Piaget's Theory of Intellectual Development

Adolescence

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Thus far we have reviewed the sensorimotor period (birth to 2 years), the preoperational period (2 to 7 years), and the concrete operational period (7 to 11 years). In Piaget's theory the final period of intellectual development is that of *formal operations,* which begins at about age 12 and is consolidated during adolescence.

There are several major themes which run through Piaget's account of adolescent thought. One is that the adolescent's system of mental operations has reached a high degree of equilibrium. This means, among other things, that the adolescent's thought is flexible and effective. He can deal efficiently with the complex problems of reasoning. Another major theme is that the adolescent can imagine the many possibilities inherent in a situation. Unlike the concrete operational child, whose thought is tied to the concrete, the adolescent can deal with hypothetical propositions. He can compensate mentally for transformations in reality; this is one of the determinants of equilibrium.

These general conclusions are based on a number of studies performed by Inhelder and Piaget,[1] on adolescent reasoning (*The Growth of Logical Thinking from Childhood to Adolescence, GLT,* 1958). These studies, which use the revised clinical method, describe the adolescent's performance on various problems involving scientific concepts. In a typical investigation, a number of adolescents were given several problems based on classical physics, chemistry, or other disciplines. In each case the adolescent was presented with some apparatus or materials (a pendulum, a balance, etc.) and was required to explain how they work. Each subject was allowed to manipulate the apparatus, and to do experiments—in short, to behave as a scientist. The investigator kept a detailed record of the adolescent's activities and occasionally asked a few questions if verbal clarification seemed necessary. Piaget's major question, of course, is not whether the adolescent can come up with the "right" answer. Rather, the issue is whether and how the adolescent's thought differs from that of the younger child. Piaget's interest is in how the adolescent copes with scientific problems, how he experiments, and how he reasons about the observed data. As we shall see, Piaget's theory of adolescent thought is stated in terms of two logical models—the sixteen binary operations[2] and the INRC group. These two models together describe the period of formal operations. Since the models are quite complex, we will consider only limited portions of Piaget's theory.

THE SIXTEEN BINARY OPERATIONS

The Pendulum Problem

In one investigation all subjects were presented with the following situation. A pendulum was constructed in the form of an object hanging from a string, and the subject was shown how to vary the length of the string, how to change the weight of the suspended object, how to release the pendulum from various heights, and how to push it with different degrees of force. The subject was required to solve what is essentially a problem in physics, to discover which of the four factors, that is, length, weight, height, or force, alone or in combination with others, affects the pendulum's frequency of oscillation (the number of swings within a given interval of time). The correct solution, of course, is that the major causative factor is the length of the string: the shorter the string, the more frequent the oscillation. To solve the problem, the subject was allowed to experiment with the pendulum in any way he pleased. He could, for instance, make the pendulum heavy or light and see what happened. The examiner played a limited and nondirective role, recording the subject's experiments and verbal statements, and intervening in the course of events to question the subject on a few points that were not clear. In addition, the examiner also asked the subject to prove his assertions when he did not voluntarily do so. To summarize, the subject assumed the role of a scientist seeking an answer by empirical means to a classical problem in physics, and the examiner recorded his behavior.

To show the true measure of the adolescent's accomplishment, we will first present a brief account of how children in the preoperational and concrete operational periods deal with the problem. Preoperational children below 7 years of age approach the task in a very haphazard way. First, the "experiments" which they devise reveal no overall plan or pattern. These younger children seem to make random tests which in fact yield little information of value. For example, one child began by pushing a long pendulum with a light weight, then he swung a short pendulum with a heavy weight, and then he removed the weight altogether. Such a procedure can tell one nothing about the role of weight or length for reasons that should be clear (and if they are not, they will be later). Second, the child does not even report the results accurately. He hypothesizes, for instance, that his pushes influence the frequency of oscillation, and reports that this is what occurs when in fact it does not. Apparently the child's expectations influence his observations, and this attitude is hardly a mark of scientific objectivity. Third, the child's conclusions are faulty and unrelated to the evidence. This may occur because the child reports the results inaccurately; for example, he may mistakenly perceive that frequency of oscillation increases as the pendulum is pushed more vigorously. On other occasions the conclusions are inaccurate because the child reasons about the results in a faulty way. For example, if he (correctly) perceives that a short, heavy pendulum swings with greater frequency than a long, light one, he may incorrectly conclude that weight, and not length, is the causative factor.

The concrete operational child shows considerable improvement in his intellectual ability. He investigates a number of potential determinants of oscillation and observes the results in an accurate way, perhaps even discovering the correct answer. But there are many features of his procedure which are unsystematic and illogical and which require further development. Consider this protocol:

> BEA (10;2) varies the length of the string [according to the units two, four, three, etc., taken in random order] but reaches the correct conclusion that there is an inverse correspondence: "*It goes slower when it's longer.*" For the weight, he compares 100 grams with a length of two or five, 50 grams with a length of one and again concludes that there is an inverse correspondence between weight and frequency. (*GLT* pp. 70-71)

The child performed well in two respects. First, his answer was at least partially correct, although he mistakenly inferred that weight played a role too. Second, he observed all the results correctly: for example, the short, light pendulum *did* swing with greater frequency than the long, heavy one. His objectivity as a scientific observer is no longer in doubt; expectation does not influence observation.

But there were two important deficiencies in the child's approach. First, he did not design the experiments properly. To investigate the role of weight, he compared a short, light pendulum with a long, heavy one. This is not the proper procedure. What he should have done was compare a short, light pendulum with a short, heavy one and a long, light pendulum with a long, heavy one. That is, he should have *held length constant* to test the effects of weight, and vice versa. Second, the conclusions drawn from the empirical results (which were, as we noted, correctly observed) were imperfect. The judgment that there was an inverse relation between weight and frequency of oscillation (the heavier the weight, the less frequent the oscillation) does not follow from the observed data. This kind of faulty reasoning can be seen even more clearly in another subject, who (correctly) observed that a short, heavy pendulum swings with greater frequency than a long, light one. From this result, he concluded that both length and weight were determining factors; that is, increased length caused less frequent oscillation, and increased weight caused more frequent oscillation. This, of course, is not necessarily the correct inference. In the absence of further information, one cannot decide among three possibilities: (1) the foregoing interpretation, (2) that increasing the length slows the oscillation, while weight is irrelevant, and (3) that adding weight increases the frequency, while length is irrelevant. Unfortunately, the child did not design his experiment so as to provide the information necessary for deciding among the alternatives, and without sufficient justification unwisely settled on one of them.

Consider, on the other hand, the behavior of the adolescent in the period of formal operations. After passing through a transitional stage, which we will not discuss here, the adolescent performs well at three aspects of the problem: (1) he plans the tests adequately, or designs the experiment properly, (2) he observes the results accurately, (3) and he draws the proper logical conclusions from the observations. Here is an example:

> EME (15; 1), after having selected 100 grams with a long string and a medium-length string, then 20 grams with a long and short string, and finally 200 grams with a long and short, concludes: *"It's the length of the string that makes it go faster or slower; the weight doesn't play any role. "* She discounts likewise the height of the drop and the force of her push. (*GLT,* p. 75)

TABLE 1 ARRANGEMENT OF OSCILLATION EXPERIMENT

Length	*Weight*	*Oscillation*
1. long	light	?
2. short	light	?
3. long	heavy	?
4. short	heavy	?

