CHAPTER 1

Problems of Equilibration*

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The title "Equilibration" refers to one factor that I think is essential in cognitive development. In order to understand the role of this factor, we must relate it to the classical factors that have always been understood to be pertinent in cognitive development. There are three such classical factors: the influences of the physical environment, the external experience of objects; innateness, the hereditary program; and social transmission, the effects of social influences. It is clear that all three are important in cognitive development. I will begin by discussing them separately. But as we discuss them, I think we will see that no one of the three is sufficient in itself. Each one of them implies a fundamental factor of equilibration, upon which I shall place special emphasis.

I will start by discussing the role of physical experience. It is clear that this is indispensable in cognitive development. There can be no development without contact with physical objects, that is, contact with the physical environment. In terms of classical empiricism, the role of acquired experience simply amounts to perceptions that we draw from objects and associations among perceptions. As I see it, there never can be pure association in the classical sense in which the empiricists mean it. The manner of linkage that always intervenes in the whirlpool of associations is in reality an assimilation in the biological sense of the term, an integration of external data into the structures of the subject.

Any action on the part of a subject gives rise to schemes of assimilation. That is, an object can be taken into certain schemes through the actions that are carried out on it; each of these schemes of assimilation goes hand in hand and with an aspect of accommodation of the schemes to the situation. Thus, when a subject takes cognizance of or relates to an object, there is a pair of processes

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going on. It is not just straight association. There is a bipolarity, in which the subject is assimilating the object into his schemes and at the same time accommodating his schemes to the special characteristics of the object. And in this bipolarity and sharing of processes, there is already a factor of equilibration between assimilation and accommodation.

Assimilation is a form of integration. It presupposes an instrument by which the data can be assimilated into the structures of the subject. An excellent example of assimilation as integration is the notion of horizontality of the level of water. Children see water in various forms every day. They see water in glasses from which they drink; they see water in bottles that they tip. Moreover, they see water running in bathtubs and lakes and rivers. In all cases, the water is horizontal. So the notion that water is horizontal should be a basic permanent notion. It even seems to assert itself in a more primitive manner as the child's own body is bound to positions where horizontality or verticality intervene. He can tell whether he is standing up or whether he is lying down; he is aware of the sensoritonic attitudes. You would expect this postural awareness to give him the understanding necessary to realize that water is always horizontal.

In some research we did many years ago, we asked the child to predict what would happen to the water inside a bottle if we tipped it. The child was unable to see the water inside the bottle because it was covered. He was asked to draw a picture of the water inside the bottle when it was tipped. The average age at which children could answer this correctly and draw a horizontal line was about 9 years of age. I say average age because, of course, some children advance more rapidly than others. Moreover, the populations we studied were from an impoverished area of Geneva, and it is possible that in more highly civilized regions the age is younger. However, in Geneva the average child is 9–10 years of age before he can predict where the water will be in the covered container when it is tipped. Before that, he always draws the line parallel to the bottom of the bottle as it is when the bottle is upright. Then there are various intermediary stages between drawing a parallel and drawing a horizontal line. This seems to be quite strong evidence of the fact that seeing is not enough, because children have been seeing this phenomenon all their lives. But within the experiment, we even gave the children a chance to see by taking the cover off the bottle. If the child had drawn the water parallel to the bottom of the bottle, when we uncovered and tipped the bottle and the child compared the bottle with his drawing, he would say, "Yes, that's just the way I drew it. Just like my drawing." He doesn't even seem to be able to see that the line is horizontal.

Why is the child unable to see that the line of water is horizontal? The reason for this is that he does not possess the necessary instruments of assimilation. He hasn't yet developed the system of coordinates that will enable him to put the water into a frame of reference with points outside the bottle, such as the table top or the floor. As adults, we operate with a coordinate spatial system of verticality and horizontality at all times. The child doesn't have the framework that enables him to make the extrafigural comparison needed to go outside the framework of the bottle. He reasons only by an intrafigural frame of reference until about the age of 9, when these systems of coordinates are being built. He remains inside the framework of the bottle; his only points of reference are the base of the bottle, which results in his drawing the water parallel to the base or sometimes to the corners of the bottle. He may draw a line from one corner to another that is slightly tipped, but it is still not considered horizontal. His frame of reference remains the bottle itself.

