall return to this issue at the end of the chapter.

Clearly a skill or schema is a P-model. That is, both C-models and P-models can be used to represent what people "have" when we say they have a skill (indeed, we may only be interested in the attribution of competence, not the details of process), but the P-model comes closer to the level of description required if we are to make predictions about performance, to instruct or facilitate practice, or to explain the development of skills.

The role of C-models is essentially to set boundaries on their corresponding P-models, at the outer level and at the inner level. By the outer level I mean that the psychologist must work in a C-mode as long as he is isolating those properties of the system whose process of operation he wants to understand. The terms and relations in the C-model are essentially hypotheses that come from three sources: observation, deduction from other C-models, and induction from P-models. In each case the task is to refine the P-model, to account for the subject's competence in terms of processes we actually believe to be operating in the production of the behavior we observe.

By the inner level I mean that we always have to accept some level of refinement at which the elements of the P-model are themselves C-models, names for processes we accept—temporarily, at least—as givens. This means that the difference between the two modes of theorizing is relative rather than absolute, and I am merely arguing that research on cognitive development has been crippled by too much infatuation with the geometry and algebra of C-models with too little in the way of attempts at specifying the actual processes of behavior.

Action, Learning, and Development

That charge cannot be leveled at cognitive psychology in general. On the contrary, the whole history of the field has been one of greater and greater specification of processes in perception, memory, sentence comprehension and production, etc. (Klahr, 1976; Neisser, 1967). This is true of research on children as well as on adults (e.g. Resnick & Glaser, 1976). When psychologists have tried to explain development from one stage to another, however, they have almost invariably tried to do so between one C-model and another, by principles as arbitrary and fallacious as my invoking a Law of Polygon Burgeoning to account for Figures 2.1–2.4. Pylyshyn (1972), Osherson (1974), Feldman and Toulmin (1975) and others have made substantially this same criticism, but apparently it has not yet had any effect upon research or theorizing on cognitive development.

The explanation of development is fundamentally different from the explanation of action. It is one thing to describe behavior, another thing to describe the acquisition of behavior, and still another thing to describe the development of whole systems of behavior and even the development of the acquisition of behavior. Tinbergen (cited in Hinde, 1966) studied the behavior of Eskimo dogs that avoid one another's territories. The behavior was complex enough in its own right, involving the use of smell and other cues. But Tinbergen also analyzed it at a second level, tracing its learning history in mature dogs. At a third level, he found that young dogs were incapable of learning to avoid other dogs' territories. The developmental problem involved more than simple maturation of the sensory and response systems involved in the avoidance responses. Tinbergen concluded that the avoidance-learning limitations of the young dogs were associated with the fact that they did not yet defend their own territories. The level of development of one set of skills limited the potential for modification of another. Thus all three levels of analysis, involving three different methods, contributed to an understanding of the dogs' behavior.

At least two developmental factors affect skills. First, there is maturation of the sensory and motor organs used in skilled behavior. Thus some kinds of improvement in skilled performance—walking, for example—involve learning only to the extent that learning interacts with maturational development. The second developmental factor arises from the fact that skills are organized hierarchically. As a particular skill is acquired—that is, learned or modified—it affects other skills to which it may be ancillary. The child learns to walk at about 12 months, and this development in turn leads to changes in the way he deals with detours. Thus modification takes place simultaneously in many different skills, and these changes interact in complex ways.

If this distinction is observed, we should prefer the term *language development* to *language acquisition*. This would not mean replacing the notion of a Language Acquisition Device (Chomsky, 1962) with a Language Development Device. I mean, rather, that we ought to assume that the Language Acquisition Device itself develops as the child's language skills become differentiated and coordinated.

It is difficult to delimit the boundary in time between a skill, or program for action, and a developing system, or program for searching, organizing, and storing information. In fact, the concept of an "open system" includes both the properties of goal attainment in the short run and self-organization for greater efficiency of goal attainment in the long run (von Bertalanffy, 1968). In principle this means that any P-model of skilled action can be enlarged to account for the subject's performance over a longer period of time. The P-model of reaching after about a year of age, for example, when Figure 2.6 becomes obsolete, includes subroutines for searching, selecting appropriate means of exploration, remembering cues that prove informative, and basically rewriting the program itself so that on subsequent occasions the detour can be found more efficiently.

The program (or the P-model of the program) for solving a problem like the detour box is no different from the program for learning *how* to solve problems like the detour box. This is why there is transfer to similar tasks. The infant not only attains the goal of reaching and grasping the toy inside the box; he also attains, though perhaps over several trials, the goal of *being able* to reach around detours. In other words, he has not just been trying to solve the detour problem, he has been trying to understand it. The word *understand,* as applied to an infant lacking symbolic processes, can be taken to mean that he will generalize from the solution of this problem to the solutions of other, similar problems. Since he will approach those new problems differently and more effectively than if he had not had the experience of encountering our detour, we can say that his skill has developed: The way he processes information in real time has changed, and the change itself is a matter of processing information in real time.

Thus a P-model that takes sensitive account of the way a person at some stage of life processes information is also a representation of developmental processes. But this means it must also be possible to represent development in terms of its formal structure, for we have already said that every P-model has a corresponding C-model. Such a formal structure would be nothing other than the laws of development, the "invariant functions" or whatever one might choose to call them. My thesis is simply that the formal structure of development cannot be inferred from the formal structure of action at two or more stages; it comes from a functional or performance model of developmental processes, which in turn can be drawn from the functional models of action at different stages.

THE FUNCTIONAL STRUCTURE OF SKILLS

Skills are unified, generic, purposive, and hierarchical. I have shown above how these formal properties of skills logically imply one another, and I have also argued that P-models come closer than C-models to representing specific hypotheses about changes in functioning and about the actual processes of skill, emphasizing its programmatic structure. This section will discuss some of those basic processes.

Transfer

Because a skill can only be defined generically (in reference to a whole class of situations and class of responses), to say that a skill has been acquired is to predict that a learning experience will have some positive effect on the learner's future encounters with more or less similar tasks. This is commonly called *transfer,* and tests of transfer are the psychologist's only source of information as to what exactly has been learned.

To understand thoroughly how skills transfer we would have to answer such questions as, What constitutes "similarity" or "familiarity" of objects and situations? What are the learning conditions that maximize the transferability or generalizability of skills? Exactly how are skills stored in the nervous system? and To what extent is consciousness of our own skills veridical? Unfortunately little is known about such questions. People often transfer their skills into new situations, yet they just as often fail to do so; there is no obvious correlation between the likelihood of a skill's generalizing and any particular kind of similarity between the transfer situation and the original learning situation. There seem to be many factors involved: not just perception and memory but anxiety, social norms, role learning, etc. Most of these factors lie beyond the scope of this chapter, but one—intention—provides some empirical support for the way we have defined skill.

In a simple experiment, we gave 15 6-month-old infants practice in reaching around the plexiglass barrier shown in Figure 2.7 (Kaye, 1978a). Each mother held her infant in her lap facing a table top obstructed on either the infant's right or left by the plexiglass, which ended just even with the infant's midline. The mother was told how to reach around behind the barrier slowly, waving her fingers, and then withdraw the hand and wait 10–15 seconds for her infant to imitate. This was repeated for 15 trials, by the end of which 6 of the 15 infants had reached around the barrier at least once. Then a toy (which they played with for a minute) was placed behind the barrier, and the infants were given 2 minutes to reach for it. All began by trying to reach through the plexiglass, as though they had learned nothing. Seven did retrieve the toy after some trial and error, but these 7 bore only a chance relation to the 6 who had imitated the detour reaching when there was no toy. Furthermore, in a control group of 15 infants who had not had the prior experience, exactly 7 succeeded in getting the toy by trial and error.

