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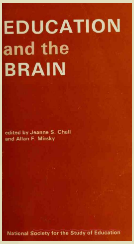

CHAPTER X

Growth Spurts during Brain Development: Implications for Educational Policy and Practice

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Introduction

Mental development is manifestly linked to and limited by the development of the child's brain. Because of recently uncovered facts from the neurosciences, we can now suggest a new frame of reference for educational strategies, curriculum planning, and evaluation of educational experiments. To aid the reader in grasping the data and following the arguments supporting the above contentions, I begin by summarizing the main contents of this chapter.

From biology we learn that formation of brain cells ceases early in life; the most recent data indicate its cessation before the end of the second year of life.[1] The cessation contrasts markedly with the increase of about 35 percent in brain weight after that age. This weight increase must appear in the form of (a) more extended and branched axons and dendrites of brain cells, (b) the laying down of the fatty insulation (myelin sheath) of axons, and (c) increased input of energy and materials through an increase in arterial blood supply to the brain. All these sources of increase in brain weight suggest an increase of complexity and speed of intercellular connections, leading to more complex and more reliable neural networks.

If these modifications occur continuously during child development, then each child at any age represents a point on a continuum of development. However, if increases are not continuous, but rather occur at discrete periods during life, then we have to think

1. John Dobbing and Jean Sands, "Quantitative Growth and Development of Human Brain," *Archives of Disease in Childhood* 48 (1973): 757-67.

in terms of *stages* of brain development. Such brain development stages may well manifest themselves in correlated, if not causally related, stages of mental development.

This chapter includes a brief account of my finding that human brain growth indeed occurs primarily during the age intervals of three to ten months and from two to four, six to eight, ten to twelve or thirteen, and fourteen to sixteen or seventeen years, and that these stages correlate well in timing with stages found in mental growth. Further, those experimentally established intervals correlate in time with the classical stages of intellectual development as described by Piaget, except that the fourteen- to sixteen-year brain growth stage has no Piagetian counterpart.[2] We therefore predict a hitherto unknown stage of intellectual development. Very recent work by Arlin yields the beginning of evidence for such a stage, which appears at about the predicted age.[3]

Given the body of facts sketched above, one can think of possible consequences for learning in general and for schooling in particular. One working hypothesis would be that intensive and *novel* intellectual inputs to children may be most effective during the brain growth stages. Anatomical data might be interpreted to lead to the inference that novel challenges to the child's mind that are presented at the wrong time might cause an active and potentially permanent turn-off of the ability to absorb some of those challenges at a later and more appropriate age. The question of what to do during the putative "fallow" periods will be answered definitively only by executing in schools (not in psychology laboratories!) some well-designed experiments aimed directly at that question.

The connection between brain growth stages and the ages of origins of the main Piagetian stages leads to a proposal for a new kind of evaluation scheme for educational experiments. It is known that even in the most affluent of developed countries appreciably fewer than 100 percent of adults manifest concrete operations (the third stage—age seven years), while only 30 percent manifest for-

2. Jean Piaget, *Psychology of Intelligence*, trans. Malcolm Piercy and D. E. Berlyne (Totowa, N.J.: Littlefield, Adams, and Co., 1969).

3. Patricia K. Arlin, "Cognitive Development in Adulthood: A Fifth Stage?" *Developmental Psychology* 11 (1975): 602-6.

mal operations (the fourth stage—age eleven years) that permit solving abstract reasoning problems at the highest level.[4] We may then speculate that even smaller percentages of children from disadvantaged situations will show the onset of the various stages at the normal ages. Thus, we could think of evaluating the effects of an intervention program or any experimental schooling program in terms of what it does to the percentage of children manifesting the *next* Piagetian stage at the expected age.

It is important to emphasize that the brain growth stages are not a theoretical notion but a scientific fact for which the evidence will be sketched in the pages to follow. Mental growth stages have a similar factual character, as does the correlative connection of brain growth stages with the ages of onset of the main Piagetian stages (whose age-linkage will also be demonstrated below).

In contrast, inferences from these facts constitute working hypotheses for adapting schooling strategies and curricula to the facts. We shall begin our study with a brief collection of some twentieth century suggestions that the stagewise mental growth of children has been ignored despite many indications of the existence of such stages.

Stages in Intellectual Development

Why has the idea of intellectual development stages penetrated so little into the thinking about education? It is not because there were no suggestions about such a possibility. Without trying to research the matter completely, I have traced the idea back at least fifty years to Alfred North Whitehead's *The Aims of Education.* In the second chapter, "The Rhythm of Education," the following quotation appears:

> The pupil's progress is often conceived as a uniform steady advance undifferentiated by changes of type or alteration in pace. . . . I hold that this conception of education is based upon a false psychology of the process of mental development which has gravely hindered the effectiveness of our methods. Life is essentially periodic. . . . There are . . . periods of mental growth, with their cyclic recurrences. . . .

4. Pierre R. Dasen, "Cross-cultural Piagetian Research: A Summary," *Journal of Cross-cultural Psychology* 3 (1972): 23-29.

Lack of attention to the rhythm and character of mental growth is a main source of wooden futility in education.[5]

Whitehead goes on to details of these rhythms, but without more than approximate indication of the ages. Between two and four years the child goes from achievement of perception to the acquirement of language. The next cycle ends around age seven years with classification of thought and keener perception. Manifestation of developed powers of observation and manipulation develops between ages eight and twelve. The three years between ages twelve and fifteen, according to Whitehead, should be dominated by a mass attack upon language. Finally, he asserts, the age of precision in language and of romance in science ends about age fifteen and is followed by a period of generalization in language and precision in science. There is a remarkable concordance between this scheme and that derived from forty years of hard work by Piaget and his followers and associates.