Let us consider in turn each of the three aspects of the adolescent's behavior.

1. Designing the experiment. From the outset, and before carrying out any tests, the adolescent believes that there are several possible determinants of the frequency of oscillation. The causative factor could be length, weight, or any other of the factors present. Furthermore, she realizes that it is also conceivable that some combination of factors might be responsible: perhaps weight and length combined increase oscillation while neither by itself is a sufficient cause. In other words, the adolescent begins by imagining a series of purely hypothetical results; before acting, she conceives of all the possibilities. The evidence for this assertion is that later she proceeds to test all *possible* causes of oscillation. The systematically exhaustive way in which she performs the test suggests that she must have imagined all of the possibilities at the outset. Also, these imagined possibilities are abstractions of a sort. While she considers length, for instance, as an isolated and independent determinant of oscillation, it is the case that in reality length never stands alone; it is always accompanied by other factors such as weight. A swinging pendulum is never just long or short; it also has a certain weight, is released from a particular height, and so forth.

The adolescent's next step is an attempt to discover which of the many possibilities is operative. She uses a method which involves holding some factors constant while varying others. EME's approach was to first test a long string with 100 grams, then a shorter string with 100 grams, then a long string with 200 grams, and finally a short string with 200 grams. A schematic overview of her procedure is given in Table 1.

Note that four possibilities are tested, and that they involve holding one factor constant and varying another. In the case of the first two steps, the weight is light and the string is either long or short. In the case of steps 3 and 4, weight is heavy and the string may be long or short. Thus in both steps 1 and 2, and in 3 and 4, weight is held at one level (or is constant) while length is varied. If length is a causative factor, then its effects should be manifest in a comparison of 1 versus 2 and in a comparison of 3 versus 4.

We can easily arrange Table 1 to show the strategy of holding length constant while varying weight. Table 2 shows more clearly what is, of course, already contained in Table 1, namely, that the four tests can be used to get information on the role of weight. If one compares 1 and 3, for example, the length is long in both cases, while weight changes.

TABLE 2 ALTERNATIVE ARRANGEMENT OF OSCILLATION EXPERIMENT

Length	*Weight*	*Oscillation*
1. long	light	?
2. long	heavy	?

3. short	light	?
4. short	heavy	?

Actually, for purposes of illustration, we have simplified the matter somewhat. In dealing with length and weight, the adolescent also holds constant the other factors—height of the drop and force of the push—since varying them would confuse the results. All these variables are held constant so that the effects of the two factors, length and weight, may be assessed. Also, after testing the effects of length and weight, EME went on to do the same for the height of the drop and force of the push.

The adolescent's procedure seems very reasonable, of course, and one might even consider a detailed description of it to be trivial; surely, everyone would go about the problem in this way. But as we have seen before, for example, in the case of conservation, what is obvious and trivial to the adult is not necessarily apparent to the child. Similarly, in the case of designing experiments, the child in the concrete operational period does not always follow the "obvious" procedure. Remember the child whose *only* comparison involved a short, light pendulum versus a long, heavy one (steps 2 and 3 of Table 3), and who felt that this test resulted in sufficient information for firm conclusions.

2. *Observing the results.* It comes as no surprise that the adolescent, like the concrete operational child but not like the preoperational period child, observes the empirical results without bias.

3. *Drawing logical conclusions.* When the adolescent performs the four-step experiments shown in Tables 1 and 2, she obtains the results shown in

TABLE 3 OBSERVED RESULTS, OSCILLATION EXPERIMENT

Length	*Weight*	*Oscillation*
1. long	light	infrequent
2. short	light	frequent
3. long	heavy	infrequent
4. short	heavy	frequent

TABLE 4 RESULTS NOT OBSERVED, OSCILLATION EXPERIMENT

Length	*Weight*	*Oscillation*

1. long	light	frequent
2. short	light	infrequent
3. long	heavy	frequent
4. short	heavy	infrequent

Table 3. It should be clear from Table 3 that whenever the pendulum is short, it swings with greater frequency; and whenever it is long, it swings with lesser frequency. None of the other factors has any effect on oscillation.

Table 4 shows the results which were not observed. The reason for presenting this table will be clear later.

To introduce Piaget's use of logic, we will simplify the tables by means of a few abbreviations. If we let p stand for short and p for long, q stand for light and q for heavy, r for frequent and r for infrequent, and T (true) for observed result and F (false) for non-observed result, then we have Table 5. In that table, p and q are the factors and r is the result. T and F merely indicate whether the result was observed or not. For example, line 1 says that it was observed (T) that a long (p), light (q) pendulum swung with low frequency (r). Line 7 says that it was not observed (F) that a long (p), heavy (q) pendulum swung with high frequency (r).

What does the adolescent conclude from this pattern of observed and non-observed results? In regard to weight, Table 5 shows that it is observed that when heavy or light, the pendulum swings with low or high frequency. Consequently, the weight makes no difference whatsoever on the frequency of oscillation. Piaget writes this conclusion as q * r (read: weight is irrelevant to oscillation) and calls it *tautology* or *complete affirmation.*

TABLE 5 SYMBOLIZATION OF OSCILLATION EXPERIMENT

	Length	*Weight*	*Oscillation*	*Result*
1.	P	q	r	T
2.	P	q	r	T
3.	P	q	r	T

4.	P	q	r	T
5.	P	q	r	F
6.	P	q	r	F
7.	P	q	r	F
8.	P	q	r	F

(Clearly, it could be shown in the same way that force and height are also irrelevant.)

In regard to length, Table 5 shows that it is observed that a short pendulum always swings frequently and a long one infrequently (and it is *never* observed that a short pendulum swings with low frequency and a long one with high frequency). Therefore, the length of the pendulum fully determines the frequency of oscillation, and height is irrelevant. Another way of saying that is that short length is a necessary and sufficient cause of frequent oscillation.

In propositional logic, the pattern of results for length and oscillation may be described by a relation usually called "reciprocal implication" and is written p Λ r. Thus, the adolescent has found that p Λ r (length determines oscillation), whereas q * r (weight is irrelevant).

To summarize, the adolescent begins in the realm of the hypothetical and imagines all the possible determinants of the results. To test hypotheses, the adolescent devises experiments which are well ordered and designed to isolate the critical factors by systematically holding all factors but one constant. She observes the results correctly, and from them proceeds to draw conclusions. Since the experiments have been designed properly, the adolescent's conclusions are certain and necessary.

The Bending of Rods

To investigate another aspect of adolescent thought, Piaget presented subjects with a problem involving the bending of rods. We shall first review the logical conclusions drawn from the results of the experiment, and later see how this form of reasoning differs from that observed in the case of the pendulum problem.