Immediately after the 2-minute test period, all 30 mothers were again asked to show their infants how to reach around the detour and retrieve the toy, 15 times alternating with 10- to 15-second waiting periods in which the infants could imitate. (Each time the mother removed the toy we placed it behind the barrier for the infant's "turn.") Eight of the 15 experimental-group infants succeeded on at least one of these trials, though they were beginning to show fatigue and fussiness. In the control group 12 of 15 succeeded, and 11 of these were able to retrieve the toy on a posttest without help. The posttest successes were not a matter of haphazard groping and accidental successes but were for the most part immediate reaches around the detour—or else immediate correction of an attempt to go directly through the plexiglass. The results demonstrate the importance of a goal object eliciting an intention in both the learning and the transfer of a skill. With or without the toy, the mothers demonstrated exactly the same movements. When the toy was behind the barrier, the mothers were demonstrating a solution to a problem, a means toward an end that already existed in the form of aroused intention (observable in the fact that the infants banged on the barrier, etc.). Without the toy the movements had no meaning, and even those infants who imitated the movements of reaching around the detour learned nothing that would help them when we put the toy there. (Incidental learning of that kind does, of course, occur in older children and adults [e.g., Bandura & Huston, 1961], but representational skills are involved; here it is just a matter of a sensorimotor schema.)

When infants learn to reach around a detour for a particular object in experiments like the one described, they have no difficulty transferring the skill to other objects we substitute for the original toy. This fact is additional evidence that what has been learned is not a set of responses to a particular class of stimuli, but a unitary schema defined in terms of some intention (in this case, intention to reach and grasp) as well as a context (the plexiglass barrier, the mother's lap).

Feedback

The tennis player bends forward, then arches back as she tosses a ball into the air. Her eyes follow it. While the ball is still ascending she positions the racquet above and behind her head. As it begins to fall she swings, using her whole body to adjust the racquet's height, its angle of orientation along vertical and horizontal axes, its forward and downward speeds. She aims at an invisible point through which—responding to the force and direction of her toss, to the spin imparted by her fingers, and to the wind—the ball will be passing at the moment the racquet hits it. Some milliseconds before that moment, the athlete has made her last adjustment, irretrievably committed to the swing and follow-through. The ball's speed, its height, its curve, its spin, its bounce are all determined.

This is an ordinary bit of human behavior. It becomes extraordinary only when we think about it. How does a human being take account of so many vectors of movement, compensate for them, and control a ball's flight so precisely? From the point of view of a theory of skill, the critical features are intention and feedback, which in turn take us directly back to our theme: Action is constructed by the embedding of subroutines in a hierarchical program.

By saying that *intention* is a critical feature of skill we are insisting upon an essential difference between the behavior of the ball and that of the tennis player. The ball *moves;* the human *acts*. The movements of the ball can be analyzed as a function of immediately prior events; the actions of the human cannot. The tennis player makes decisions, processes information so as to achieve an end. We cannot explain the angle at which she holds the racquet, for example, as a response to prior events. She aims the racquet in that way—in a way she has never aimed it before—so the wind will not blow the ball too far to the left. This might sound like teleology. In fact it would be teleological if we were to attempt to explain the mechanisms of skill by their results. But we do not claim that the purposive character of skill is a sufficient explanation. Following the lead of Tolman (1925), who showed that intention or purpose, far from being heresy, was a necessary ingredient of behaviorism, we regard the specification of goals and subgoals as necessary to the description of the skilled acts we hope to explain.

Intention is therefore one of the properties that defines skill. Skill is an open system for the accomplishment of ends by variable behavioral means. Open systems are those that can take a variety of paths depending upon circumstances, recognizing when specified ends have been attained (von Bertalanffy, 1968). Closed systems include solar systems and river systems. The planets and rivers respond to gravitational forces; their movements are determined by the forces acting upon them. Open systems, on the other hand—respiratory systems, government systems, biological and social systems—have alternative courses open to them, which they may try out successively or simultaneously. The results of those trials will lead to a decision that affects the way the system operates in the future. Skills, as open systems, develop; they become organized so as to deal more efficiently with whatever factors have to be controlled in the attainment of particular goals. As soon as we choose to describe human activity in terms of intention, we are choosing an open-system model of skill.

This choice is based on behavioral evidence. Intention is defined operationally: The subject persists in the face of failure or obstruction, he varies his movements nonrandomly in a direction to circumvent obstruction, he initiates or resumes his activity in the absence of any external stimulus, and he ceases his activity when the goal has been reached.

Feedback, the use of information generated in the course of action, is a concept from cybernetics used to account for the way in which our tennis player, for example, adjusts the speed of her racquet. Visual information about the movement of the ball is compared with visual and reafferent information about the movement of the arm, and a series of adjustments is made within fractions of seconds. Although in principle purposive action is possible without the use of feedback en route to the goal, many kinds of action must require periodic tests both in order to facilitate adjustment and in order to know when an intermediate goal has been reached so that the next step can begin. These periodic tests are what Miller *et al.* (1960) called TOTE units, discussed earlier. The behavior of a human singer who has to sustain a constant note is similar in this respect to that of a skier, or of a gull flying in the slipstream of a ship. Nearly every kind of animal alters some of its actions as a function of movement-generated feedback. The experiments proving this involve either deprivation or distortion of feedback produced by action (Hinde, 1969). In some cases the feedback is afferent discharge from the limbs themselves. For example, a monkey makes no voluntary movements with an arm that has been deafferentated (Mott & Sherrington, 1895). In other cases the organism is able to use information from another modality such as vision, apparently comparing this information with its knowledge of how the world should look (von Holst & Mittelstaedt, 1950). Feedback-control loops play a central role in models of human skill developed by Deutsch (1960), Bernstein (1967), and Welford (1968), and the analogy with computer programs has been with us since before the modern computer was invented (Craik, 1943). Neisser's (1976) reformulation of his theory of perceptual processing stresses the cyclic as opposed to linear relation between stimulus and perceiver.

In addition to its guidance function, this kind of feedback seems to be important for learning. Certain kinds of environmental information will either not be attended to, not be processed, or not be stored by organisms unless the information is generated as feedback from voluntary action. In the classic study by Held and Hein (1963), for example, kittens who had been reared entirely in the dark and then walked through a patterned arena developed the appropriate depth reflexes, whereas each kitten's partner, which it towed through the arena sitting passively in a little cart, was noticeably retarded in visual perception of depth. The development of these reflexes apparently requires experience with the visual consequences of voluntary movement. With human subjects, corroborating results have been found for both perceptual and motor learning (Held, 1965; Holding & Macrae, 1964). Furthermore, infants and children often resist attempts at teaching them new skills by pulling or pushing their limbs (Kaye, 1977); they prefer voluntary trials that generate feedback.

As for reinforcement by the consequences of acts, it is not wholly inappropriate to extend the word *feedback* to include this kind as well as the response-contingent information used en route to a goal. We should simply regard the consequences of a completed act as feedback in a higher-order program for improvement of the skill in question. In other words, reinforcement is information used en route to the goal of competence.

Hierarchy and Attention

We have emphasized that skills are organized hierarchically, or programmatically, referring to the fact that the attainment of a goal often requires certain subgoals along the way; subskills are nested within other skills. The tennis player's serve cannot be seen as a chain of acts. She tosses the ball up as part of a larger unit, the hitting of the ball with the racquet; this too is part of a larger unit, the serving of the ball over the net, and so on. It is not simply a matter of how we choose to analyze the acts. It can be shown empirically, in terms of human response time, that the response of swinging the racquet has to begin before the ball is tossed (Bartlett, 1932). We mentioned the example of a pianist, which Lashley (1951) used to make this point: If we tell a skilled pianist to hit a certain note as soon as he hears the preceding note, the response time between notes will be on the order of .5–1 second. When the same musician reads sheet music, however, the keys may be hit as rapidly as 10 per second, and his eye movements will be two or three measures ahead of his fingers. Skilled behavior does not consist of a sequence of acts, each one beginning when the previous one ends. There is not enough time.

Although Lashley's example is frequently cited, he first raised it (in Lashley, 1917) to make a somewhat different point. He argued that skilled behavior does not always utilize feedback: The pianist has gone on to subsequent notes in less time than it would take to monitor and respond to the notes he hears. What we would say today is that the monitoring goes on simultaneously, as other steps in the planned sequence are in various stages of preparation and execution. In order to put the parts of the skill together, therefore, one has to be able to negotiate each component with less than full attention. In fact, the less monitoring required for each of the constituents, the more attention can be focused upon the way they are put together and upon the goal to be reached. This is what Bruner (1973) finds in studies with children under 2; this is what Elliott and Connolly (1973) find with children between 3 and 6, with a simplified version of the game of "tilt," in which the two hands coordinate to control a board on which a metal ball is to avoid falling into a hole; and this is what common experience tells us about the learning of skills like tennis.