Another way to explain the lack of impact of ideas of stagewise development on educational practices is that of Vygotsky, who found it necessary to warn his fellow psychologists to set forth first the factual details of the development of intelligence.[6] As Vygotsky argues so cogently, when one looks at a new phenomenon one should beware of all analogizing until the basic facts of the situation have been set out in terms of the new concept itself. Otherwise one is likely to be misled by the analogies into irrelevant and fruitless paths of investigation. Based on such reasoning, Vygotsky's initial attack on the problem is presented in the same article with the very explicit title of "The Problem of Age-periodization of Child Development."

In this article, Vygotsky discusses what he calls critical periods, defining them as times of rapid change in children, associated with transitions from one level of intellectual functioning to another. Between these critical periods are periods of stable growth. Vygotsky states that critical periods occur during the first year of

5. Alfred North Whitehead, *The Aims of Education* (New York: Mentor Books, 1929).

6. Lev Vygotsky, "The Problem of Age-periodization of Child Development," trans. Mary A. Zender and B. F. Zender, *Human Development* 17 (1974): 24-40.

life, around age three years, and age seven years. Age thirteen years (puberty) is given as a period of stable growth. Vygotsky remarks that there are no critical periods from about age seventeen years through the appearance of final maturity. Again, there is a remarkable concordance with the results of the Piagetian studies.

The Piagetian studies themselves have been the major sources of experimental evidence for four major stages in the development of intelligence: during the first eighteen months, from two to four years, from seven to eleven years, and from eleven to fifteen years. There appears to be a fairly general acceptance of the stages, especially their sequence in normally-raised children; the question remains as to whether the stages are age-linked. Even if age-linkage can be shown, there are two possible prominent interpretations of such a fact. First, the linkage could be cultural in that the usual external factors affecting child development in a society appear at about the same age for most children. Second, the linkage could be the expression of a basis in the biological development of children.

The first interpretation is unlikely because, as set forth by Dasen, the same linkage and sequence have been found in a number of countries that are culturally quite dissimilar.[7] Thus, the observed age-linkage is likely due to biological factors. Recently, Brown and Webb have provided evidence of a very strict linkage to chronological age. Webb studied appearance of the Piagetian stage four (formal operations) in children from ages six to eleven years who had IQs of about 160; their mental ages were therefore between about ten and eighteen years. His results were unequivocal: no child showed any trace of stage four until he reached close to age eleven years chronologically.[8] Brown found a similar result for appearance of stage three (concrete operations) at about age seven years.[9]

Of importance for our later discussion is another aspect of

7. Dasen, "Cross-cultural Piagetian Research."

8. Roger A. Webb, "Concrete and Formal Operations in Very Bright Six- to Eleven-Year Olds," *Human Development* 17 (1974): 292-300.

9. Ann L. Brown, "Conservation of Number and Continuous Quantity in Normal, Bright, and Retarded Children," *Child Development* 44 (1973): 376-79.

Webb's work. He found that the rate of maturation of a new stage depended on IQ. His high-IQ children achieved maturity in the stage in a few months, while normal-IQ children took a year or two. Inferentially, children with subnormal intelligence may never develop the matured aspects of the stage.

In essence, the Piagetian scheme gives us the rises and plateaus in the development of human intelligence—its phenomenological topography. What is lacking is a similar topography of human brain development. The work of White suggests a connection between mental and biophysical growth.[10] First, he showed that the very abundant information is consistent with the inference of a marked shift in level of intellectual functioning of children between ages five and seven years. Second, several of White's studies deal with biophysical parameters that also shift quantitatively and markedly in this interval. The major difficulty with using White's analysis lies in his mixing of body and brain parameters. This is equivalent to the assumption that they change or spurt in parallel, an assumption now known to be incorrect.

Other than White's studies, I have found no published information on the age-linkage of the brain/mind relationship. In the next section we will look at the data for brain and skull growth to see if there are any indications of special events related to any of the intellectual periodization discussed above.

Brain Growth from Birth to Maturity

In a very thought-provoking book, Fodor pointed out that if we accept the existence of stages of development in intelligence, it becomes difficult to understand why and how a child ever goes on to a next stage; this seems to be part of the source of his skepticism about the existence of stages.[11] The argument is that if there is a truly definable stage, it cannot already possess the essential factors needed for going on to the next stage, for there would then be no stable stage in the first place. Some external input is then

10. Sheldon White, "Some General Outlines of the Matrix of Developmental Change between Five and Seven Years," *Bulletin of the Orton Society* 20 (1970): 41-57.

11. Jerry A. Fodor, *The Language of Thought* (New York: Thomas Crowell, 1975).

needed to permit the transition. In our case, this means that to pass from one stage to another requires the prior change in the structure containing the mind: an expansion of the brain.

First, we shall ask if there is any indication of a linkage of any kind between brain and intelligence. It is generally stated that there is no such linkage. In some textbooks we find mention of the fact that Goethe had a 2200-gram brain while Anatole France's brain weighed only 1100 grams. Therefore, runs the implied argument, brain weight is random with respect to intellect. Of course, such comparisons of individuals have no bearing on relations and correlations based on large populations of individuals. Dobzhansky remarked that "it is a fallacy to conclude that, since brain size alone does not unalterably set the level of intelligence, the two variables are not in any way related. Such a conclusion would probably reflect the misconception that a trait is either wholly genetic or wholly environmental."[12] And, indeed, the one set of data I have found seems to show clearly that there is a substantial connection.