Piaget presented the subjects with a series of rods which were attached to the edge of a basin of water. The rods were in a horizontal position (parallel to the water). The rods differed in (1) composition (steel, brass, etc.), (2) length, (3) thickness, and (4) cross-section form (round, square, rectangular). In addition, (5) different weights could be attached to the end of the rod above the water. The subject's task was first to determine which of the rods bend enough to touch the water, and then to explain the results. As in the case of the pendulum problem, the subject was allowed to vary the factors in any way. He might place on the apparatus a long, thin, round, steel rod with a heavy weight; a short, thin, square, brass rod with a light weight; or any other kind that he preferred. Again, the examiner's role was nondirective; mainly he noted the subject's tests and remarks and initiated a few questions to clarify uncertain points.

Here is a protocol of one adolescent's behavior:

TABLE 6 DESIGN OF RODS EXPERIMENT

Length	*Weight*	*Bending*
1. long	heavy	?
2. long	light	?
3. short	heavy	?
4. short	light	?

DEI (16; 10): "Tell me first [after experimental trials] what factors are at work here." — " *Weight, material, the length of the rod, perhaps the form.*"— " Can you prove your hypotheses?"—[She compares the 200 gram and 300 gram weights on the same steel rod.] "*You see, the role of weight is demonstrated. For the material, I don't know.*"—"Take these steel rods and these copper ones."—"*I think I have to take two rods with the same form. Then to demonstrate the role of the metal I compare these two* [steel and brass, square, 50 cm. long and 16 mm.^{2} cross section with 300 grams on each] *or these two here* [steel and brass, round, 50 and 22 cm. by 16 mm.^{2}]: for length 1 shorten that one [50 cm. brought down to 22.] *To demonstrate the role of the form, I can compare these two*" [round brass and square brass, 50 cm. and 16 mm.^{2} for each.]—"Can the same thing be proved with these two?" [brass, round and square, 50 cm. long and 16 and 7 mm.^{2} cross section.]—"*No because that one* [7 mm.^{2}] *is much narrower.* "— "And the width?"—"*I can compare these two*" [round, brass, 50 cm. long with 16 and 7 mm.^{2} cross section]. (GLT, p. 60)

It should be clear from the protocol that the adolescent's procedure is highly systematized. DEI considered that any one of several factors may be involved in determining the flexibility of the rods. For example, an increase in weight or an increase in length may make the rod bend. To test these hypotheses, the adolescent employed the method of varying one factor at a time while holding the others constant. To test the role of weight, for instance, DEI put first a 200 gram weight and then a 300 gram weight on the *same* rod. Because it was identical in the two cases, the rod obviously held constant the factors of material, length, and the like, while only weight varied.

We will now examine the adolescent's procedure in detail. For purposes of economy, let us suppose that only two factors, that is, length and weight, were present in the problem. In that case, a full account of the adolescent's procedure is given by Table 6. This shows that when steps 1 versus 2 and 3 versus 4 are compared, length is held constant and weight varied. And when 1 versus 3 and 2 versus 4 are compared, weight is held constant and length varied. This procedure should be familiar to the reader, since it is the same as that employed in the pendulum problem.

DEI correctly observed the results given in Table 7, which also lists the data *not* observed.

TABLE 7 RODS EXPERIMENT

Length	*Weight*	*Bending*
	Results Observed	
1. long	heavy	great
2. long	light	great
3. short	heavy	great
4. short	light	little
	Results Not Observed	
5. long	heavy	little
6. long	light	little
7. short	heavy	little
8. short	light	great

For example, line 2 says that the subject *did* observe a long, light rod bend a great deal, and line 5 says that the subject did not observe a long, heavy rod bend just a little. At first, the results may seem somewhat confusing. Rows 1 and 2 show that long rods bend a lot, but line 3 shows that short rods also bend a great deal. Similarly, lines 1 and 3 show that heavy rods bend a great deal, but line 2 shows that light rods do so also. Perhaps the results may be clarified if we consider the outcomes for each factor separately. Table 8 shows the results for length (ignoring weight). It should be clear from the table that a long rod always bends a lot, whereas a short rod may bend a great deal or just a little.

Table 9 shows the same pattern of results in the case of weight. Again, the obvious interpretation is that heavy rods are always observed to bend a great deal (and never just a little), whereas light rods may either bend a little or a lot.

Before we continue, let us symbolize the results once again: Table 10 first presents the case of both length and weight, and then shows the cases of length and weight separately, p stands for long length, p for short length; q for heavy weight, q for light weight; r for great bending and r for little bending; and T for an observed result, and F for result not observed. For example, line 4 under "weight alone" says that the subject did *not* observe (F) a heavy (q) rod bending only a little (r).

TABLE 8 LENGTH AND BENDING

Length	*Bending*
Results Obtained	
1. long	great
2. short	great
3. short	little
Results Not Observed	
4. long	little

TABLE 9 WEIGHT AND BENDING

Weight	*Bending*
Results Observed	
1. heavy	great
2. light	great
3. light	little
Results Not Observed	
4. heavy	little

The adolescent draws the following conclusions from the pattern of observed and non-observed results. First, length is a cause of the rod's bending. Whenever there is a long rod, it always bends. But do not short rods also bend (at least sometimes) and does this not contradict the hypothesis? The adolescent reasons that the hypothesis of causality is not disconfirmed. A special kind of cause—sufficient cause—is involved. In the present case, a long rod is always *sufficient* to cause bending. But the fact that the rod sometimes bends also when the length is short means that length is not the only causative factor. In other words, length is not *necessary* for bending; other factors may cause bending too. Second, the adolescent concludes that weight also is a sufficient cause of bending. Whenever the rod is heavy, it bends. But as was the case with short length, sometimes light weights bend and sometimes they do not. Again, the result depends on what other factors are present. To summarize, the adolescent makes the judgment that both length and weight are *sufficient* to cause bending, although neither one alone is *necessary.* In prepositional logic, these results may be represented by a relation "implication," and are written p D r, q D r (read: length implies bending, weight implies bending).

TABLE 10 SYMBOLIZATION OF RODS EXPERIMENT

	Length	*Weight*	*Bending*	*Result*
		Both length and weight		
1.	P	q	r	T
2.	P	q	r	T
3.	P	q	r	T
4.	P	q	r	T
5.	P	q	r	F
6.	P	q	r	F
7.	P	q	r	F
8.	P	q	r	F
		Length alone		
1.	P		r	T
2.	P		r	T
3.	P		r	F
4.	P		r	F

Weight alone

1.	q	r	T
2.	q	r	T
3.	q	r	T
4.	q	r	F

TABLE 11 THREE LOGICAL RELATIONS

			Hypothetical results showing:	
Length	*Bending*	*Results showing implication*	*Reciprocal implication*	*Tautology*
1. P	r	T	T	T
2. P	r	T	F	T
3. P	r	T	T	T
4. P	r	F	F	T

Perhaps we may achieve a better understanding of implication if we contrast it with reciprocal implication (previously observed in the pendulum problem). Table 11 shows both the pattern of implication and the (hypothetical) pattern of reciprocal implication in the case of length in the rods problem.