As she becomes more skillful, the athlete will devote less attention to the nested subroutines in her serve and have more attention available for what is going to happen at the end. The good player concentrates on where the ball is going to go, and the serve somehow takes care of itself. A good illustration of the extent to which we attend to the aims, not the components, of our actions is to think about cutting with a pair of scissors. What do your fingers feel? Not the handles of the scissors, but the blade slicing through the paper (Gibson, 1966).

One of the feedback loops in our P-model of the young infant's reaching skill, Figure 2.5, is enlarged in Figure 2.8. This is a TOTE unit, with the rectangle representing the "operate" component and the diamond the "test." The feedback loop can be seen in the infant's reaching behavior from the very beginning. In fact it can be seen more easily at first, when, as Piaget (1952) points out, the infant can often be seen glancing back and forth between hand and object. Later, he does not seem to need to

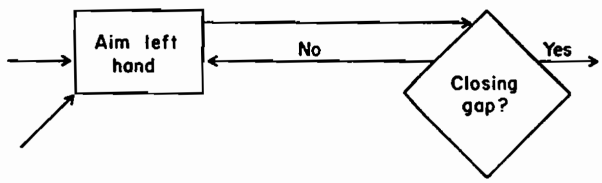

Figure 2.8. Feedback loop (a TOTE unit from Figure 2.5)

monitor his hand visually—he can attend to the goal alone. So the tennis player watches the ball, not the racquet; the quarterback watches the movements of his receiver and the defenders around him and throws to where the receiver will be when the ball gets there; the musician attends to the sound, not to his fingers; the skier to the slope ahead; etc.

All of these phenomena suggest two important developmental changes in the way in which the intention, or goal state, is represented internally by the organism. One change is that the various sensory and afferent modalities become highly coordinated, and the second is that this coordination becomes more automatic, free of attention. Thus instead of one's having to carry out a series of tests, as the 6-month-old does by looking back and forth between hand and object, the information from several modalities is integrated very rapidly, and from the organism's point of view essentially automatically. The skillful tennis player knows before the ball leaves her racquet whether it will go where she wants it to go, perhaps even before the racquet reaches the ball. Yet she cannot say how she knows—it just "feels" right or wrong.

The "interiorization," or automatization, of components of action sequences (what used to be called the formation of habits) carries disadvantages as well as advantages, as Schneider and Shiffrin (1977) have recently shown with respect to perceptual recognition tasks. What is automatic requires less attention, is faster, and can be more efficiently combined with other components; but it is also less flexible when contingencies change. Often the major task in correcting a bad habit, in any skill, is bringing one's attention back to the components from which it had been "freed."

I have emphasized the programmatic organization of skills, the hierarchical relation between skills and the subskills of which they are composed. I have also said skill development involves the smoothing of the lower-order constituents, the subskills (or "subroutines" in analogy to computer programs) so that they can be executed with little or no monitoring and attention can be devoted to the higher-order combinations. These too then gradually become more automatic, until the highly skilled individual is one whose conscious attention is devoted only to strategies. The feedback processes we described above are, of course, still going on at all levels, but they require relatively little attention and they can go on in parallel with one another: Each component of the skill does not have to wait for conscious attention.

It is easy to find examples supporting this view of what happens as skills develop. I have used examples of an athlete and a musician. An elegant empirical demonstration was provided by Stern (1977), who analyzed a film of a boxing match, measuring the reaction time of each boxer to punches thrown by the other. The data (Figure 2.9) indicate that a professional boxer typically reacts to a punch almost before the opponent's fist begins to move. The commonly measured "human reaction time" on the order of about half a second has no place here. Anyone with a reaction time that was even as fast as a quarter of a second would be knocked uncon-

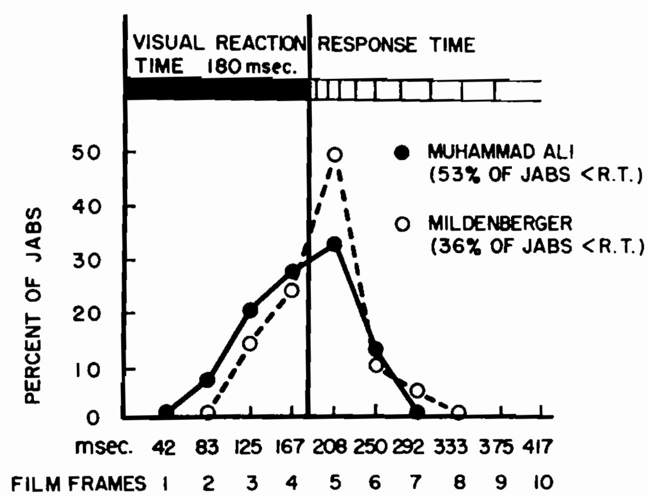

Figure 2.9. The duration of a jab in the first round of the Muhammad Ali–Mildenberger world heavyweight title bout, 1966. (From Stern, 1977, p. 87. Reprinted by permission of the author and Harvard University Press.)

scious at the opening of the first round. We say boxers on the order of a Muhammad Ali have "instinct," but a more accurate description would be that they have trained so well, for so long, that constituent skills like throwing a punch and blocking a punch are no longer in the realm of conscious action and reaction. Ali is not thinking about the punches but about strategy, such as how best to tire the opponent sufficiently so that his "instincts" slow down. If you or I were in the ring with such an opponent, we would have little time to think about strategy.

DIFFERENTIATION AND INTEGRATION

Any act is constructed by the insertion of schemata within other schemata, as means toward means toward means toward ends. Does a similar process of construction and integration account for the development of the schemata themselves over time? Do we develop skills by perfecting and polishing parts, and then putting them together into wholes? Are constituents first practiced independently to the point where they become habits, then combined with other constituents, practiced until they become well coordinated and integrated, then combined, etc., like units of a prefabricated house? To some extent, yes. The development of sensorimotor skills in infants provides some good examples. As each new skill is achieved, it can be seen in play, where it occurs autonomously for no other apparent motivation than that of competence for its own sake (White, 1959). Bruner describes this as "mastery play":

> The 6-month-old infant, having learned to hold on to an object and get it easily to his mouth, then begins a program of variation. When he takes the object after mastery has been achieved, he holds it to look at, he shakes it, he bangs it on his high chair, he drops it over the edge, and before long, he manages to *fit the object into every activity* into which it can be put. Inversely, when the young infant masters a new step in sensory-motor development, as in simultaneous use of power and precision grips so that he can hold an object steady in one hand while exploring it with the fingers of the other, he very soon uses this new act *on any object* that has a "loose end" or "pick-at-able" property. In the first case, a new object is fitted into as many routines as available; in the second, a newly mastered act is addressed to as many different objects as available. Both are absorbing work (or play) for the child [Bruner, 1973, pp. 6–7].

The idea of breaking down a task into its necessary component skills and providing practice for them before trying to put them together occurs, not surprisingly, to mothers. In the detour-reaching study described earlier (Kaye, 1977), 25 of 92 mothers adopted a strategy of primarily simplifying the task and letting the infant practice reaching for the toy when it was not behind the plexiglass barrier. Then they would gradually move it behind the barrier over a series of trials. We observed essentially the same strategy in several different teaching tasks with mothers and infants. At first it seemed that this "shaping" strategy—as opposed to a "showing" strategy relying upon the infant's imitation, or "shoving," which involved pushing his hand around the barrier—characterized the more educated mothers in our Cambridge, Massachusetts sample. (This trend in the data seemed to be confirmed when one mother said, "Now let me see, what would B. F. Skinner do in this situation?") But in a replication study education did not predict this strategy (Barker, 1977). Furthermore, Greenfield and Childs (reported in Bruner, 1969) observed it in Zinacanteco Indian mothers with 1-year-olds and a nesting-cups task, and Poppei (1976) observed a 24-month-old using such a strategy in spontaneously trying to teach an 18-month-old how to operate a cookie dispenser. In both of these cases it seemed that simplifying the task or concentrating on a constituent act was resorted to when the task appeared to be well beyond the skills of the learner. Wood, Bruner, and Ross (1973) found exactly the same thing in an attempt to teach children of 3, 4, and 5 how to put together a complex puzzle. The 3-year-olds elicited far more from the tutor in the way of breaking down the task, whereas with the 5-year-olds the tutor mainly assumed a commenting role.