Hooton studied the head circumferences of white Bostonians as part of his massive study of criminals.[13] The following table

TABLE 1

MEAN AND STANDARD DEVIATION OF HEAD CIRCUMFERENCE FOR PEOPLE OF VARIED VOCATIONAL STATUSES

Vocational Status	N	Mean (in mm.)	S.D.
Professionals	25	569.9	1.9
Semiprofessional	61	566.5	1.5
Clerical	107	566.2	1.1
Trades	194	565.7	0.8
Public Service	25	564.1	2.5
Skilled Trades	351	562.9	0.6
Personal Services	262	562.7	0.7
Laborers	647	560.7	0.3

SOURCE: Ernest A. Hooton, *The American Criminal*, vol. 1 (Cambridge, Mass.: Harvard University Press, 1939), Table VIII-17.

12. Theodosius Dobzhansky, *Mankind Evolving: The Evolution of the Human Species* (New Haven, Conn.: Yale University Press, 1962), pp. 200-1.

13. Ernest A. Hooton, *The American Criminal*, vol. 1 (Cambridge, Mass.: Harvard University Press, 1939).

shows that the ordering of people according to head size yields an entirely plausible ordering according to vocational status. It is not at all clear how the impression has been spread that there is no such correlation.

The age-relationship of brain growth has been surprisingly rarely studied; I have found only three collections of autopsy data giving average brain weight of humans over the entire period from birth to brain maturity around age eighteen years. The only reason for taking seriously so few studies is that they give the same results. Otherwise the variations I interpret as brain growth spurts would have to be ascribed to statistical fluctuations found in all data.

Analysis of the data into biennial increments shows that brain growth has two components.[14] The first shows the increase in brain weight associated with the increase in body weight. The second component appears in the form of spurts of 5 to 10 percent in brain weight during the periods from two to four, six to eight, ten to twelve, and fourteen to sixteen years, the latter two spurts being slightly earlier for girls and slightly later for boys. The same spurt periods are found by examining the brain/body weight ratios so we know that the spurts are not just expressions of spurts in body growth in general. More recent data from biochemical studies show that there is also a brain growth spurt during the first year of life, roughly between ages three and ten months.[15]

Additional information can be obtained by making use of studies showing that human brain weight is proportional to the cube of the head circumference from birth through brain maturity.[16] Thus, we may use head circumference data to supplement those from brain weight. There are many published studies (including longitudinal ones) of head circumference and they yield the same

14. Herman T. Epstein, "Phrenoblysis: Special Brain and Mind Growth Periods: I. Human Brain and Skull Development," *Developmental Psychobiology* 7 (1974): 207-16.

15. Dobbing and Sands, "Quantitative Growth and Development of Human Brain."

16. Myron Winick and Pedro Rosso, "Head Circumference and Cellular Growth of the Brain in Normal and Marasmic Children," *Journal of Pediatrics* 74 (1969): 774-78; Herman T. Epstein and Erika B. Epstein, *American Journal of Physical Anthropology*, in press.

pattern and ages of growth spurts as found for brain weight.[17] Nellhaus has recently completed preparation of head circumference charts for pediatricians, based on data from a dozen countries.[18] Analysis of his data yields the same pattern of spurts (figure 1) at

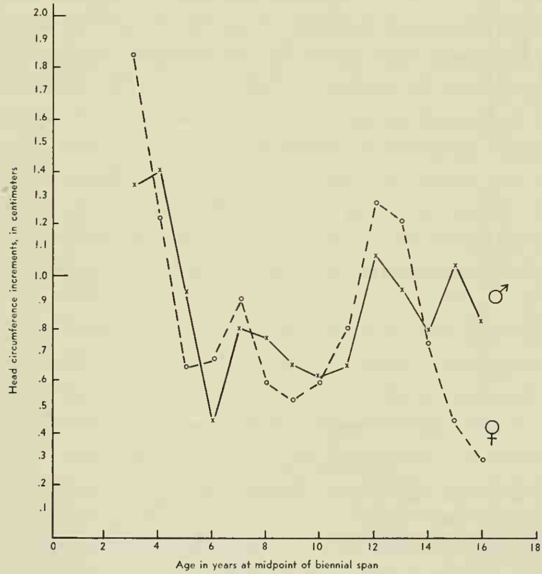

FIG. 1. Head circumference increments
SOURCE: Personal Communication from Gerhard Nellhaus, 1975.

the same ages as found for brain weights. His data include so many thousands of children at each age that the standard errors are smaller than the symbols used to plot the curves in that figure.

The growth of brain weight and head circumference both show a marked difference between the sexes after age ten years. This is clearly evident in the upper graph of figure 2 taken from a longitudinal study of head circumference.[19] Girls' head growth between

17. Epstein, "Phrenoblysis."

18. Gerhard Nellhaus, personal communication.

19. Dorothy Eichorn and Nancy Bayley, "Growth in Head Circumference from Birth through Young Adulthood," *Child Development* 33 (1962): 257-71.