This seems to me a very striking example of the complexity of the act of assimilation, which always supposes instruments of integration. A well-developed structure within the subject is needed in order for him to take in the data that are outside. Assimilation is clearly not a matter of passively registering what is going on around us. This leads to the critical examination of the famous stimulus–response scheme, the classical model of behaviorism.

It is true, of course, that stimuli give rise to responses. However, this only raises much more basic, more preliminary questions. Why does a given stimulus give rise to a certain response? When is an organism sensitive to a particular stimulus? The very same organism may at one time not be sensitive to a particular stimulus and not give any response to it and then later be sensitive to the stimulus and respond to certain stimuli, whereas other organisms may not. Therefore, the fundamental question is: What makes an organism respond to a certain stimulus?

The organism is sensitive to a given stimulus only when it possesses a certain competence. I am borrowing this word from embryology in the sense in which Waddington has used it. He has referred to the influence of an inductor. Waddington has shown that an inductor that modifies the structure of the embryo does not act in the same way at all levels of development. If the inductor is present before the embryo has the competence to respond to it, the inductor has no effect at all; thus, it does not modify the structure. The embryo must be at a point of being competent to respond to the inductor before the inductor can have its effect.

The phenomenon is the same in cognition. Stimulus–response is not a one-way road, a unilateral scheme. A subject is sensitive to a stimulus only when he possesses a scheme that permits the capacity for response, and this capacity for response supposes a scheme of assimilation. We again have to create an equilibrium between assimilation, on the one hand, and accommodation to a given or an external stimulus, on the other hand. The stimulus–response scheme must be understood as reciprocal. The stimulus unleashes the response, and the possibility of the response is necessary for the sensitivity to the stimulus. The relationship can also be described as circular, which again poses the problem of equilibrium, an equilibrium between external information serving as the stimulus and the subject's schemes or the internal structure of his activities.

I would like to make two final points concerning the role of the physical environment. I will first discuss the development of the notion of conservation. As you know, if one transforms a ball of clay into a sausage shape, the young child will tell you that there is more clay in the sausage than in the ball because the sausage is longer. Second, even though no clay was added and no clay was taken away, the child believes that the sausage shape and the ball will weigh differently. The child will also say that one would displace more water in a vessel than the other, indicating different volumes in the ball and the sausage shapes. These notions of conservation are acquired in a certain order: first, the conservation of the substance, that is the quantity of material; next, with quite a notable time-lag, the conservation of weight; finally, the conservation of volume, in the sense one can evaluate volume by the displacement of the level of water. What strikes me as very interesting is that the conservation of the amount of clay—the conservation of the substance—is the first concept of conservation that a child attains. But it is clear that conservation of substance—that is, the amount of clay—is not observable. The child can observe the size of the clay, perceive its volume, and lift it to sense its weight, yet he believes they have changed. And yet somehow he believes that the amount of clay has remained the same even though it is not observable or clearly measurable.

It is, it seems to me, very important that conservation of substance can only be the product of reasoning. It is not a product of perception. The child has simply become aware that something must be conserved when things are transformed in order to make the process of rational thought at all possible. So the scheme of the conservation of the amount of clay imposes itself on the child for rational rather than for perceptual reasons.

Finally, I would like to distinguish between two kinds or experience in connection with the factor of external experience. Classical empiricists assume there is only physical experience. In physical experience, information is drawn from the objects themselves. For example, you can have various objects and see that they differ in weight. But there is a different kind of experience that plays a necessary role at the preoperational level. I will call this *logicomathematical experience.* In logicomathematical experience, the information is drawn not from the object but from the subject's actions and from the subject's coordination of his own actions, that is, the operations that the subject effects on the objects.