In other words it occurs naturally to anyone in the role of instructor, when a learner is so far from being able to do a task as not even to be able to recognize its constituents, to isolate those constituents for separate practice. This is accomplished either as a matter of curriculum—as tennis instructors and piano teachers do—or by restructuring the task itself so that the constituents will occur to the learner. With an infant, verbal instruction is of little use, so tasks are often restructured. We give the infant his first walking practice while holding his hand, for example. The leg movements are in his repertoire already (at birth, as a matter of fact, though they disappear for a while), but they need practicing without the added complication of having to worry about balance.

So there is indeed much support for a theory of skill development as proceeding by the practicing and integration of constituents. In Piaget's terms, schemata begin as circular reactions executed for no other purpose than "to make interesting experiences last" (Piaget, 1952). Then they are assimilated to one another and coordinated, and more complex schemata arise with the ability to vary means in the service of some intention with respect to the objective world.

This, however, is only one side of the story. We must also as Piaget does, address the question of where the constituents come from. They come from two directions. The first is quite consistent with the practice-and-integration theory, but the second is almost exactly the opposite: differentiation.

The first source of constituents—the one that is easy to relate to the idea of integration into higher-order skills—is maturation. We mentioned the walking reflex, one of many with which the infant is endowed. Its presence at birth, elicited by holding the infant upright and placing his weight on his feet, merely shows that the coordination necessary for alternate motion of the legs is wired into the nervous system. As the cerebral cortex takes over more and more functions during the first few months of life, the unexercised walking reflex drops out. The coordination reemerges when the infant is able to stand upright toward the end of the first year. We do not know whether the walking reflex serves any function for the newborn (Andre-Thomas & Autgaerden, 1966; Zelazo, Zelazo, & Kolb, 1972) but probably it does not. Probably it is there only as a byproduct of the fact that the lower parts of the nervous system—the parts below the brainstem—are in humans (as in other mammals, reptiles, insects, etc.) prewired for alternate cycling of the limbs. We can use the word *preadapted* for features of behavior, as we do for features of morphology, physiology, etc., that are provided to the growing organisms by evolution. In other words, the adaptation was accomplished by the species over many generations, so that the individual organism does not have to develop this particular feature (e.g. coordination of the limbs in walking) as a result of its own experience.

Other newborn reflexes such as grasping, sucking, and orienting to sounds can all be seen as preadapted constituents for later incorporation into skills for manipulating objects, feeding, locating particular objects, etc. Bruner (1972, 1973) points out that this is an important issue in the evolutionary study of how complex behavior has emerged in primates (see also Schiller, 1952). Elliott and Connolly put the issue in an interesting way:

> An infant's early endeavours to use its hands may be seen as an attempt to acquire mastery of the possibilities permitted by his developing neuromuscular system. The fact that acts of this sort may be defined in terms of structure and movement, or position, does not affect or specify the functions of these abilities once mastered [Elliott & Connolly, 1973, p. 142].

Thus we can account for the emergence of certain constituents of skilled behavior by maturation, but detailing them does not explain how the developing organism combines them as means toward ends. The prevailing view is that the combination of components is made possible when the components are sufficiently practiced to be executable free of attention.

At best, such preadapted behavior can account for only a small proportion of the constituents an infant puts together into his repertoire of schemata. In skills acquired by older children and adults, such as tennis or piano playing, it is hard to conceive of any preadapted constituents being involved at all. They seem to come from the differentiation of other skills.

Differentiation is almost the opposite of integration—except that when parts have been integrated into a whole, the whole can then be differentiated into other parts that may not have existed before. A good biological analogy that Piaget definitely had in mind when he worked out his theory of differentiation and integration of schemata (Piaget, 1951, 1952) is the genesis of an embryo. The blastocyst differentiates into what will become the various organs, and they in turn are later integrated into the systems of the organism. We can imagine the same process occurring repeatedly, in the genesis of an infant's behavioral repertoire. For example, when a 5-month-old reaches for a cylindrical object, cinematography reveals that his hand is adjusted to grasp a cylinder—horizontally, vertically, or obliquely as appropriate—before it reaches the object (Bower, 1974a). Adjustment to the shape of the object is one constituent of reaching in infants of this age. We can see it as an isolated element rather clumsily attached to others: adjusting the height of the hand, gauging distance from the body, anticipating the trajectory of the object if it is moving, etc. Over a period of weeks the infant puts these components together more smoothly. But the adjustment to the shape of the object originated as part of an earlier schema, grasping, which in turn was the integration of several reflexes including the grasping reflex, pronation of the hand, etc. (Twitchell, 1965). The infant had become less clumsy at grasping a wide variety of objects, adjusting his hand to their shape after contact. What we see at 5 months is an anticipatory adjustment, differentiated out from the grasping schema, and now a schema capable of being combined with others.

Differentiation and integration are postulated in Piaget's theory as "invariant functions," which means that they operate throughout the life span and that how they function is not explained. In a P-model of developmental processes, these "functions," like assimilation and accommodation, have the status of boxes whose internal workings are not specified. We can say something about when they occur, but not how. Still, they are powerful ideas that make the development of skills plausible in terms of basic biological processes.

Skill Learning versus Development

At times in the foregoing discussion I have been describing the way skills develop over a relatively short period of time. Yet at times I have been describing the way infants develop over many months. Is there no distinction to be made between the way an organism at a particular age learns a skill, and the way an organism develops from one age period, or "stage," to another?

The answer is that there is indeed a distinction to be made, but it seems less important to psychologists now than it did 10 or 20 years ago. We can think of development in the broader sense as the sum of many developments in the narrower sense—that is, as the growth of many particular skills. A distinction is worth making, however, for two reasons. The first is that the set of skills one has available is bound to affect the acquisition of new skills, often to such an extent that the process of acquisition itself is different. The Eskimo dogs studied by Tinbergen were used as one example earlier in this chapter. We can list several important ways in which existing skills affect learning: in the constituents they provide for recombination; in the mechanisms available for processing information, getting and using feedback from the environment; in the new tasks that are posed because of the organism's current ways of dealing with the world; and in interaction with other persons, especially those who play significant tutorial roles. The acquisition of particular skills that will become subskills in some more complex activity; or particular perceptual, memory, or reasoning skills; or particular new goals; or particular modes of interpersonal interaction, perhaps with particular individuals, are all likely to produce qualitative changes in *how* as well as *what* learning takes place.

The second reason for distinguishing between development in the broader sense and what is more often called *learning*, the development of particular skills, is the possibility of making generalizations about certain age periods with respect to the child's or adolescent's basic agenda, his basic relations to others, and the caliber of the highest intellectual operations of which he seems to be capable. In Piaget's work, for example, we have the sensorimotor period, the preoperational, the concrete-operational, and the formal-operational. The reader is assumed to be familiar with the characteristics of these periods, descriptions that have proved useful as broad generalizations but that have not been of much use in predicting the performance of individuals in non-Piagetian tasks.

In endeavoring to convince a parent to stop at a fast-food restaurant, 4- and 5-year-olds typically display propositional reasoning skills indistinguishable from those which are supposed to define the period of formal operations: "But we were on the way home last time and we stopped there, and it didn't spoil my appetite" (ergo the statement "We're on the way home for dinner" is inadequate justification for the answer "No" to the question "Can we stop at McDonald's?"; ergo the request is still legitimate).

On the other side of the coin, adults (even very intelligent, educated adults) often fail to perform at the formal-operational level when features of a problem make certain incorrect answers appear intuitively (preoperationally) correct (Wason & Johnson-Laird, 1972). Carey (1973) has demonstrated that the cognitive level attributed to a child in a Piagetian conservation task depends largely on the extent to which the task taps his knowledge as opposed to his intuitions, which in turn depends upon the precise form of the task and the questions. With respect to inconsistency, for example, one of the supposed hallmarks of the preoperational period,

> Inconsistency is not a general property of the thinking of a child at a certain age or stage of development. It is task specific. Any child (or adult) would be inconsistent on *some* task which could be devised for him. Such inconsistency is found precisely in those cases where the child or adult knows several things which are relevant to some problem but cannot keep them all straight, or does not know all the relationships between them [Carey, 1973, p. 173].