The implication column states, as we have already seen, that long rods always bend a great deal, and that short rods bend either a little or a great deal. The (hypothetical) reciprocal implication column says that long rods always bend a great deal, and that short rods *always* bend only a little. Therefore, in this hypothetical case only length causes bending. It should be clear from the table that reciprocal implication and implication differ only in the pattern of T's and F's (observed results and non-observed results). Finally, to review further, consider the last column, showing tautology or complete affirmation. This hypothetical case states that all possible combinations of length and bending can be observed. A long rod bends both a little and a lot, and so does a short rod. Clearly, then, length is irrelevant to bending. Thus, we have reviewed p *q* r (reciprocal implication), p ⊃ r (implication), and p * r (tautology).

TABLE 12 THE SIXTEEN BINARY OPERATIONS

	The four possible outcomes of an experiment			
	1.	2.	3.	4.
Length	P	P	P	P
Bending	r	r	r	r
Name of operation	*All ways in which four possible outcomes can be observed or not observed**			
1. Negation	F	F	F	F
2. Conjunction	T	F	F	F
3. Inverse of implication	F	T	F	F
4. Inverse of converse implication	F	F	T	F
5. Conjunctive negation	F	F	F	T
6. Independence of p to r	T	T	F	F
7. Independence of r to p	T	F	T	F
8. Reciprocal implication	T	F	F	T
9. Reciprocal exclusion	F	T	T	F
10. Inverse of independence of r to p	F	T	F	T
11. Inverse of independence of p to r	F	F	T	T
12. Disjunction	T	T	T	F
13. Converse implication	T	T	F	T
14. Implication	T	F	T	T
15. Incompatibility	F	T	T	T
16. Tautology	T	T	T	T

*Only number 14, implication, is actually observed in the case of rods. The rest are hypothetical.

The Other Binary Operations

In describing the adolescent's behavior on the various scientific reasoning problems, we have thus far covered three logical relations: p ⊃/⊂ r, p ⊃ r, and p * r. In Piaget's system, there are thirteen more, and the whole set is called the *system of sixteen binary operations.* Rather than discuss each of the sixteen operations in detail, we will instead merely list them all, in terms of patterns of observed and non-observed results and briefly discuss only a few operations. Suppose, again, we have the variables of long length (p) and short length (p); great bending (r) and a little bending (r). There are four combinations of p, p, r, and r. These are shown on the top of Table 12. They correspond to possible outcomes of the experiment. It could conceivably occur that a long rod (p) bends a lot (r) or a little (r) and that a short rod (p) bends a lot (r) or a little (r): these are the four possible outcomes of an empirical test. Each of the possible outcomes may be observed (T) or not observed (F). It is possible for all of them to be observed or for only some to be observed, while others are not observed. In other words, there are a large number of ways in which the experiment might turn out in terms of observed and non-observed results. Table 12 lists all the ways in which the four outcomes may be observed or not observed. (It is, of course, understood that instead of p and r, we could have a and b or any other symbols, and that instead of length and bending, we could have weight and oscillation or any other factors; Table 12 is completely general.) For example, row 2 says that if we did the experiment we could observe that long length produces great bending (p and r) and could fail to observe that long length produces little bending (p and r) and that short length produces a great deal of bending (p and r) or little bending (p and r).

We have already seen parts of the table before. For example, in connection with the pendulum problem we have seen that the pattern of observed and non-observed outcomes shown in row 16 is tautology, or p * r. Row 14 is implication, p ⊃ r, the obtained relation in the rod experiment, and row 8 is reciprocal implication, p ⊃/⊂ r, also found in the pendulum experiment. The other rows involve analogous logical operations.

For example, suppose we did an experiment and obtained the hypothetical results shown in row 2. Then, column 1 says that it is observed (T) that long (p) rods bend a lot (r), while it is not observed (F) that long (p) rods bend a little (r), and that short (p) rods bend a little (r) or a lot (r). In other words, all we know from the experiment is that long rods bend a great deal. This pattern of results is called "conjunction" and is written as $p \wedge r$. It means merely that long rods *and* great bending go together: the two occur in conjunction. While this operation seems a bit unnatural in the present context of rods and bending, there are many other situations in which conjunction makes as much sense as we hope implication does here.

Such, then, are the sixteen binary operations. We have seen how the adolescent uses three of them and have briefly reviewed what the rest are like. Now let us consider another feature of the adolescent's thought, the INRC group.

THE INRC GROUP

Thus far we have seen how the adolescent draws conclusions from the pattern of observed and non-observed results of an experiment. These conclusions may be stated in terms of logical operations, like $p * q$ or $p \supset q$. In other words, to this point we have been concerned with how the adolescent derives from the results of an experiment the proper logical relations among the factors involved. Each of the sixteen binary operations is a logical relation of this type. These logical relations are usually called "functions," and that is the terminology we will use here.

Following the analysis of functions, Piaget goes on to describe how the adolescent manipulates the conclusions which he has derived from an experiment. For this purpose, Piaget introduces another logical model, the INRC group. We will see how the INRC group is an attempt to specify the rules which the adolescent uses in manipulating or transforming functions. There are four such rules: identity (I), negation (N), reciprocity (R), and correlativity (C). We will consider two of them.

Reciprocity

To illustrate R, let us return to the problem of the bending rods. If you will recall, after designing the experiment properly (using the method of holding constant all factors but one), and observing the results accurately, the adolescent came to the conclusion that length was a sufficient cause of bending ($p \supset r$) and that weight was also a sufficient cause of bending ($q \supset r$). Another way of phrasing each of these statements is to say that (1) a long rod which is light will bend and (2) a heavy rod which is short will bend. In terms of our symbols, (1) may be written as $(p \wedge q) \supset r$, and (2) may be described as $(p \wedge q) \supset r$.

To restate these functions once again, $(p \land q) \supset r$ says that a rod which is long (p) and ($\land$) light (q) implies ($\supset$) bending (r); $(p \land q) \supset r$ states that a rod which is short (p) and ($\land$) heavy (q) implies ($\supset$) bending (r). In the course of his experiments, then, the adolescent has come to the conclusions which may be described in terms of both of the propositional functions just given. (He has also come to similar conclusions about the other factors in the experiment—material, cross-section, etc.—but we shall ignore these for the moment.)

Having derived the conclusions, the adolescent discovers that in the case of each rod, one factor *compensates* for the other. (Recall our discussions of compensation in the case of conservation.) In the first rod the weight is light, but the length compensates for this and causes the rod to bend. In the second rod the length is short, but the increased weight makes up for this and produces bending. Another way of looking at the matter is as follows. Suppose we observe that a rod of a given weight and length bends a certain amount. Imagine further that we want to keep the amount of bending exactly as it is and make the length shorter. The way to do this is to increase the weight—that is, compensate for a decrease in length by an equivalent increase in weight. Or, conversely, if we want to decrease the weight while maintaining the same degree of bending, we would have to increase the length.