There is a very banal example of logicomathematical experience that I have often quoted. One of my friends who is a great mathematician described to me an experience that he had as a child. While counting some pebbles, he arranged them in a line, counted them from left to right, and found that there were ten. He then decided to count them from right to left and found there were still ten. He was surprised and delighted, so he changed the shape again. He put them in a circle, counted around the circle, and found there were still ten. With mounting enthusiasm, he counted around from the other direction and there were still ten. It was a great intellectual experience for him. He had discovered that the sum ten is independent of the order of counting. But unlike their weight, neither the sum nor the order is a property of the pebbles. The sum and the order come from the actions of the subject himself. It was he who introduced the order and it was he who did the counting. So logicomathematical experience is experience in which the information comes from the subject's own actions and from the coordinations among his actions. This coordination of actions naturally poses a problem of equilibrium much more than a problem of action from external experience.

Finally, as for the role of experience, it is clear that there is an undeniable role played by experience in cognitive development; however, the influence of experience has not resulted in a conception of knowledge as a simple copy of outside reality. In external experience, knowledge is always the product of the interaction between assimilation and accommodation, that is, an equilibrium between the subject and the objects on which the knowledge rests.

The second factor I would like to discuss is that of the innateness or hereditary programming of development. It is, of course, obvious that the factor of innateness plays as fundamental a role as the maturation of the nervous system and is a condition of cognitive development. But it is a condition that only opens up possibilities. The problem is how these possibilities are realized, that is, how they are actualized. In sensorimotor development, it is easier to see how hereditary transmissions play a central role. For instance, at the sensorimotor level, the coordination between grasping and vision seems to be clearly the result of the myelinization of certain new nerve paths in the pyramidal tract, as physiologists have shown. This myelinization seems to be the result of hereditary programming. However, in the domain of higher, representative, and especially operational cognitive structures, these structures are not innate. Logical transitivity, for example, imposes a necessity on the subject with an obviousness internal to the subject. Yet this necessity is not a proof of innateness.

We have conducted a very simple experiment to test the notion of transitivity. We asked children first to compare the length of two pencils. Children see that A is smaller than B. We then hide A and show B and C; C is very obviously longer than B. We then ask the child, "Do you think that C is longer than the first one you saw, smaller than the first one you saw, or about the same length?" The little children will say, "I can't tell. I didn't see them together." The child does not make the inference we would make from the information that allows for transitivity. It seems to impose itself on us with a feeling of necessity that C must be longer than A. But small children do not have that same feeling of necessity. This feeling of necessity is tied to the operational structure I have been calling *seriation* or *serial ordering.*

As you know, if children are asked to put ten sticks in order or length from shortest to longest, their ability to do so develops through very varied stages, in which they experience some laborious trial and error. Small children are likely to make pairs of short and long sticks but fail to coordinate the pairs among themselves. They have recognized that some sticks are short and some are long, but not much more than that. Older children make trios—the repetition of a pattern of short, medium, and long—but do not coordinate the trios among themselves. Slightly older children are able to produce an incomplete empirical series, that is, with errors, gropings, and corrections. Finally, at about 7 years of age, children have developed a method, a method that I call *operational.* They first look for the shortest of all the elements and place it on the table, then look for the smallest of those remaining and place it next to the shortest, and then look for the next shortest and place it. I refer to this method as *operational* because it implies a certain reversibility. It implies the comprehension of the fact that any element—say, element *E*—is at once bigger than all those preceding it and smaller than those that remain. There is a coordination that permits a construction of the seriation without errors. When this system is followed, once you know that objects *A, B,* and *C* were the shortest on the table, it is not necessary to compare object *D* with objects *A, B,* and *C.* You know that it must be longer than them and that it must be shorter than the others.

The notion of transitivity is, thus, tied to the operational structuration of the series. Transitivity feels necessary to us and imposes itself upon us because of the nature of the closed operational structure; it is a result of the closing of this structure. And this, of course, means equilibrium. The structure, until it is closed, is not in a state of equilibrium. Once it is closed, we again find equilibrium to be an important factor.

The notion of the influence of innate factors in development is gaining new acceptance these days. Two of its leading proponents are Chomsky, the linguist, and Lorenz, the ethologist. Chomsky, of course, has done very great work in his development of the notion of transformational grammar, work that I admire greatly. He has hypothesized that from the beginning of these transformations, there is a fixed innate core that contains the most general forms of language, for example, the relationship between subject and predicate. This innate core contains both the possibility of construction of language and a rational structure, which consequently would be innate.