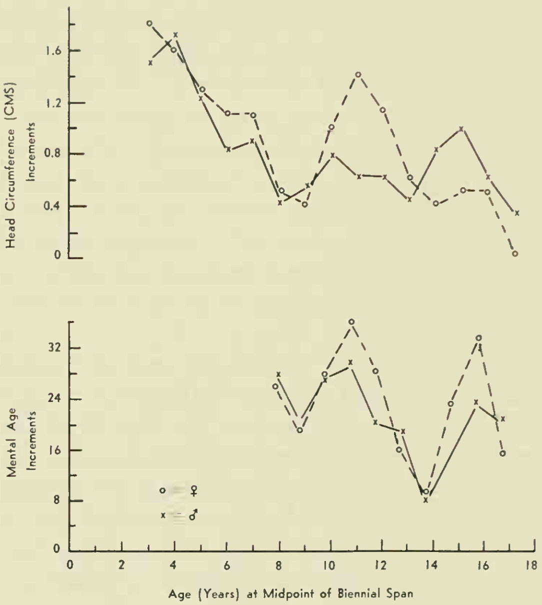

FIG. 2. Increases in head circumference and in mental age

SOURCE: Top, Dorothy Eichorn and Nancy Bayley, "Growth in Head Circumference from Birth through Young Adulthood," *Child Development* 33 (1962): 257-71; bottom, Frank K. Shuttleworth, *The Physical and Mental Growth of Girls and Boys, Age Six to Nineteen, in Relation to Age at Maximum Growth, Monographs of the Society for Research in Child Development* 4, no. 3 (1939): 1-291.

ages ten and twelve years is about twice that of boys, while the situation is reversed for the growth spurt centered around age fifteen years.

The biochemical natures of the various spurts are known only in rather general terms, but one important inference emerges from those data. Cell replication ceases by about age one and a half years.[20] Therefore, increases in brain weight after that age must reflect changes within the cells themselves—in protein, ribonucleic acid (RNA), lipids, and water. The water content was shown to decrease steadily after birth, so that weight increases must be due to the other three substances. These substances would increase as a result of growth of the cells represented in lengthening and/or

20. Dobbing and Sands, "Quantitative Growth and Development of Human Brain."

branching of axons and dendrites or in myelination (insulation) of axons. The latter event would increase the efficiency of signal transmission while the axonal and dendritic changes bespeak increased complexity of neural networks, which should then exhibit increased functional complexity and competence.

The use of brain weight as the defining parameter lets us detect all brain growth substantially exceeding that associated with increase in body weight. But, since it reflects *all* sources of weight increase, we do not know in what region or regions of the brain the growth has taken place nor anything about its anatomical or biochemical nature. And, we surely do not expect that the same localizations and events will be found in all the spurts. Thus, the detailed characterization of each of the spurts awaits the study of the neuroanatomical and neurophysiological correlates of the growth spurts.

Postnatal insults to human brain development mainly take the form of undernutrition and, possibly, environmental deprivation. The former is a well-known cause of decrease in both cell number and network complexity. The latter, which is generally branded in public as a significant source of the poor school performance of many disadvantaged children, is not yet known to affect brain, as distinguished from mind, but there has been no published account of any effort to study the possibility in humans. In rodents, the question is under study in a number of laboratories.

A clue to the role of experience in shaping neural networks (and, eventually, behavior and intelligence) comes from the work on vision in cats and monkeys, initiated mainly by Wiesel and Hubel.[21] In their first experiment, they sutured closed the eyes of newborn kittens. Closing one eye thusly for a month or more results in kittens with essentially no binocular vision, as verified by finding that, unlike the situation in normally raised kittens, no cells could be found in the visual regions of the brain that responded to light impinging on each eye separately. The response was only to light in the eye that had been left open. There are two competing explanations for this result. First, the loss of binocular vision could be due to lack of experience of binocular vision; that experience is

21. Torsten N. Wiesel and David H. Hubel, "Comparison of the Effects of Unilateral and Bilateral Eye Closure on Cortical Unit Responses in Kittens," *Journal of Neurophysiology* (London) 28 (1965): 1029-40.

thus assumed to be the cause of the binocular connections of the eyes to the visual regions of the brain. Second, the binocular connections could have already existed at birth but have been lost due to the lack of experience, which thereby fixes the connections.

The choice between the explanations was gained by the results of the experiment of sewing both eyes closed at birth for periods of up to age one year. In this experiment there could not have been any experience of binocular input. Yet, after removing the sutures, many cells were found to respond to both eyes. Therefore, the network must have existed in the newborn kitten. In the experiments with one eye closed, the connection from that eye to the cells must have been lost due to lack of binocular experience before some critical age.

A similar inference comes from recent studies of nerve-to-muscle connections in rodent fetuses, showing that connections present during fetal life are later lost due to later experience.[22] Thus, there is strong indication that the role of experience is to select from alternative network possibilities that exist before the experience begins.

By analogy, the role of intellectual experience or learning is to select among existing networks created by the genetic apparatus during brain development. If the complete spectrum of needed experience is not available to the organism, it loses forever the possibility of having those functions that are operated by the lost networks. It is possible that during later development another network may take on the lost function, but this is likely to be a secondary strategy of lower effectiveness. In this way, we can understand the role of experience in shaping the minds of men and the drastic consequences of lack of experience or of improper balances of early life events.

Mental Growth from Birth to Maturity

Given the existence of brain growth spurts, their meaning has to be sought in the special functions of the brain. We shall examine first the cognitive or intellectual functions.