Thus far, the adolescent has come to conclusions about the factors causing bending in each rod, and has also noticed, again in the case of each rod separately, that one factor compensates for the other to produce a given degree of bending. In one rod, length makes up for weight—$(p \land q) \supset r$—and in the second, weight makes up for length—$(p \land q) \supset r$.

Next, the adolescent sees a certain relation between the compensations affecting each rod: reciprocity is involved. That is, by linking his separate conclusions about each rod, the adolescent realizes that the compensation within one rod is the reciprocal of the compensation within the other. While in one rod length makes up for the weight, the reciprocal (weight making up for length) holds in the other rod.

Piaget again states the adolescent's reasoning in logical terms. If you will recall, the functions intended to describe the adolescent's initial conclusions were $(p \land q) \supset r$ and $(p \land q) \supset r$. Now, to describe the adolescent's understanding of the relation *between* these conclusions, we may write $(p \land q) = R(p \land$

q), or a long, light rod is the reciprocal (R) of a short and heavy one. Thus, we see how two separate functions, (p Λ q) and (p Λ q), are related to one another by means of one operation of the INRC group, namely, R, or reciprocity. This is intended to describe how the adolescent perceives relations between his conclusions.

Negation

To illustrate the rule N, consider the following study. Piaget presented the subjects with another problem from physics. Subjects were shown an apparatus in which a spring device launched balls, one at a time, across a horizontal track. The balls were of various weights and volumes. The task was to predict where the balls would stop on the track. In addition, subjects were asked to explain the results. Piaget was particularly interested in whether subjects would come to discover the principle of inertia. This states, in essence, that if no factors impede the motion of the belli, then it will forever maintain a uniform rectilinear motion; it will keep going at the same speed. Of course, under normal conditions, several factors are always present to impede movement. Friction slows the belli as a function of its weight, air resistance impedes the ball as a function of its volume, and the irregularities of the track, among other factors, hinder motion, too. The result of all these interfering factors is that one can never observe the operation of inertia in a pure state. In other words, since the real world always and unavoidably contains impediments like friction or air resistance, it is impossible to view enduring, uniform rectilinear motion. The conservation of motion by inertia is a theoretical possibility, not an empirical fact. For Piaget, the interesting problem is how the subject discovers an ideal principle which is not observable.

The adolescent goes about solving the problem in a systematic way. As we have already seen, he designs a series of experiments properly and uses the method of holding constant all factors but one. Since we have covered this matter before, we will not review it again. The adolescent's observations allow the construction of several valid statements concerning the behavior of balls on the horizontal plane. DEV (14;6), for example, concludes that a ball "stopped because the air resists . . . the bigger they are, the stronger the air resistance" (*GLT,* p. 129). He and other adolescents are successful in identifying additional factors, too—for example, that friction stops the ball. We can conclude, then, that using the experimental procedures already discussed, adolescents are able to derive legitimate causal statements about the forces impeding a ball's motion.

Once again, Piaget describes the adolescent's conclusions in terms of propositional logic. Letting p = the ball's stopping, q = the presence of friction, and r = the presence of air resistance, Piaget writes p ⊃ q (read: stopping implies friction) and p ⊃ r (stopping implies air resistance). The functions may be combined into p ⊃ (q V r), where "V" stands for "or." Furthermore, the function can be expanded to p ⊃ (q V r V s V t V . . .), where s, t, and . . . indicate an indefinite number of other factors. Thus far, then, the adolescent's thought merely illustrates several of the sixteen binary propositions, again a matter we have already reviewed.

Next appears the step which is of particular interest. After coming to a conclusion which may be described by the function p ⊃ (q V r V s V t V . . .), "the subject asks himself what should be the result of the negation of all these factors, this negation implying a corresponding negation of statement p, that is slowing down. This is equivalent to the assertion of the continuation of motion:

q . r . s . T . . ⊃" (*GLT*, p. 130). [3]

That is to say, the adolescent begins with conclusions concerning the stopping of motion. The conclusions may be described in terms of the function p ⊃ (q V r V s V t . . ,)or stopping implies friction, and so on. Then the adolescent transforms the original function by the operation of negation, N, which is one of the INRC group. The result of this transformation is a new function, namely, q Λ r Λ s Λ T. . . ⊃ p. The new function states the principle of inertia: it reads, the absence of friction (q), and (Λ) the absence of air resistance (r), and (Λ) the absence of all other impeding factors ("s Ț . . .) implies (⊃) the absence of stopping (p). Since the precise logical rules for applying negation are rather complex, they will not be covered here. The important point is that the adolescent has used certain rules to transform the initial conclusion into yet another. This transformation allows him to discover the principle of inertia which he cannot observe in the world of fact. Without manipulating the initial conclusion, and thus going beyond the evidence provided by reality (the factors causing stopping), the adolescent could not achieve the statement of the ideal (the principle of inertia). It is the adolescent's mental operations, his reasoning, rather than his observations, which allow him to discover the ideal possibility. The operation N is simply Piaget's attempt to describe *how* the adolescent manipulates the initial conclusions to go beyond them.

Further Aspects of the INRC Group

Thus far we have discussed two operations of the INRC group: negation and reciprocity. As we have seen in the discussion of conservation in Chapter 4, negation and reciprocity are both forms of *reversibility,* that is, ways of reversing the operations of thought. Of course, the reversibility of the period of formal operations differs from that of the period of concrete operations. In the latter case, operations on concrete objects may be reversed; in the former case, operations on hypothetical propositions (functions) may be reversed.

Piaget goes on to discuss two further aspects of the INRC group, I and C, which we will only mention here. I is an identity operator: when applied to a function, I leaves it unchanged. C is more complex. Applied to a function, C changes conjunction (Λ) to disjunction (V), and vice versa, but leaves everything else unchanged.

THE LOGICAL MODELS

We could go on to describe further aspects of the logical structures or models. Piaget's discussion is quite extensive and complex. It is also very technical. Piaget has a tendency to elaborate on the logical features of his models. He stresses, for instance, that the sixteen binary operations have *lattice* properties and that the INRC operations form a *group* of four transformations. We will not review these logicomathematical features of the models, since a proper exposition requires far more mathematical development than lies within the scope of this book. (For example, to define a lattice we must introduce the notions of *partially ordered set, relation,* and so on). Instead, we will offer a few general comments on Piaget's models.

First, like the groupings that were discussed in connection with concrete operational thought, the sixteen binary operations and the INRC group are *not* intended to imply that the adolescent understands logic in any explicit way. Most adolescents do not know propositional logic or group operations. Piaget does not use logic to describe the adolescent's explicit knowledge, but to depict the structure of his thought. Piaget is interested in how logical thinking *mediates* the adolescent's problem solving.