In short, the formal structures abstracted from performance in particular cognitive tasks usually fail to predict anything about the same individuals' performance in other tasks which ought to require the same logic, or which an individual at the same stage of cognitive development ought to do equally well (Shweder, 1975). P-models of particular skills should do better at prediction only because they are less vague, more specific about situation, features of the task, intentions, etc. Unfortunately, this also makes them less useful as general predictions.

Fischer (1978) has attempted to improve upon the predictiveness of Piaget's progressions from sensorimotor schemata to operational thought by formulating very specific sequences of skills. Each stage, or level, literally incorporates the prior level of skill. To go beyond the very specific tasks that he has studied, Fischer abstracts certain "transformation rules" that provide general predictions about the ways in which more advanced skills will differ, structurally, from their prior forms. However, such predictions are not explanations of the processes by which the skills actually develop. Fischer thus falls heir to the criticisms I have already made of his predecessors: Instead of moving back and forth between P-models and C-models he seems to be proposing a compromise between the two. The danger is that such a theory of skill development may achieve neither the specificity that elucidates actual processes nor the generality that inspires new hypotheses.

Piaget, though responsible for refining the notion of schema from Baldwin (1894), Head (1920), and Bartlett (1932), is also of course the chief proponent of a formal-structural view of development. As the child progresses toward formal operations, Piaget proceeds toward formal models. Vygotsky, on the basis of Piaget's earliest books, criticized him nearly half a century ago:

> He proposes to replace the explanation of phenomena in terms of cause and effect by a genetic analysis in terms of temporal sequence and by the application of a mathematically conceived formula of the functional[2] interdependence of phenomena. . . . This substitution of the functional for the causal interpretation deprives the concept of development of any real content [Vygotsky, *Language and thought*, Cambridge, M.I.T. Press, 1962, pp. 20–21].

More recently, Bruner (in Bruner, Olver, & Greenfield, 1966) has criticized the formalisms of Piaget and likened them to linguistic descriptions:

> Psychological events require explanation in terms of psychological processes and are not fully explicated by

[2]Vygotsky here uses a word translated as "functional" for what I have been calling "formal," and "causal" for what I have called "functional"; his meaning, however, is clear.

translation into sociological, physiological, evolutionary, linguistic, or logical terms. Cognitive growth is a series of psychological events. A child does not perform a certain act in a certain way at a certain age *because* the culture he lives in exhibits a certain pattern, *because* it is inherent in the evolution of primates that vision is a dominant sense, *because* his language has or does not have an easy or an obligatory way of making a significant distinction, or *because* the child's act exhibits a certain underlying logical structure. Nor, obviously does it suffice to explain any aspect of human growth to say merely that "this is typical of the five-year-old."

Such final causes, formal causes, material causes, and historical causes are all interesting and challenging to the psychologist who seeks to understand the growth of mind. But for him they must remain insufficient. For what is needed for a psychological explanation is a psychological theory. *How* does a culture in which a child lives affect his way of looking at the world? Does the dominance of visual and auditory cues in early life (primate in origin though they may be) operate by a channeling of attention, by selectivity of memory, or how? Why do *some* linguistically available distinctions *not* affect thought; for example, the obligatory masculine–feminine distinction in the nouns of some but not all Indo-European languages? If a syntactical distinction is reflected in thought, how does it achieve this status? Finally, are we any nearer an *explanation* of a child's solution to presuppose some kind of grasp of the principle of logical implication? [Bruner, J., Olver, R., and Greenfield, P., *Studies in cognitive growth*, New York, Wiley, 1966, p. 3].

This provoked a response from Piaget:

We should mention the fact that, especially in America, our kind of structuralism is not unanimously endorsed. J. Bruner, for example, does not believe in "structures" or in "operations"; in his view, these are constructs ridden with "logicism" which do not render the psychological facts in and of themselves. He does credit the subject with cognitive acts and "strategies" (in the sense of von Neumann's theory of games). But why, then, assume that such acts cannot become internalized and thereby turned into "operations"? And why must the subject's strategies remain isolated instead of becoming integrated into systems? [Piaget, J., *Structuralism*. (translated and edited by Chaninah Maschler © 1970 by Basic Books, Inc., Publishers, New York, p. 70.) Originally published in French as *Le Structuralism* © 1968 by Presses Universitaires de France, Paris].

"Operations" certainly are "internalized" in the sense that acts are brought under unconscious control, and strategies certainly are integrated into systems. Bruner would not disagree, and that is obviously the main point of this chapter. However, in moving beyond the learning of particular skills to the broader level we call development, it is not necessary to move exclusively to formal representations, to ignore the temporal structure of action in favor of the logical. An important set of considerations must be reintroduced whenever we wish to explain development.

So, whilst we have in the past decades learned much about the *structure* of language, we have perhaps overlooked important considerations about its functions. Our oversight has, I think, turned our attention away from how language is used. And since the uses of language are, I believe, crucial to an understanding of how language is acquired, how it is *initially* used, the study of language acquisition has been distorted. That distortion has, of course, been in the direction of a preoccupation with syntax, an emphasis on the changing structure of language. It is a preoccupation whose results have hopefully purged us of simpleminded accounts of language acquisition as a gradual process of storing up reinforcements or associations or imitations. But language is acquired as an instrument for regulating joint activity and joint attention. Indeed, its very structure reflects these functions and its acquisition is saturated with them [Bruner, J. S., The ontogenesis of speech acts, *Journal of Child Language*, 1975, *2*(1): 1–2].

Differentiation and Integration as Conflicting Forces

Since differentiation and integration are more or less opposite functions, it would not be surprising to find that they are a source of disequilibrium in the system. In my reading of Piaget the conflict between these two forces, even better than that between assimilation and accommodation, accounts for what propels the organism forward like a sailboat pressed between sea and wind.

All open systems tend toward integration, which reduces the information load or (in a different model) conserves energy. Thus we can see the tendency of skill systems toward smoothing, simplicity, freedom from attention, etc. as an instance of a very general intrinsic property of all open systems. The fact that we are biological systems makes us tend to integrate the components of our skills. Assimilation of objects to existing schemata is one form of integration.

Uzgiris (1978) points out that the question of "familiarity" versus "novelty" of objects in the infant's world is really a question of how differentiated his schemata are. When a schema is relatively undifferentiated, as the reaching schema is at age 3 months, there is practically no such thing as a novel object: All are treated alike once they come within arm's length. A year later, when reaching, grasping, and manipulating schemata are highly differentiated, almost any object may be novel, provoking cautious and deliberate exploration. Many toddlers develop what appear to be obsessions with the hubcaps or taillights of parked cars, with kitchen utensils, toys with wheels, etc. All these phenomena may be conceived in terms of the transfer of skills. As they transfer to new objects, the skills are pressed to differentiate (through accommodation to some of the features of those objects), but the system also tends intrinsically toward assimilation. Assimilating the new objects to existing schemata broadens the class of objects to which those schemata then apply, thereby broadening the schemata's ability to transfer. Transfer is a matter of assimilation.

An open system becomes more complex—differentiates—only in response to the environment with which it has to deal. Skills differentiate when they are inadequate to deal with unavoidable distinctions in the real world: hard versus soft foods, heavy versus light objects, male versus female tennis opponents. Such differentiations are only necessary when a certain level of competence in skills is reached. This is why we say that cognitive development is always a matter of equilibration; a relative equilibrium is attained only briefly before a new disequilibrium arises.

These generalizations about differentiation and integration are supported by an observation that has been made frequently. It takes various forms in the cognitive development literature, being expressed most recently and cogently by Bower (1974b, 1976). He points out that many developmental transitions are repeated in very specific ways over the course of the life span. The infant learns conservation of weight—the expectancy that something will weigh the same when transformed in shape but will weigh less when reduced in size, etc.—at the sensorimotor level, in expectancies that can be revealed by the force with which he takes hold of objects. He later takes several years to acquire essentially the same knowledge on the level of verbalized predictions. There are many other examples, some involving simply the repetition of a transition on a higher level (what Piaget calls vertical *decalage*) and some involving actual regression to what looks like a lower level.