A substantial amount of data already exists for what is defined

22. Jeremy Brockes, "Suppression of Foreign Synapses," *Nature* 260 (1976): 281.

as mental age, along with other studies of intelligent performance. All studies we have found that give mental age over a substantial span of ages yield spurts, and these spurts turn out to correlate well in ages with those found for the brain.[23] This may be seen in the results of the mainly longitudinal Harvard Growth Study, from which the biennial increments are given in the bottom half of figure 2.[24] At all ages at which there are data in both halves of that figure, it is seen that there is a good correspondence of spurt ages.

It is surprising that supporters of the Piagetian scheme had not previously examined the data on mental growth to see if there were manifestations of the appearance of the main Piagetian stages. But it is equally surprising that, despite their viewpoints as presented earlier, both Whitehead and Vygotsky did not engage in the testing of the possible implications of their periodization views for the developmental aspects of children's intelligence and school performances.

Probably the strongest test for any theory is the verification of a prediction of an unknown and significant fact. In our case, such a prediction is required by the fact that there is a brain growth spurt between ages fourteen and sixteen, which is after the last known Piagetian stage appears. If there is a hard connection between brain and mind growth spurts, we are forced to predict that a new Piagetian stage will someday be found, and that it will appear first around age fifteen years.

Arlin's recently published paper gives evidence for the existence of a new stage in the development of intelligence that she has found in female college students of ages nineteen to twenty-one years.[25] The new stage is called *problem finding*, to distinguish it from the problem-solving competency that is another way of labelling the

23. Herman T. Epstein, "Phrenoblysis: Special Brain and Mind Growth Periods: II. Human Mental Development," *Developmental Psychobiology* 7 (1974): 217-24.

24. Frank K. Shuttleworth, *The Physical and Mental Growth of Girls and Boys, Age Six to Nineteen, in Relation to Age at Maximum Growth, Monographs of the Society for Research in Child Development* 4, no. 3 (1939): 1-291.

25. Arlin, "Cognitive Development in Adulthood."

earlier fourth stage; other descriptive terms could be inductive reasoning, creative thought, or divergent thinking.

Since the publication of that paper, Arlin has completed work on grade school children to verify that the new stage does not appear at any age through thirteen years.[26] At the other end of the age spectrum children in grades ten and eleven (ages sixteen and seventeen) manifest stage five to about the same extent as the college students, and both sexes have been shown to display stage five. Thus, there is presently good reason to assume that this new stage is congruent in age of appearance with the fifth and last postnatal spurt in human brain growth. The prediction may already have been verified.

A major problem with the study of stages in the development of intelligence is that their universality is not yet proven. Dasen has summarized the data on cross-cultural studies of the Piagetian stages, noting that there are many societies in which many or even most adults do not attain even the third stage (age seven years).[27] It may be that the Piagetian scheme is not universal. Or, the failure may be due to various forms and extents of environmental deprivation. All that we know at present is that those who display the various Piagetian stages first show them at the given ages, so that this normal pattern of stages in the development of intelligence parallels very well the pattern of appearance of the brain growth stages.

The finding of a correlation between brain and mind growth spurts as a normally occurring pattern led to the creation of a new word to prevent confusion with the notion of a critical period that is usually discovered by finding some abnormal functioning caused by earlier deficits. We have chosen the name *phrenoblysis* (derived from the Greek meaning a welling-up or spurting of mind and/or skull) to signify these correlated brain and mind growth spurts. Phrenoblysis does not refer to the separate brain and mind spurts.

Perturbations of Brain and Mind Development

Is there any evidence that interference with brain growth is connected in any way with lowered intellectual competence? The

26. Patricia Arlin, personal communication.

27. Dasen, "Cross-cultural Piagetian Research."

first work on this subject with humans called attention to the effects of marasmus (general food deprivation resulting in lowered protein and calorie intake).[28] The report showed about a 25-point lowering of IQ in the roughly four-year-old children along with a smaller head circumference than both their siblings, the control children, and the general local population. The very low socioeconomic status of these children prevented a clean statement that lowered IQ was a consequence of the effect of nutritional deficit on brain growth and resultant IQ. These workers have continued to follow these same children who, since the time of their hospitalization from marasmus, have been on adequate diets. When tested recently at an average age of about seventeen and a half years, the children had come closer (but not yet equal) to the control group in body parameters.[29] The IQ deficit remained about 25 points, as it had been some thirteen years earlier. As the authors noted, however, the biggest surprise was the fact that head size showed not only no catch-up but it did not even keep pace. There was a larger difference between experimental and control children! To be specific, the head circumference difference increased about 20 percent while body weight difference decreased about 30 percent and, as mentioned above, the IQ difference was an unchanged 25 points.

The conclusion is that there is no catch-up in intellectual level and that the building of an adolescent brain on top of an architecturally abnormal brain yields an even greater abnormality than that existing at the time of the end of the marasmic condition. It is hard to escape the conviction that brain abnormality is linked causally to the intellectual deficits, although clean proof is still lacking and, because the subjects are humans, is likely never to be achieved. The direct evidence on this point will come from animal studies, but until such work is done with the higher primates, it will not be possible to show at all convincingly any deficit in intellectual performance that is similar to human kinds of intelligence.

From the point of view of phrenoblysis, it will be important

28. M. B. Stoch and P. M. Smythe, "Does Undernutrition during Infancy Inhibit Brain Growth and Subsequent Intellectual Development?" *Archives of Disease in Childhood* 38 (1963): 546-52.