Second, the logical models are qualitative, not quantitative. The adolescent comes to conclusions like "length is involved in oscillation" or "thinness causes bending in rods." His conclusions are statements which do not involve numbers; therefore, the model of the statements must also be non-numerical. Neither the sixteen binary operations nor the INRC group involve numbers. For example, a statement of implication might be "the addition of weight causes bending." Implication would not be expressed by a statement like, "the addition of 5 pounds causes 4 inches of bending."

Third, the logical models are intended to describe the underlying structure of adolescent activities. It is not the case that the models exactly duplicate the adolescent's performance in full detail. The models are not simply protocols which list everything that the adolescent does; instead, they are abstractions which are intended to capture the essence of his thought. For example, in one study, adolescents were required to discover the factors causing the stopping of a roulette wheel type of device. Subjects performed certain tests and made a number of verbal statements. While the details of the study are not of interest to us at the moment, we will review part of one protocol to illustrate the function of Piaget's logic.

The following operations can be distinguished in his protocol:

1. Disjunction (p V q). . . . It's either the distance or the content (or both).

2. Its inverse, conjunctive negation (p * q): changing the position of the boxes verifies the hypothesis that neither weight nor color is the determining factor.

3. Conjunction (p * q): both content and distance are effective.

4. Its inverse, incompatibility . . . the effect of the magnet is incompatible with moving the boxes from the center for the needle may stop without the boxes being moved and vice versa, or neither occurs. (GLT' p. 103)

Piaget's account continues for twelve more steps. Note that for almost everything that the adolescent says or does, there is a corresponding logical representation. Piaget is able to translate almost the entire protocol into logical form. Such logical representations have the advantage of describing the basis of the adolescent's activities in a *general way.* The logical statements go beyond the details of the particular problem and describe fundamental intellectual skills which the adolescent uses in many situations.

Fourth, like the groupings, both the system of sixteen binary operations and the INRC group are integrated systems. According to Piaget, none of the sixteen binary operations or the INRC group exists in isolation from the others. An operation like implication, for example, does not stand alone; it is part of a larger system which makes implication and other operations possible.

Fifth, like the Groupings, the formal operations describe the adolescent's *competence.* Both the sixteen binary operations and the INRC group describe the capacities of the adolescent, and not necessarily what he does on any one occasion at any one time. It may be, for example, that factors of fatigue or boredom prevent an adolescent from displaying the full extent of his capacities. The models do not describe the actual performance, which may be deficient, but define the adolescent's capability.

Sixth, the models may be said to explain and predict behavior. There is explanation in the sense that the models describe basic processes underlying the adolescent's approach to problems. We can say that the adolescent solved a particular problem *because* his thought can utilize the logical operations of implication or negation, and so forth. Such a structural description is one kind of explanation. Also, there is prediction in the sense that the models are general. That is, having knowledge of the basic structure of his intellectual activity, we can predict what his performance will be like in general terms in other, similar tasks. Since the models describe the essence of his thought, we can predict how the adolescent will operate on problems that are similar in form to the ones with which Piaget presented.

These, then, are the goals of Piaget's theory: to develop formal systems which are clear, adequately descriptive, and general. It is now possible to consider how successfully Piaget's models fulfill his stated intentions. A judgment of this type is unfortunately not a simple matter. For one thing, the models may be successful in some respects but not in others. Also, considerable knowledge of logic is necessary for a fair evaluation of the system. And finally, no model is ever definitive. It is always possible to revise a given model, to state it in another language, to modify its features, and so forth. Consequently, we will limit our comments to a few points.

First, it is not entirely clear that a binary logical model is fully appropriate. (A binary model is one in which only statements involving two truth values may be made; for example, the rod is long or short, or heavy or light.) Recall that Piaget feels that one of the advantages of binary prepositional logic is that it can deal with non-numerical statements. While this feature of the model is no doubt often advantageous, there are times when it is not. Sometimes, the adolescents' methods and conclusions are not binary in the way Piaget describes. For example, in the rods problem, PEY (12;9) concluded, "The larger and thicker it is, the more it resists" (*GLT,* p. 56). Note that PEY did not deal just with large and small rods, as prepositional logic demands, but with the entire continuum of size. The same is true of thickness and resistance, with the result that the conclusion applies to rods of *all* possible gradations of largeness and thickness. Thus, PEY's statement is not restricted merely to two values (long and short) of each factor. Or consider EME's behavior in the pendulum problem. To assess the role of weight, she tested first a 100 gram weight, then a 20 gram, and finally a 200 gram. Thus, the weight did not assume just the two values of heavy and light as is necessary for binary propositioned logic, but rather involved a scale with three distinct values. It would seem necessary, then, to alter the model to bring it closer in line with data of this sort.[4]

Second, some authors believe that children fail to use many of the sixteen binary operations described by Piaget. Neimark (1975, p. 558) describes several studies showing that some children seem to solve the Piagetian problems without *any* hypothetico-deductive reasoning, and others use only conjunction and implication. Further research is needed in this area, for perhaps these studies did not adequately assess competence.

Third, the weight of the evidence seems to support Piaget's general characterization of adolescent thought, but does not necessarily confirm the details of his logical models. As Neimark (1975) puts it, "All of the research reviewed supports the validity of formal operational thought as an empirical phenomenon distinct from concrete operations. . . . The research does not, however, shed much light upon the precise nature of the changes or the variables which affect them" (p. 572). In brief, while Piaget's work points to some important characteristics of adolescent thought, it is not clear that the logical models accurately describe them.

GENERAL CHARACTERISTICS OF ADOLESCENT THOUGHT

We have reviewed in some detail the adolescent's methods of problem solving, and have illustrated aspects of the sixteen binary operations and the INRC group. Until this point, the description of Piaget's theory has of necessity taken an extremely technical form, and we are aware that some readers may not have followed every p and q. Fortunately, Piaget also discusses adolescent thought in a more general way, and it is to this discussion that we now turn.

Adolescent thought may be considered in terms of several broad characteristics. First, the adolescent makes reality secondary to possibility. To understand this point, let us consider first the behavior of the younger, concrete operational child. Given the oscillation problem, the child makes various experiments and observes the results quite carefully. He may correctly judge that short pendulums swing more rapidly than long ones; or in the rods problem, he may decide quite accurately that rod A bends more than rod B, which in turn bends more than rod C, and so forth. Thus, to solve the problem the child can efficiently perform the concrete operations, as in ordering the degree of bending of rods. But there are several major deficiencies in this procedure. The child begins his experiments with little foresight and does not have a detailed plan for carrying them out. The concrete operational child does not consider all the possibilities before he begins. Instead, he is limited to thought concerning empirical results—concerning things that are available to immediate perception. He fails to make consistent use of the method of holding constant all factors but one. The part played by possibility is very small indeed; it is restricted to the simple extension of actions already in progress. After the child has ordered a set of rods in terms of the extent of their bending, for instance, he could, if given several new rods, place them in appropriate positions in the series. The concrete operational child does not consider possibilities on a theoretical plane. Instead, he works efficiently with the concrete and real and has the potentiality to do to new things what he has already done to old ones.