Children learning English usually produce their first verb forms without inflections (*go* for *go* or *goes* or *going* or *went*, etc.) and then learn the proper inflections. Among the words whose inflections are learned first are the irregular verbs like *go*, *eat*, and *see*. These words and their past tenses, etc. are obviously very frequent in the language spoken to as well as by children, so it is not surprising that they should be learned first. What is surprising is that after using them correctly for 2 or 3 years, all children begin saying *goed*, *eated*, *seed*. Even after a child has stopped saying *bringed*, he may insist on *brang* instead of *brought* well into the school years. (In fact, many such overregularizations have come into the dialect in some places, and thus become the "correct" adult usage that children hear; and those children never reinvent *brought*.)

The phenomenon of overregulatization is an example of integration: It makes the linguistic skills simpler and more consistent, and is a definite cognitive advance over the period in which each verb's past tense was learned as a separate item of knowledge. The problem is that the child continues to be exposed to people who use the irregular endings. Even if they never correct him, he still has to know the irregular endings to decode their speech. Integrating the language he comprehends with the language he produces forces him to differentiate the latter. Integration, then, is an intrinsic function, whereas differentiation is more externally motivated.

IMITATION

The most important mode of interaction with the world, from the point of view of differentiation and integration of skills, is imitation. There are very few skills in whose development imitation does not play a major role, and there are many skills that develop entirely by imitation. Such a bold claim requires a broad definition of imitation: any process in which the form of an act is guided by comparison with an observed, similar act. We say that imitation plays a relatively smaller role in the development of a skill to the extent that other sources of information are also involved. It is hard to conceive of any skill—even ones whose development is largely a matter of practice, like typing—in which at least the basic instruction is not a matter of being "shown how." Our definition includes, of course, learning from verbal models as well as visual ones ("Place the baby on his back so that his legs are facing you; holding one hand on the diaper, unfasten the pins"), since comparison with a model is still involved and only the method of observation differs.

Imitation is itself a skill or set of skills, undergoing its own development, about which there is much controversy (Kaye & Marcus, 1978; Meltzoff & Moore, 1977; Piaget, 1951). Here, however, we shall be concerned only with its role in the differentiation and integration of other skills. We can think of imitative skills as programs for updating other programs, for modifying one's own skills when necessary to make their products (sentences, paintings, observable acts, etc.) match those of others. This has two important implications. First, the match is never perfect; it is always a matter of how similar one wants the match to be, and in what ways, as well as how similar one can make it. Second, every act of imitation is at the same time an act from one's repertoire of existing skills, an accommodation to a model, and a creative act. We are never zombie-like slaves of the model, though if the model is extremely skilled we may occasionally wish we could be. As a knowledgeable student of painting can see both the master and the pupil in a work from Rubens's school, so we should in principle be able to identify features of an imitated act that are due to the imitator as well as those due to the model.

It is possible to imitate without making any change in one's own skills if the features of the model one wants to match can be assimilated to one's repertoire of schemata. The match will always be an imperfect one. Whether the act of imitating has any effect upon one's future actions—that is, upon the development of skills—depends largely on the extent to which one is satisfied or dissatisfied with the degree of match obtained by immediate assimilation. When a subject assimilates a model to existing schemata and merely reproduces the model in some degree, we call this imitation but not accommodation. The latter term is reserved for the change in schemata that can take place as a result of imitation but does not necessarily occur. (In fact there is also an issue as to when accommodations are only temporary and when they are more long-lasting, but this issue has barely been explored by psychologists.)

When accommodation does take place, it may involve differentiation of existing schemata, or integration, or both. Accommodation by integration occurs when the subject recognizes (assimilates) components of the model in a way that he has never combined them before. Dancers, ice skaters, musicians, and others who have mastered what we call the "rudiments" of a skill (or, if you prefer, an art) can copy complex strings of steps, turns, or chord progressions and add them to their repertoire. The integration process goes slowly or quickly depending on the complexity and novelty of the sequence, the ease of assimilation of the components, and whether the imitator must consciously label each of the parts (e.g., "ball–toe, ball–toe, flap, shuffle") or has them so well internalized that the sequence can be imitated immediately as one unit. In the latter case, integration begins with the first trial but still continues as the sequence is improved with practice.

Imitation does not always proceed by putting together recognized features of a model. It would be of much less importance if it did. It often happens, instead, that the imitator reproduces the whole model, matching it rather poorly, and then proceeds over many trials (either alternating with presentations of the model, or preserving some representation of it in memory) to differentiate the salient features. Young children learning their first language, and people of all ages learning a second language, repeat whole phrases and sentences that are only partly intelligible to them. From the point of view of their matching a phonetic sequence, they are stringing together those sounds that they are able to assimilate to the set of phone-schemata in their own repertoires. From the point of view of morphemes, however, they gradually differentiate over many imitations of a phrase and of similar phrases. The learner has the task of working out what the distinctive features of the models are. How long does a naive French-speaker, for example, comprehend and use correctly the phrase *n'est ce pas?* before differentiating its components, in terms of his linguistic skills, so that he can then say *ils ne sont pas*, etc? I can remember, at the age of 4 or 5, long after I had learned to say the alphabet, my surprise at discovering that "ellemenno" was not one letter between K and P but actually four letters.

A Choice, Not an Echo

In the foregoing overview of the topic of imitation I have merely touched upon many issues that deserve fuller treatment than there is space for here and fuller investigation than has yet been accorded them.[3] One point should be emphasized above all because it challenges the way we conceptualize skills: Those features of the model that are imitated on a given trial and affect the differentiation of schemata over a number of imitations are a matter of active choice. At some unconscious level the imitator is always making a decision of this kind: "I am going to try to match these features of what X is doing and not those." Such a decision is revealed in the fact that the match is never perfect, always an extension from the subject's existing schemata in a direction toward the model. There are many ways the attempt at imitation could be similar to the model. What determines the dimensions on which the imitator tries to produce a match and the dimensions on which the model is merely assimilated to existing schemata?

Whatever factors are involved in these decisions can be divided into two categories: those due to the model and those due to the subject. The former category would include physical properties of the model such as sound and movements; the salience of various features in terms of duration, proximity to the subject's focus of attention, etc.; the way parts of the model are segmented from one another in space and time; even the order with which a particular constituent appears in the sequence (which affects memory). These factors, however, are insufficient to account for the way an imitator accommodates his attempts to certain features of a model and persistently ignores others even when they are emphasized. Take this excerpt from a mother's attempt to get her 30-month-old child to imitate a particular sentence, in one of our current studies:

DAY 1

M: In the chairs there were three bears.
In the chairs there were three bears.
C: In the chair bears.
In the chair bears.
M: (laughs) Now I'll say it one more time, okay?
C: Okay.
M: In the chairs there were three bears.
Now you say it one more time.
C: Okay. Chair the bears in the chairs.

DAY 2

M: In the chairs there were three bears.
C: In the (unintelligible)
M: In the chairs there were three bears.
C: In the chairs three bears.
M: All right, I'll say it one more time.
C: Okay.
M: In the chairs there were three bears.
C: In the chairs three bears.
M: Okay.
C: Okay.

DAY 3

M: In the chairs there were three bears.
In the chairs there were three bears.
C: In the chairs there freeze bears.
M: In the chairs *there were* three bears.
C: (unintelligible)
M: Are you going to say it again?
C: Yeah. In the chairs there three bears.
M: Okay.

DAY 4

M: In the chairs there were three bears.
C: In the chairs there three bearrr-bers.

[3]Imitation is discussed by every comprehensive theory in psychology, yet remarkably little empirical research has been devoted to it and virtually all the major questions regarding *how* remain unresolved. Most investigators have concerned themselves only with *when*.

M: In the chairs *there were* three bears.
C: In the chairs *there three* beaaa-bears.

DAY 5

M: In the chairs there were three bears.
In the chairs there were three bears.
C: I want mine books.
•
•
•
M: Are you going to say this?
I'm going to say the sentence once more.
C: Okay. You.
M: Okay. In the chairs there were three bears.
C: In the chairs there three bears.
You say that.

DAY 6

M: In the chairs there were three bears.
C: In the, in the chairs there three beaaarrs.
M: In the chairs *there were* three bears.
C: In the chairs *there* three bears.

DAY 7

M: In the chairs there were three bears.
In the chairs there were three bears.
C: Yeee. Bachoo, bachoo. (pounding)
•
•
•
M: Do you want to say the sentence?
C: Yeeees.
M: Then say it.
C: (laughs) Okay. In the chairs there three bears.
M: In the chairs there were three bears.
C: In the chairs there three bears.
M: Okay.