29. M. B. Stoch and P. M. Smythe, "Fifteen-year Developmental Study on Effects of Severe Undernutrition during Infancy on Subsequent Physical Growth and Intellectual Functioning," *Archives of Disease in Childhood* 51 (1976): 327-36.

to look into two aspects of these human studies. First, head size deficit will have to be studied as a function of the age of the children at which the deprivation first starts. It is not unlikely that such data exist and can be obtained by a survey of populations in any of several countries. Second, it will be important to follow the head circumferences of marasmic children on a yearly, if not a half-yearly, basis to learn about the longitudinal development after an early deprivation.

There is a small amount of evidence supporting the idea that deprivations during later growth spurts can affect brain growth substantially even when the first years of life are without trouble. Baertl et al. have supplemented nourishment of newborn children from families that had already produced marasmic children, the supplement continuing until an average age of nearly eighteen months. At that age statistics for these children showed generally normal development. The children were then released to total care of their families, and within a half-year their measurements had dropped to about the substandard environmental norms through a total cessation of growth in height and in head circumference, plus a loss of nearly 1 kg. in body weight.[30]

Implications of Phrenoblysis

LEARNING CAPACITY

Mental age may be expressed as a compound of the child's inherent learning capacity and the richness of his life experience. By this expression, mental age measurements do not permit us to estimate learning capacity by itself. Of the few studies that purport to get at the learning capacity directly, the following is the best executed.

The work of Cattell and his associates has resulted in a separation of the general intelligence factor, g, into two components: g_c and g_f. The former is called the crystallized intelligence factor and can be roughly related to mental age since it purports to give an estimate of the developed intelligence at the time of measurement. The latter,

30. Juan Baertl, Blanca Adrianzen, and George G. Graham, "Growth of Previously Well-nourished Infants in Poor Homes," *American Journal of Diseases of Children* 130 (1976): 33-36.

the fluid intelligence factor, is an estimate of the child's ability to develop new intellectual competencies—his creative intelligence at the age of measurement; the value varies between 0 and 1.

Estimates of these two components have been given in a recent review.[31] The value of g_f in verbal, numerical, and reasoning capacities has a peak near age eleven years, thus correlating with the brain growth spurt at that age. Age thirteen and a half years, however, is certainly a low point, because the g_f values in all three capacities are very close to zero. Thus, there would appear to be little or no store of creative intelligence around ages twelve to fourteen years, in good agreement with the brain growth plateau found at that period.

INTERVENTION PROGRAMS: THE JENSEN CONTROVERSY

I shall show below that the massive failure of Head Start Programs to achieve their goals in cognitive development of disadvantaged children was not due to genetic factors, as suspected by Jensen,[32] but rather to an age-linked development factor unsuspected by both Jensen and the defenders of Head Start Programs. Black children turn out to be not especially, if at all, different from whites in intellectual capacities. But, it is instructive to give an analytical account of the way the controversy developed.

Virtually all the data on remedial programs come from Head Start programs that occurred and occur in the thousands, probably in the tens of thousands. Virtually all of these programs were set in the age bracket of about three and a half to five and a half years. Jensen pointed out the massive failure of these programs in the cognitive growth aspects of their work, using as data the results of the half dozen official evaluations of such programs. The number of programs said to be definitely successful was variously given as between ten and thirty out of the many thousands that existed.

The typical results of these Head Start programs were a rise in IQ of from ten to fifteen points during the first year or so, fol-

31. Raymond B. Cattell, "The Structure of Intelligence in Relation to the Nature-Nurture Controversy," in *Intelligence*, ed. Robert Cancro (New York: Grune and Stratton, 1971).

32. Arthur R. Jensen, "How Much Can We Boost IQ and Scholastic Achievement?" *Harvard Educational Review* 39 (1969): 1-123.

lowed by a steady decay so that by the second grade there was no difference between the experimental and control children.

The brilliant analysis by Jensen was followed by a collection of so-called refutations which did little credit to the subject or to the profession. In essence, these refutations amounted to saying that Jensen might have had one or another source of error in one or more portions of his analysis; it was not shown that, in fact, the postulated source of error actually existed in the data or in the analysis. Indeed, in later writings, Jensen took up these criticisms and showed, in a way convincing to this writer, that the proferred sources of error did not in fact occur.

As an example, take the question of culture-fair IQ tests. Jensen pointed out that revision of some of the obviously unfair items did *not*, in fact, alter the results *on those very items* for which black children were presumed to be penalized. Thus, this potentially explanatory criticism does not apply to the situation.

It is correct to say that Jensen was wrong, but such a statement does wrong to Jensen because of the context of controversy surrounding his work. His argument was that if no experiential (environmental) changes helped the black children to attain white norms, then we should entertain the interpretation that blacks are genetically different from whites and, in IQ terms, inferior. The only writer I have found who seems to have looked carefully at the real thrust of the argument is Hunt, who had already pointed out in 1961 the possibility of developmental features that could be deterministic in child development.[33]

Jensen's error was in supposing that the only alternative interpretation that remained was that of genetic difference. In fact, as Hunt had already pointed out, there may be a developmental program that was somehow being bypassed. In other words, Jensen did not realize (any more than did his detractors) that there could have been an unlikely accidental choice of exactly the wrong ages for the intervention. From the point of view of phrenoblysis, the four-to-six year age period is one of minimal brain and mind growth, so that Head Start programs at this age should fall short of their cognitive goals for *biological* reasons. Further, phrenoblysis leads

33. J. McVicker Hunt, *Intelligence and Experience* (New York: Ronald Press, 1961); idem, "Reflections on a Decade of Early Education," *Journal of Abnormal Child Psychology* 3 (1975): 275-336.

to the prediction that both earlier and later programs (for children aged two to four and six to eight years) should have much greater likelihood of success. The facts below support this prediction.