For the adolescent, on the other hand, possibility dominates reality. Confronted with a scientific problem, he begins not by observing the empirical results, but by thinking of the possibilities inherent in the situation. He imagines that many things *might* occur, that many interpretations of the data *might* be feasible, and that what has actually occurred is but one of a number of possible alternatives. The adolescent deals with *propositions,* not objects. Only after performing a hypothetical analysis of this sort does the adolescent proceed to obtain empirical data which serve to confirm or refute the hypothesis. Furthermore, he bases experiments on deductions from the hypothetical and therefore is not bound solely by the observed. In the pendulum problem, he might suppose that length is a causative factor, and then deduce what must occur if such a hypothesis were true. The experiment is then designed to test the deduction. Thus, the adolescent's thought, but not that of the concrete operational child, is hypothetico-deductive.

The second distinctive feature of formal operations is their “combinatorial” property. For purposes of contrast, recall again the behavior of the concrete operational child. When confronted with several factors which might influence an experimental result, the child of this stage usually tests each of them alone, but fails to consider all their combinations. On the other hand, when given the task of discovering which mixture of five colorless chemicals produces a yellow liquid, the adolescent combines them in an exhaustive way. He mixes one with two, and one with three, and one with four, and so forth, until all combinations have been achieved. This is another way, then, in which possibility dominates the adolescent’s encounters with reality. If, like the concrete operational child, the adolescent had not beforehand conceived of all the possibilities, he would have designed a more limited set of experimental situations.

It can be said, then, that adolescent thought has achieved an advanced state of equilibrium. This means, among other things, that the adolescent’s cognitive structures have now developed to the point where they can effectively adapt to a great variety of problems. These structures are sufficiently stable to assimilate readily a variety of novel situations. Thus, the adolescent need not drastically accommodate his structures to new problems. This does not mean, of course, that the adolescent’s growth ceases at age 16. He has much to learn in many areas, and Piaget does not deny this. Piaget does maintain, however, that by the end of adolescence, the individual's ways of thinking, that is, his cognitive structures, are almost fully formed. While these structures may be applied to new problems with the result that significant knowledge is achieved, the structures themselves undergo little modification after adolescence. They have reached a high degree of equilibrium.

The adolescent’s thought involves a number of additional features. First, the adolescent’s thought is flexible. He has available a large number of cognitive operations with which to attack problems. Given some preliminary statements, the adolescent can manipulate them by means of the INRC group to derive definitive conclusions. This ability is completely lacking in the concrete operational child. The adolescent is versatile in thought and can deal with a problem in many ways and from a variety of perspectives. Second, the adolescent is unlikely to be confused by unexpected results because he has beforehand conceived of nearly all the possibilities. In the pendulum problem, for instance, it would not at all surprise the adolescent if it occurred that the only determinant of oscillation were the combination of weight and length with neither factor by itself being effective; this result was one of the possibilities considered. For the younger child, however, the same result might be seen as inconsistent and incomprehensible, since it contradicts the simple relationships which the child can understand. Third, the adolescent's thought is now simultaneously reversible in two distinct ways.[5] That is, he has available both the operations N and R, each of which involves a kind of reversibility. In less technical terms, this means that his thought can proceed in one direction and then use severed different methods for retracing its steps to return to the starting point.

The effect of the adolescent's intellectual achievements is not necessarily limited to the area of scientific problem solving. Piaget finds repercussions of formal thought on several areas of adolescent life, although his remarks probably hold more particularly for certain subgroups within European cultures than for American culture. In the intellectual sphere, the adolescent has a tendency to become involved in abstract and theoretical matters, constructing elaborate political theories or inventing complex philosophical doctrines. The adolescent may develop plans for the complete reorganization of society or indulge in metaphysical speculation. After discovering capabilities for abstract thought, he then proceeds to exercise them without restraint. Indeed, in the process of exploring these new abilities the adolescent sometimes loses touch with reality and feels that he can accomplish everything by thought alone. In the emotional sphere the adolescent now becomes capable of directing emotions at abstract ideals and not just toward people. Whereas earlier the adolescent could love his mother or hate a peer, now he can love freedom or hate exploitation. The adolescent has developed a new mode of life: the possible and the ideal captivate both mind and feeling.

We may now make some comments concerning the actual use of the formal operations. First, as we have already mentioned, Piaget does not mean to say that the typical adolescent of the formal stage *always* employs all or some of the formal operations in scientific problem solving, but rather that he is *capable* of doing so. Various factors may prevent their use. Under conditions of fatigue or boredom, for instance, the adolescent may not fully display the organization of thought available to him. Piaget's model of formal operations describes the adolescent's optimum level of functioning, and not necessarily his typical performance.

Second, we can inquire into the generality of the formal operations. Are all adolescents capable of them? Are the formal operations universal? The evidence seems to show that they are not.[6] In Western cultures, some adolescents do not seem capable of the formal operations; in some non-Western cultures, the formal operations seem to be completely absent, even in adults.

Why this apparent lack of universality? For one thing, Piaget's original subjects may have been a rather special group. Piaget points out that his subjects were taken from the "better schools in Geneva" and that "we cannot generalize to all subjects the conclusion of our research which was, perhaps, based on a somewhat privileged population" (*Intellectual Evolution from Adolescence to Adulthood, IE,* p. 6). Presumably Piaget's subjects were both affluent and well trained in school science. Their stimulating environments and educational training may have contributed to the early development of the formal operations. Perhaps other adolescents, lacking both stimulating environments and sound education, develop intellectually at a much slower rate, with the result that the formal operations do not appear until adulthood. Furthermore, "perhaps in extremely disadvantageous conditions, such a type of thought will never really take shape" (*IE,* p. 7). This indeed may be what happens in some existing societies. In brief, some adolescents may not give evidence of formal operations because an unstimulating environment slows down their rate of development or fails to promote their development entirely.

There is, however, another possible interpretation, which Piaget favors. Perhaps adolescents and adults use formal operations only in situations which are compatible with their interests and professional concerns. As Piaget states, "All normal subjects attain the stage of formal operations [no later than] 15 to 20 years. However, they reach this stage in different areas according to their aptitudes and their professional specializations" *(IE,* p. 10). Piaget points out that the experimental tasks used to investigate the formal operations were of a very special sort: they involve traditional science experiments for which Piaget's privileged children were well prepared by their education. By contrast, other children who are less well educated or who grow up in another culture are placed in a disadvantageous position by these special tasks. Piaget says of such less well-educated adolescents: "They would be capable of thinking formally in their particular field, whereas faced with our experimental situations, their lack of knowledge or the fact that they have forgotten certain ideas that are particularly familiar to children still in school or college, would hinder them from reasoning in a formal way, and they would give the appearance of being at the concrete level" *(IE,* p. 10).