We all know individuals who learned English as adolescents or adults, became fluent enough to think in English and even write it better than we natives do, and yet never lost their heavy accents. Usually we can identify their native language phonetically in their spoken English, even perhaps tell whether they came from Germany or Austria, Spain or Mexico, Paris or *les provinces*. Perhaps the most remarkable thing about such people is that they themselves usually have great difficulty hearing the difference between their pronunciation and ours:

FLUENT BILINGUAL: Put it zere.
RUDE AMERICAN: You mean there.
FLUENT BILINGUAL: Yeh, zere.
RUDE AMERICAN: *Th*-ere
FLUENT BILINGUAL: Zz-ere
RUDE AMERICAN: *Th*-ere
FLUENT BILINGUAL: Zat's what I said, zere.

The person with the accent here is not being stubborn, any more than the child quoted above was. Both persist with some features and are quite willing to accommodate others, depending upon some factor having to do with the relative status of the various schemata in their repertoire. Phonemic systems are learned very early (beginning in babbling at around 4 months), and though they are malleable until some time in adolescence, they become more and more difficult to change. In terms of the practicing of subroutines until they require less and less attention, it seems that phonetics moves into a realm where it requires so little attention that most of us find it impossible to attend to it at all. To be able to do so is to have developed a special skill for mimicry—or, we might say, to have preserved that special skill infants have which most of us lose.

It is not stretching the point to say that the degree to which a schema has moved into this less accessible realm is a matter of confidence, a kind of weighting attached to each of the schemata in our repertoire. Some are more, some less ready to be modified in imitation of a model. Furthermore, the confidence-status of particular schemata is subject to change. The child who refused to say "there were" will not always do so; his doing so in that particular week was due to an agenda, a readiness to begin differentiating some aspects of syntax but not others. The whole course of language development reflects this phenomenon, which is really a characteristic of skill development in general.

Thus the active selection process that we see in imitation, the decision in imitating a whole act to accommodate to some features of it and not to accommodate to others, reveals something about skills. A truly complete P-model of a skill would specify for each of its components how confident the subject is of it, how willing he is to alter it and under what conditions or in what directions.

Instruction

An important implication of the fact that imitation involves active decisions and creative differentiation and integration of schemata is that it makes instruction possible. If instructors had to do the whole task of analyzing a skill into all of its constituents and analyzing the learner's complement of relevant existing schemata, then providing feedback as to how each trial came closer or missed significant features of the desired behavior, our repertoires would be limited indeed. That is what animal trainers in the circus do, and we marvel at their patience when they succeed in teaching a single elephant to stand on its head. The reason such feats are remarkable in an elephant—but less so in a chimpanzee, and quite routine in a human—is just that the information processed by the elephant in the course of learning is limited to the instructor's reinforcement of particular acts at particular times. An animal that imitates can be taught much more, even when the instructor does not really understand (as we do not, yet) exactly how the learning takes place.

When our tennis player, for example, takes a lesson to improve her serve, she is the one who is going to be doing most of the analysis (and not at a conscious level, or only partly so) of the discrepancies between her serve and the instructor's and between the feel of the serves that send the ball where she intends it to go and those that do not. The instructor stands outside the learning process itself, trying to facilitate it but mostly watching for something to "click" inside the learner. Nothing "clicks" inside elephants.

What then is the instructor's role, and why are some more effective than others? Four functions are worth mentioning. The first is that of providing extrinsic motivation. However, what motivates human learners and keeps them driving toward greater competence is somewhat more complex than the loaf of bread tossed into the elephant's mouth immediately after each headstand. And the means by which our motivation is achieved and maintained probably have little to do with the actual processes by which we differentiate our skills once motivated to do so. Furthermore, the internalization of a motive to improve our skills—to seek competence—is not just a general drive maintaining our arousal but must somehow be related to the confidence weightings for particular features of our skills, discussed above. That is, the decisions as to which features to accommodate and which to ignore for the moment are an aspect of motivation for which the learner may be more responsible than the instructor.

The second function of an instructor is curriculum—knowing an order of acquisition that has been found to be effective with other learners. The curriculum will include subroutines to be mastered to some level of proficiency before being integrated. A juggler teaches his pupil to toss one ball from hand to hand until he can control its height and path before going on to two balls. Similarly a language curriculum includes exercises in verb conjugation, a fledgling programmer learns to write simple "DO" loops, etc. A curriculum will also introduce wholes, however, for subsequent differentiation. Beginning tennis players play what passes for tennis, chess players play games of chess, and language learners communicate in sentences. The instructor has to know which aspects of the learner's crudeness should be ignored at first and which aspects should be differentiated. There are also skills introduced into the curriculum that will later be replaced completely, like the "snowplow" turn many skiers are taught in their first lesson. These skills put the learner in a position to learn the real skills that are the ultimate goal. It was easier, for example (before the invention of short skis), to introduce a parallel turn as a variation of the snowplow than to introduce it right from the start. Much controversy about elementary school curriculum has to do with the utility of various "false starts" of that kind: for example, whether children should begin reading phonetic transcriptions before moving on to the ordinary alphabet, which provides fewer cues for English pronunciation.

Since questions about the effectiveness of all such methods are largely empirical questions based on the experience of many learners, instructors usually follow a curriculum provided for them rather than custom-designing one. There are, however, alternatives that can be followed for different learners, so some degree of diagnostic skill is useful to the instructor even in the area of curriculum.

The question of order of acquisition is closely tied to that of motivation, and makes the latter a more complex matter. Curriculum can be thought of as selective motivation for particular exercises. One of the tasks of an instructor is to balance a pupil's interest in the activity as a whole with his interest in perfecting particular subskills. In principle, it might be better for children learning figure skating to practice school figures for years while their bodies develop before they attempt jumps. Nonetheless, their teachers allow them to work on jumps and even to put together "numbers" they can perform to music. A tennis instructor shows his pupils the new backhand grip made famous by So-and-so even though it is not really appropriate for their level of mastery. Examples are not limited to sports: Piano teachers hold recitals with 8-year-old performers, and elementary school pupils produce a newspaper though they can hardly write sentences. These are obviously instances of letting skills be practiced as wholes for subsequent differentiation. They are also important for other reasons having to do with fantasy, imitation of role models, and self-concept. Along with the development of skills themselves—the motor processes—goes the development of one's conception of oneself as possessing the skill. Certainly these two developments progress together, and I am not sure they are separable.

A third function of an instructor is to highlight significant features of skilled performance. What is significant for a particular learner at a particular time is a matter of curriculum, but that is only part of what the instructor needs to know. He also must diagnose the learner's performance to judge what the most important inadequate features are, and then must make those features more salient to the learner (both in the models provided and in the learner's behavior). Again, the most difficult analyses and corrections are made by the learner himself; but the instructor influences which part of the skill those processes will focus upon.

Diagnosis of a learner's problems by an instructor is similar to a psychologist's construction of a P-model. It is a matter of inference from the external results, not even the actions but the *products* of the actions (the music, the flight of the ball, the visual appearance created by the dancer), to the underlying skills that produced them. The instructor, of course, does not go so far as to diagram a skill completely, but the more specific he can be about the underlying cause of a problem, the more effective the learner can be in correcting it. This task is difficult even when the features in need of highlighting correspond directly to the features of the product that the instructor sees as problematic—that is, even when the problem is directly apparent. A ski instructor knows, for example, that one's downhill shoulder should never turn in toward the mountain. This is a problem most beginners have, which can be seen at a glance and highlighted both by pointing it out to the learner at the moment he does it and by giving exaggerated demonstrations of the correct and incorrect postures. It is just one example of a basic pattern of interaction occurring between instructor and imitator in every domain of skill (the examples from language development presented above show that highlighting a feature does not necessarily lead to its imitation, however).