The Milwaukee Project worked with black children who were taken in to the project before the age of six months.[34] The children were brought to a day-care setting under the supervision of middle-class black women for about eight hours per day. The twenty-five matched control children exhibited the steadily deteriorating IQs and failing school performances characteristic of most of the sub-population from which the experimental and control children were drawn. The twenty-five experimental children registered IQ gains from the very first test, and their presently estimated average IQs of about 115 are a match to the expected values based on school performance of these children who have completed fourth grade. Hunt gives a detailed analysis.[35]

The Mother-Child Home Program,[36] also analyzed by Hunt,[37] has now spread to at least a half dozen cities. It takes two-year-old children and produces normal IQ children who have remained at that level to the fourth grade. In this project the IQ increase is only about 17 points over the control children compared with the roughly 30-point effect in the Milwaukee Project. But, the Mother-Child Home Program interacts with each family only about one hour per week compared with about eight hours per day, five days per week in the Milwaukee Project.

The Robinsons' project in North Carolina also started with two-year-old children in a day-care setting and produced IQ gains about the same as those obtained in Milwaukee by age four years, which was the termination point of this study.[38]

34. Howard Garber and Rick Heber, "The Milwaukee Project: Early Intervention as a Technique to Prevent Mental Retardation" (Storrs, Conn.: University of Connecticut National Leadership Institute, Teacher Education/Early Education, 1973).

35. Hunt, "Reflections on a Decade of Early Education."

36. Phyllis Levenstein, "The Mother-Child Home Program," in *The Pre-school in Action: Exploring Early Childhood Programs*, ed. Ronald K. Parker (Boston: Allyn and Bacon, 1972).

37. Hunt, "Reflections on a Decade of Early Education."

38. Halbert B. Robinson and Nancy M. Robinson, "Longitudinal Development of Very Young Children in a Comprehensive Day Care Program: The First Two Years," *Child Development* 42 (1971): 1673-83.

Thus, all three projects have produced seemingly permanent increased intellectual functioning of children from disadvantaged homes provided the intervention started by age two years and lasted at least through age four years. Hunt reported the existence of several additional programs that cover much of this age period and seem to have been similarly highly effective.[39]

The upshot of all the work discussed in this section is that the Jensen inference was not logically compelling because he did not take into account the possibility of age-linked child development stages of mental growth. In addition, there appears to be at least some support for the predictions of the phrenoblysis approach for the ages of greater and lesser effectiveness of intervention programs.

It should be stressed that phrenoblysis could also predict limited novel intellectual growth at the other brain growth plateau periods: eight to ten and twelve to fourteen years. The data for such periods are scanty, so that no analysis will be attempted. It is worth pointing out, however, that those who believe that junior high school students are not at ages of great intellectual growth can find compelling support in the fact that there is very little brain growth at that period.

GOALS OF SCHOOLING

The most obvious working hypothesis for schooling that can be drawn from the existence of phrenoblysis is that intensive intellectual input should be situated at the spurt ages. To this end we have given samples of the evidence that learning capacity and the success and failure of intervention programs are tied directly to the periods of the brain growth spurts.

The general idea is not a new one. We have quoted Whitehead and Vygotsky as among the early proponents of such an idea. More recently, this idea has been broached by the Piagetians who point out that their stages of intelligence development cry out for applications to schooling. The most direct of these proponents is Hans Furth, who has not only written a book entitled *Piaget For Teachers*,[40] but also, in collaboration with Harry Wachs, has run a Piage-

39. Hunt, "Reflections on a Decade of Early Education."

40. Hans Furth, *Piaget for Teachers* (Englewood Cliffs, N.J.: Prentice Hall, 1970).

tian type of program in a grade school in West Virginia, as described in their book *Thinking Goes to School.*[41] Furth and Wachs have tried to use Piagetian characterization of the development of intelligence in children to deduce what kinds of school activities will spur the child's development of his thinking capacity. The idea is that if he develops his capacities at the indicated normal ages, he will be able to utilize those developed capacities to acquire more readily and more deeply the informational content of school curricula.

An article by Kohlberg and Mayer may be cited as one more example.[42] Kohlberg is also a Piagetian, presumably because his own work showing the appearance of novel moral outlooks can be tied to the Piagetian stages. Kohlberg and Mayer argue that the benchmarks of development are the simultaneous appearance of cognitive and moral stages, whose fostering should be a minimal goal of both home and school activities. (This broadening of the stage idea to include both cognition and morality raises the question of whether still other aspects of child development might appear in correlation with those first two aspects. I am presently assembling the extant data on emotional or psychological development to determine if there are detectable stages and, if so, whether they appear to be correlated age-wise with the others).

From the point of view of phrenoblysis, the picture of development is even more supportive of such hypotheses because the occurrence of periods of little or no brain and mind growth raises the possibility that attempts to inject novel intellectual competencies not only will fail if tried at certain age periods, but that such attempts may be counterproductive. Children exposed to intellectual pressures and inputs for which they have no proper receptive circuitry may learn to reject such inputs; such a rejection might even result in an inability to take in such inputs later when the circuitry has developed.