Piaget’s point is extremely important: one cannot infer the lack of competence from a subject’s failure at some conventional task which is inappropriate to his interests or culture. One must always search for “ecologically valid” tasks which are personally relevant to the individual child or to members of a “primitive” culture. These points are too often ignored by researchers whose methodological concerns fail to extend beyond finding an easy way to test large numbers of subjects.

When care is taken to employ “ecologically valid” tasks, the results are often quite surprising. Consider the following example of research on the Kalahari Bushmen, who are expert hunters. Instead of administering tests using the pendulum problem, two Western scientists setup a “seminar” with several adult Kalahari to discuss hunting. Under these conditions, the Kalahari showed a high level of formal operational thought:

> As scientific discussions the seminars were among the most stimulating the Western observers had ever attended. Questions were raised and tentative answers (hypotheses) were advanced. Hypotheses were always labeled as to the degree of certainty with which the speaker adhered to them, which was related to the type of data on which the hypothesis was based.
>
> The process of tracking, specifically, involves patterns of inference, hypothesis testing, and discovery that tax the best inferential and analytic capacities of the human mind. Determining, from tracks, the movements of animals, their timing, whether they are wounded and if so how, and predicting how far they will go and in which direction and how fast, all involve repeated activation of hypotheses, trying them out against new data, integrating them with previously known facts about animal movements, rejecting the ones that do not stand up, and finally getting a reasonable fit, which adds up to meat in the pot. (Tulkin and Konner, 1973, pp. 35, 36)

In brief, some adolescents and adults fail to show evidence of the ability to use formal operations on some tasks. This may be due to a lack of environmental stimulation which results in a slowing down or stoppage of development. Or it may be due to the use of limited testing procedures which are biased in favor of adolescents from particular backgrounds. Perhaps all adolescents can use formal operations in situations of interest to them. Piaget leans toward this last interpretation.

Finally, we may ask how the stage of formal operations is attained. Why does the child pass beyond the period of concrete operations to reach a later state of equilibrium? Piaget is not very explicit on this point, and only gives an outline of a solution. He maintains, first, that it is conceivable that neurological development occurring around the time of puberty provides the basis for the appearance of formal operations. But neurological change is not sufficient: there are cultures whose members lack formal operations but not, presumably, the requisite neurological development. Second, Piaget maintains that the social environment also plays a role. Education in school or other instruction may hasten or retard the development of formal structures. It is also true that the level of intellectual accomplishment of a given culture may affect the cognitive development of its members. But the social environment explanation is not sufficient. One cannot teach a 5-year-old formal operations: the individual must be ready for them by having developed the proper preliminary cognitive structures. In other words, the child must prepare for the development of formal operations by first developing the skills of the concrete period. A third consideration is that the individual's experience with things plays a role. If the adolescent has never had a chance to experiment with anything, he will not develop formal structures. Experience, however, is not a sufficient hypothesis to explain the attainment of formal operations. The 4-year-old and the 14-year-old, given the same experience, will not benefit from it in the same way. Fourth, and finally, the child's own activity is crucial in this development. This is the "equilibration" factor. When the child in the concrete operational period attempts to apply his intellectual methods to complex situations (for example, the scientific problems already covered), he sometimes meets with contradiction and failure. When this happens, the child attempts to resolve the contradictions, and to do so must reorganize the concrete operations. Change begins with the felt inadequacy of the current state of affairs and proceeds by a process of internal reorganization so that previous structures integrate to form new ones.

To summarize, cognitive advance occurs as a function of appropriate neurological development, a proper social environment, experience with things, and internal cognitive reorganization. We shall elaborate on Piaget's theory of development in the next chapter.

SUMMARY AND CONCLUSIONS

In the stage of formal thought, the adolescent develops the ability to imagine the possibilities inherent in a situation. Before acting on a problem which confronts him, the adolescent analyzes it and attempts to develop hypotheses concerning what *might* occur. These hypotheses are numerous and complex because the adolescent takes into account all possible combinations of eventualities in an exhaustive way. As the adolescent proceeds to test his ideas, he designs experiments which are quite efficient in terms of supporting some hypotheses and disproving others. He accurately observes the results of the experiments, and from them draws the proper conclusions. Moreover, given some conclusion, he can reason about it and thereby derive new interpretations. The adolescent's thought is now so flexible and powerful that it has reached a high degree of equilibrium. Not all adolescents succeed at the usual tests of formal operations. There are at least two possible interpretations of this fact. Perhaps some adolescents lack sufficient education and stimulation. Or perhaps, as Piaget proposes, some adolescents use the formal operations only in areas which are of personal relevance but which nevertheless are not usually measured by the conventional Piagetian tests. If the second interpretation is reasonable, then psychologists need to invent testing procedures which are attuned to the individual adolescent's concerns. Piaget describes the process of adolescent thought in terms of two logical structures or models, the sixteen binary operations and the INRC group. He believes that such models are clear and capture the essence of the adolescent's mental activities.

Piaget has made a valuable contribution to our understanding of adolescent thought. First, Piaget's findings suggest that there are basic differences between the adolescent and younger child as far as scientific reasoning is concerned. It seems clear that as age increases there is an improvement in systematic experimentation, in the design of crucial tests, in attempts to isolate variables, in the appreciation of the complexity of problems, and in the ability to draw reasonable conclusions from empirical data. Second, Piaget has made a beginning in the task of developing formal models to describe and explain the adolescent's behavior. While we have doubts as to the adequacy of the proposed logical system, it is nevertheless true that Piaget is one of the very few theorists of child development who have even attempted to construct models of this sort. Third, Piaget has made an interesting proposal concerning the role of personal interests

in the development of adolescent thought. This proposal has important implications for methods of testing in both domestic and cross-cultural research.

Notes

1 For purposes of brevity, we subsequently refer to the work on adolescence as Piaget's; nevertheless, Inhelder's contributions should be recognized.

2 The model of the sixteen operations is actually a special case of a larger and more comprehensive system called the *combinatorial system*. This special case applies to situations involving two values (e.g., p and p) of each of two factors (e.g., p and q). With a greater number of factors, more complex models are necessary and can be generated from the combinatorial system.

3 Piaget uses "."as we have used "Λ" Both mean "and."

4 The reader interested in pursuing a critique of the logical aspects of the models is urged to consult an incisive paper by C. Parsons, a logician. See C. Parsons, "Inhelder and Piaget's 'The Growth of Logical Thinking'," *British Journal of Psychology*, Vol. 51 (1960), pp. 75-84. See also R. H. Ennis, "Children's Ability to Handle Piaget's Propositional Logic: A Conceptual Critique," *Review of Educational Research*, Vol. 45 (1975), pp. 1-41.

5 The concrete operational child has available the two forms of reversibility too, but they are not integrated into one system. Negation applies only to classes and reciprocity only to relations. See *Growth of Logical Thinking*, Chap. 17.

6 For a review of the literature, see E. Neimark, "Intellectual Development During Adolescence," in F. D. Horowitz, ed., *Review of Child Development* Research, Vol. IV (Chicago: University of Chicago Press, 1975).