The task becomes much more difficult when the instructor perceives that something is wrong with a performance but cannot directly observe its cause. An example comes from some observations I was fortunate to make of a virtuoso violinist giving lessons. One of his fairly advanced students played a page of Bach and he stopped her. This was supposed to be a dance; she was playing it like church music. (This meant she had been practicing it wrong for a month.) She began again, and he stopped her after a few measures. He played those measures and gave them a very different sound. She imitated. To my ignorant ear she seemed to have moved about half the distance from the way she had been playing it to the way he had played it. The differences, of course, were subtle, having something to do with the way notes faded into one another within each phrase. The teacher was still dissatisfied. He played the passage again—no more than 10 notes in all—and then he played it as she had played it. This was, to me, an uncanny imitation—naturally a better imitation of her than she could do of him—and a little unfair. I could imagine how she must envy him just then, as I have hated and admired a good many ski instructors for doing just the same thing.

He asked her if she could hear the difference and she nodded, tried again, but sounded much more like his imitation of her than his model of what Bach presumably intended. Suddenly he shouted, "Aha! Your elbow!" He imitated her again, this time parodying her posture (and grossly exaggerating its awkwardness). He told her that her elbow was moving too much, that she was trying to use her whole arm to phrase the notes instead of just her wrist. He began highlighting his movements, not just the sounds they produced, though he managed to make the passage sound beautiful when he showed her what she ought to do and ridiculous when he exaggerated her arm movements. It should be pointed out that this student was no beginner. Playing an easier piece, she would no doubt have used her arm mainly to draw the bow across and her wrist for the nuances of phrasing. The difficulty of this piece, perhaps combined with the tension of the lesson, had led her to revert to a bowing style that, I gathered, was either wrong for this piece or wrong for her. It had taken the teacher a while to figure out what she was doing that produced the sound he did not like.

This example of highlighting leads to the fourth function of an instructor, and our final consideration with respect to the development of human skills. The instructor sometimes goes beyond highlighting features of skilled performance to what we might call consciousness-raising: actually focusing the learner's conscious attention upon components of the skill. This promises to be a very difficult area for research on instruction because we cannot say that consciousness in relation to skills is always a good thing. We do not know how consciousness of what we are doing might help—or when it might hurt. Sometimes, in fact, instructors try to get their pupils to attend to some feature of their performance only in order to take their attention away from some other aspect of the skill. A ski instructor confided in me that he was making his class concentrate on planting their poles (long before they had progressed to the kind of skiing where pole plants matter) and to shout out "right pole," "left pole," etc. so that they would pay less attention to their legs and hips and let their turning develop naturally.

Even when we assume consciousness of some actions is important, it is not clear how the consciousness relates to the skill. Consciousness is itself behavior, a matter of active reconstruction and manipulation of images and symbols—in short, consciousness itself represents a set of skills. Piaget (1976) and other authors (e.g., Polanyi, 1958) have shown the extent to which our consciousness of our own actions depends upon additional processes such as logical inference that have nothing to do with the skills actually involved in those actions. We simply cannot describe very well how we do most of the things we do, which suggests that the verbal mode and consciousness in general would be of limited value in guiding the development of skills.

This means that there is another model to be considered, besides the psychologist's P-model of a skill, which is itself only an ideal. The other model is the subject's own model of what he is doing, accessible to consciousness. This model can be referred to under some conditions (but we know little about what those conditions are) and unquestionably affects the way skills develop as well as the way learners interact with instructors. It is probably also true that the subject's model is as much a product of the underlying skill as it is a cause of it. The model is a product also of the nature of symbolic thought and of verbal discourse, and that is part of the reason the development of skills in our species is so challenging to contemplate.

The Role of the Other

Social relations are at the very root of skills. So far I have touched on two different ways in which this is true. I would like to end by reiterating them and adding a third.

First, social processes including imitation and instruction are responsible for the ways skills develop. It is certainly true that the most complex analyses and corrections of the various components of a person's skills are performed by the person himself, by mechanisms about which we know so little that they appear miraculous. Nonetheless, these processes always occur in a context provided by the social group and by particular "significant others." To some extent and for some skills it is an instructional context provided intentionally and consciously. In other situations it is more a matter of the subject's imitating and internalizing the behavior of others. Finally there is learning that occurs without a model but as an adaptation to contingencies existing within a culture and a family.

We often think of skills as characteristics of human behavior, and then wonder how it is that they could possibly be acquired. They seem so complex that it is easier to imagine them being provided by evolution than by rapid adaptation of an individual organism's schemata within a short period of time. We look at the complexity of a language like English (let alone Chinese) and find it incredible that mere 1–3-year-olds can learn it. I have argued elsewhere, however, that natural languages are just those which happen to be very easy to learn given the developmental processes with which evolution has supplied us (Kaye, 1978b). Only those natural languages could have survived which happened to lend themselves to acquisition by 1–3-year-olds.

The same principle holds for skills in general. The vast set of skills, arts, knowledge of all kinds that gets passed from one generation to the next is subject to the limitation of what can be learned and taught through social processes. Thus developmental and social processes constrain the nature of skills themselves. We should say that the evolution of skills, of human anatomy, of the brain, and of social systems all must have proceeded hand in hand.

The second way in which skills are inherently social follows directly from the first. It is simply that our ways of communicating with ourselves about our skills—indeed that whole realm of skills which we call "thought"—is very closely parallel if not identical to the discourse we hold with others. To the extent that conscious thought is involved in skilled behavior and in the development of skills, the symbol systems, rules of inference, and affective tokens we have learned to use in our exchanges with others are applied to discourse with ourselves (Mead, 1934).

Finally, many of our skills are basically social skills, ways of dealing with others. Playing a game, expressing one's needs, exchanging resources, answering questions, even something as simple as walking down the street without bumping into one's fellow pedestrians all require knowledge of others' roles and of their expectable behavior under various circumstances. Many of these skills are acquired in the context of a dyad (parent–child, child–child, teacher–child, employee–supervisor) or a larger social group. Initially the skill consists of knowing one's own role and the partner's role, with respect to a particular partner. Skills transfer, however, from the dyadic interaction system in which they are originally learned to interaction with other individuals. To some extent we learn many differentiated skills for dealing with the different individuals and the different social situations in our lives. At the same time, there are continuities and similarities in the behavior of an individual person across a variety of situations and in interaction with many different people. "Personality" can be viewed as nothing other than this sort of transfer of skills out of the social dyads, families, or other interaction systems in which they are originally developed, into new social situations. Thus although this chapter has been confined to some basic points about skills and their development, concentrating upon issues in the field of cognitive development, an expanded psychology of human skills would legitimately deal (indeed, should be required to deal) with many issues traditionally relegated to social psychology, personality, psychometrics, and educational psychology.

CONCLUSION

Cognitive psychologists most typically look for the explanation of transition from one stage to the next in the structures they have chosen to represent those stages. Although the formal structures most often used to represent behavioral systems may very well be adequate models for a theory of how those systems behave at some period in their development, it does not follow that changes from one model to the next will constitute an adequate model for a theory of developmental processes. In particular, where the models are atemporal, dealing with the properties any system would have to have in order to behave as the observed system does, but without regard for real-time processes, such models can never supply a sufficient explanation for the changes from one stage to the next. This is because the models are not the things that develop.

The formal laws of development cannot be inferred from the formal structure of action at two or more stages; rather, they come from a functional or performance model of developmental processes, which in turn can be drawn from the functional models of action at different stages.

Deriving specific functional models turns out to be an extraordinarily difficult task, and one risks losing the generality that gives models their significance. We can think about skills in functional terms, however, without completely specifying their constituents. When we do so it becomes easier to think about learning and development, the ways skills change in the course of experience.

Discussion in these terms also forces us to conceptualize skills as having affective components. Something in each constituent of the skill has to do with the subject's confidence in that feature. It affects a decision as to the extent to which that feature will accommodate to a model or be modified by reinforcement. The implication of this notion is that the cognitive aspect of skills cannot be separated from the affective. This is consistent with everything we know about information processing in open systems whose actions and whose development are both guided by intention and by feedback of various kinds.

A final result of discussing skills in terms of functional or process models is that we appreciate their inherent social nature. Skills come, on the whole, from social relations. They continue to reflect those origins in the ways we communicate with ourselves about our skills, but the relation between consciousness and skill is only beginning to be explored by psychologists. It is clear that we can accurately model our own skills to some extent, but we often delude ourselves when we try to do so. This has implications for the psychologist who hopes to understand the systematic nature of human behavior, for the instructor who hopes to improve it, and for each of us as we endeavor to become more skilled.

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