It seems to me that this hypothesis is not necessary. As we all know, language develops during the second year of childhood and not from birth. As we also know, it develops at the end of the period of sensorimotor development, with all the numerous stages of construction involved in this form of intelligence. It seems to me that sensorimotor intelligence, once achieved, contains all that is necessary to furnish Chomsky's innate fixed core without having need to appeal to a hereditary structure.

Konrad Lorenz, the great ethologist, agrees with Kant: the important forms of our thinking, the important categories, are present in us before any experience; that is, they are innate. He goes as far as to say that the general ideas of the mind are preformed in the embryo before the individual has the need for them, just as the horses' hooves or fishes' fins are preformed in the embryo before they are needed by the adult. However, Lorenz, as a biologist, recognizes the limitations of such an explanation. Each animal species has its own heredity. Then, if one brings the ideas of intelligence or reason back to innate structures, that means that heredity can vary from one species to another following the hereditary patrimony of the species. Realizing this difficulty, Lorenz follows through very logically by concluding that these innate notions are not necessary, as they might be if the hereditary programs were constant across all species. Since hereditary programs vary from species to species and there is nothing necessary about them, these innate ideas must be only innate working hypotheses. Thus, this means that innate ideas have lost their aspect of necessity. This does not mean that essential categories are not *a priori* and cannot exist before any experience, but it does mean that they cannot be accounted for by their intrinsic necessity.

I would conclude in discussing the role of biology as a factor of development that what is important for us to take from biology is not the notion of hereditary programming, since it is variable and it cannot lead to the kind of necessity that we feel. We should take the much more general notion of self-regulating mechanisms. Self-regulating mechanisms are important throughout every level of biological development. One finds regulation at the level of the genome, where self-regulatory mechanisms are an essential condition of functioning. There are regulations in the course of embryological development that Waddington calls *homeorhesis.* At the physiological level, homeostasis is a self-regulating mechanism; similarly, in the nervous system, the reflex arc is a homeostat. On the level of human conduct and even at the level of logical operational thinking, there are similar self-regulatory mechanisms. It seems to me that this notion of self-regulation, which consequently is one of equilibration, is much more fundamental and much more general than the more narrow notion of variable hereditary programming. It is, then, self-regulation that is the important idea for us to take from biology.

I now come to the third classical factor of development: the social factor, the role of education and language in development. I will try to be very brief so that I can get on to equilibration. The role of education and language is clearly fundamental, but once again it is subordinated to assimilation. There can be no effect of social or linguistic experience unless the child is ready to assimilate and integrate this experience into his own structures.

The special problem of the relationship between language and logic is one that I would like to discuss at some greater length. Many people are of the opinion that an individual's grasp of logic is dependent upon the syntax and the logical relationships embedded in the language in which people are speaking to him. Logic develops out of the language. This is the position of the logical positivists.

In Geneva, one of our colleagues, Hermine Sinclair, has done some work on the problem of the relationship between logic and language. Sinclair was a linguist before she came to Geneva to go into experimental psychology. In her research, she first identified two groups of children. One group were nonconservers, in the sense that they thought that a change in shape would entail a change in the amount of substance. The other group were conservers, in that they knew that the change of shape did not alter the amount of the substance. Then, she looked at the language of these two groups of children in different situations. For example, the children were asked to compare short, long, fat, and thin pencils. She found that the children who were nonconservers did not use comparative terms in describing the pencils and did not contrast two dimensions. They would just say that one pencil is big and that one pencil is fat. The children who were conservers, however, used comparisons. They talked in sentences that contrasted variables, such as saying that one is fatter but shorter, the other thinner but longer.

Sinclair then trained the nonconservers to learn the verbal expressions of the other, more advanced group. This language training was not easy, but it was possible. After the nonconservers had mastered the language expressions of the conservers, she readministered the conservation experiment to see whether the training increased their ability to conserve.

Progress was only minimal; nine-tenths of the children made no progress toward conservation, although they had mastered the more sophisticated language. One-tenth of the children made very slight progress. This would lead us to believe they would have made this progress normally in that period of time. We have been pursuing other research in Geneva since Sinclair's study; it all supports the general conclusion that linguistic progress is not responsible for logical or operational progress. It is rather the other way around. The logical or operational level is likely to be responsible for a more sophisticated language level.

I am now discussing the role of equilibration, that is, the fourth factor in psychological and cognitive development. It seems to me that there are two reasons for having to call in this fourth factor. The first is that since we already have three other factors, there must be some coordination among them. This coordination is a kind of equilibration. Secondly, in the construction of any operational or preoperational structure, a subject goes through much trial and error and many regulations that in a large part involve self-regulations. Self-regulations are the very nature of equilibration. These self-regulations come into play at all levels of cognition, including the very lowest level of perception.

I will begin with an example at the level of perception. We have studied a number of optical illusions, by asking subjects to make perceptual judgments of an optical illusion. For example, we have often used the Müller–Lyer illusion, an illusion of the diagonal of the lozenge, which is always underestimated. One can present the subject with a successive series of judgments to make between the standard and the variable. The variable varies between presentation but the standard is a constant. The subject has to judge whether the variable is shorter than, longer than, or equal to the standard. I have always admired the patience of children under 7 years of age who will sit through 20 or 30 or 40 presentations at a time.

In children under 7 years of age, we find no notable transformations, that is, at the end of 30 or 40 trials, they make the same errors that they did at the beginning. With adults, on the contrary, the repetition of the judgment results in a very clear diminishing of the illusion. Some are able to eliminate the effect of the illusion altogether. Among children from 7 years (the beginning of cognitive operations) to adulthood, one can observe a progressive diminishing of errors. It is important to note that the subject does not know the results of his judgments. There was no external reinforcement, yet the perceptual mechanism seems to have its own regulations, so that after 20 or 30 or 40 trials, an adult subject can eliminate the effect of the illusion altogether.

At the representational level, in both preoperational and operational structures, we can distinguish three kinds of equilibrium. The first one is the relationship between assimilation and accommodation, of which I previously spoke. There is an equilibrium between the structures of the subject and the objects; its structures accommodate to the new object being presented and the object is assimilated into the structures. It is this first fundamental form of equilibration that was exemplified by the horizontality of water and the notion of conservation. I will not repeat these examples here.

The second kind of equilibrium is an equilibrium among the subsystems of the subject's schemes. In reality, the schemes of assimilation are coordinated into partial systems, referred to as *subsystems* in relation to the totality of the subject's knowledge. These subsystems can present conflicts themselves. In general terms, I will say that, for example, it is possible to have conflicts between a subsystem dealing with logicomathematical operations (such as classifications, seriation, and number construction) and another subsystem dealing with spatial operations (such as length and area). For example, when a child is judging the quantity of a number of sticks, there may be in one collection a small number of long sticks laid out. In another collection, a larger number of shorter sticks may be laid out. If he is basing his judgment on number, he would make one judgment of quantity. If he is basing his judgment on length, he would make a different judgment of quantity. These two systems can evolve at different speeds. Of course, as they evolve, there is a constant need for coordination of the two, that is, an equilibration of subsystems.

The third kind of equilibrium in cognitive development appears to be fundamental. Little by little, there has to be a constant equilibrium established between the parts of the subject's knowledge and the totality of his knowledge at any given moment. There is a constant differentiation of the totality of knowledge into the parts and an integration of the parts back into the whole. This equilibrium between differentiation and integration plays a fundamental biological role.

At the level of cognitive functions, there is a fundamental form of equilibrium because integration, as a function of differentiation, poses new problems. These new problems lead to the construction of new actions upon the previous actions, or new operations upon the previous operations. The construction of operations upon operations is probably the secret of development and of the transition from one stage to the next.

I would like to point out that the notion of operation itself involves self-regulatory mechanisms. They are—in Ashby's sense, in his cybernetic terminology—the perfect regulations in that the outcome is anticipated before the act is actually carried out. The feedback, which at lower levels has incomplete reversibility, now becomes a feedback with perfect reversibility in the sense of inversion or reciprocity. This is an example of perfect compensation—otherwise said, attained equilibrium.

I would like to explain the reasons for the role of equilibrium. All operational subject structures, on the one hand, and all causal structures in the domain of physical experience, on the other hand, suppose a combination of production and conservation. There is always some production—that is, some kind of transformation—taking place. Similarly, there is always some conservation, something that remains unchanged throughout the transformation. These two are absolutely inseparable. Without any transformation, we have only static identity. The world becomes rigid and unchanging in the sense that Parmenides (*c.* 539 B.C.) conceived it. Without any conservation, we have only constant transformation. There is total change; the world is always new and it becomes unintelligible. It becomes like the world of Heraclitis with its river in which one was never able to bathe twice. In reality, there are always both conservation and production.

Conservation demands compensations and, consequently, equilibration. If something is changed, something else must change to compensate for it, so that a conservation results. Even in physics, all the transformations that take place involve compensations that lead to a conservation. These compensations are organized in group structures, in the mathematical sense of the term. Furthermore, there is no conservation without production, and production with conservation results in a constant demand for new construction.

Where I speak of equilibrium, it is not at all in the sense of a definitive state that cognitive functioning would be able to attain. Attained equilibrium is limited and restrained, and there is a tendency to go beyond it to a better equilibrium. I would speak of the law of optimalization, if this term did not have technical meanings too precise for its psychological use. So, simply stated, there is a continual search for a better equilibrium. In other words, equilibration is the search for a better and better equilibrium in the sense of an extended field, in the sense of an increase in the number of possible compositions, and in the sense of a growth in coherence.

I would now like to point out the fundamental difference between biological or cognitive equilibrium and physical equilibrium. In physics, equilibrium is a question of a balance of forces. Take, for example, a balance with two weights, one on each side. Between the two are the level and the fulcrum, which are only organs of transmission. They are passive mediators permitting the action from one side to the other.

In another example, the Le Châtelier–Braun experiment, a piston presses down on a container that is full of gas. The gas is compressed while the force of the piston increases the pressure. The force of the piston heats the gas, making it agitate. This makes the gas hit back with pressure on the sides of the container and eventually back onto the piston. It compensates for the initial force that was pressing down on the piston and presses the piston back up again. Le Châtelier referred to this as the moderation of the original cause. Here again, the container plays the role of the transmitter, a passive mediator that receives and sends back the shocks.

In biological or cognitive equilibrium, on the other hand, we have a system in which all parts are interdependent. It is a system that should be represented in the form of a cycle. A has its influence on B, which has its influence on C, which has its influence on D, which again influences A. It is a cycle of interactions among the different elements. It also has a special feature of being open to influences from the outside. Each of the elements can interact with external objects. For instance, the cycle can take in A′ and B′.

In the case of biological or cognitive equilibrium, the links are not passive; they are the very sources of action. The totality presents a cohesive force that is specific and that is precisely the source of the assimilation of new elements of which we have been speaking since the beginning of this talk. The system forms a totality in order to assimilate the outside elements. This equilibrium between the integration and the differentiation of the parts in the whole has no equivalent in physics. It is found only in biological and cognitive equilibrium.

In closing, I would just like to cite two references on the matter of the cohesive force of the totality, the source of equilibrium in biological and cognitive structures. The first is from Paul Weiss, the great biologist, who in his work on cells pointed out that the structure of the totality of the cell is more stable than the activity of its elements. Inside the cell the elements are in constant activity, but the total structure of the cell itself has a much more continuing stability.

My second reference is in the cognitive domain. I would like to speak of the works of Presburger, cited by Tarski, which point out the existence of systems that as totalities are closed on themselves and are completely coherent. All aspects are decidable, in the logical sense of the term, within the total system, while the subsystems are not so closed and every aspect is not entirely decidable. This seems to me a very fine example of the kind of equilibrium about which I am talking; the totality has its own cohesion and equilibrium by integrating and differentiating the parts at the same time.