On a subjective level, many school officials and teachers have talked about their pupils as "turning off" at certain ages, most

41. Hans Furth and Harry Wachs, *Thinking Goes to School: Piaget's Theory in Practice* (New York: Oxford University Press, 1974).

42. Lawrence Kohlberg and Rochelle Mayer, "Development as the Aim of Education," *Harvard Educational Review* 42 (1972): 449-96.

notably on entering high school. Teachers have described the bright youngsters entering junior high school as manifesting little interest in new intellectual challenges for a time and then, when entering senior high school, appearing to have lost interest in any and all learning challenges.

This matching of inputs and receptor circuitry is probably related to the well-known pedagogical concept of *readiness*, which is, parenthetically, an expression of the only accepted indication of the existence of stagewise intellectual growth to have penetrated the school systems.

From an experimental point of view, however, the concept of "turn-off" would be impossible to study, for there is no way to know what any individual would have done if he had been raised and educated in a different way. We will, however, later show a way of evaluating whether *groups* of children may be helped to reach higher stages of development by various intervention devices or by new schooling strategies. It should also be stressed at this point that there are more usual explanations of the turn-off in terms of puberty and its associated psychological correlates. Before invoking the psychological level of explanation it is wiser, in my judgment, to explore first the biological level of explanation, and in this instance the aspect of biology (brain growth) that is more directly related to the function involved—mental function.

The proposal to give new intellectual challenges to children during brain growth spurts leaves unanswered the question of what to do during the plateau periods. I offer the following as my own best guess. The child should be exposed to large amounts of information and to a wide variety of direct experiences with nature, science, people, and work, all from the point of view of enlarging his direct experience base and avoiding much pressure for elaborate inferences about the natures and interrelationships of such experiences. Furthermore, these would be periods for perfecting the long neglected memorization skills involved in the learning of poetry and songs, of the important facts of history, the facts of geography of the nation and of the whole earth, of health science facts, of legal facts, of citizenship facts, and so forth. During such periods we could also help children increase their skills in already initiated competencies. The details of many such activities should not be difficult to discover because the Piagetian studies give the competencies at many substages of the main stages, and the ages for particular activities can then be fairly well estimated.

From the point of view of experimentation, one could argue that the fact of phrenoblysis could logically lead to a very different hypothesis about what to do during slow-growth periods. This alternative viewpoint is that precisely because the children are in a slow-growth period, the input should be intensified. For example, children should be given intensive tutoring so as to maximize their learning at the slow-growth ages. All such inferences from phrenoblysis are in the nature of working hypotheses, so that it would be desirable to run such an intensive tutoring trial in parallel with the direct experience experiment in order to learn which paradigm best accords with nature's designs.

EVALUATION

The ways of characterizing intelligent people are many. Of these, the one that has always intrigued me most is the statement ascribed to a British nobleman to the effect that the mark of an intelligent person is that he knows what to do in the situation where he does not know what to do. This means, of course, that he can see what additional information will help him arrive at the position of being able to make a decision.

This way of thinking is also contained in the essence of a proposal made informally by the late Leo Szilard, who suggested that the intelligence quotient be replaced by the development of a stupidity quotient. Szilard argued that schooling and life experience can produce people who know what to do in certain situations not very different from those about which they have received instruction, but that we really want to know what they will do in novel situations. This can only be done by placing them in novel situations and seeing what they do, especially seeing which children or adults behave stupidly. Such people may be said to have acquired rote learning but no real thinking capacities.

Development of thinking capacities is equivalent to manifestation of the Piagetian stages. The achievement of the normal pattern of stages in the development of intelligence in children and their maturation at an adequate rate would be a goal substantially different from those normally pursued in our schools today. In addition, the extent to which the achievement is reached would constitute the proper means of evaluating any particular schooling paradigm.

To this end, then, I propose an evaluation scheme based on (a) the existence of stages in development of intelligence, and (b) the fact that few apparently normal adults manifest stage 5 intelligence, most do not manifest stage 4, and many do not even manifest stage 3. Presumably, disadvantaged children will grow up to be adults with even lower-than-average achievement of these stages. Only at this time could this evaluation scheme be set forth because its realization depends on the recent expansion of its Piagetian base through the work of Webb, Brown, and Arlin.

The idea is that the results of any educational experiment or strategy concluding at some given age will be measured in terms of the fraction of experimental children displaying the *next* Piagetian stage at its normal age. If this fraction is increased over that of the control children, the experiment will be considered successful. For example, an intervention program with children ages seven to nine years will be evaluated in terms of the fraction of such children who reach the next stage (stage 4, the age eleven-year stage of formal operations) at about age eleven years. As mentioned earlier, in the United States the percentage of adults displaying stage 4 is about 30 percent. The intervention program will be considered successful if the percentage reaches above 30 percent or whatever figure obtains for control children.

This part of the evaluation scheme could have been used even before the recent studies mentioned above. Now we can use Webb's result that maturation of new Piagetian competencies follows a time course inversely related to IQ. For children with normal IQs the maturation rate is typically a year or so at each stage. Thus, we should not only determine the age of onset of the next Piagetian stage but we should also study the children at, say, a year after the onset to see how much maturation of that stage has taken place. One can imagine that an intervention program or some changed curriculum could bring about the onset at the normal age but might not have laid the basis for its normal maturation. This stagewise evaluation can be used for all ages through the end of typical schooling around age eighteen because the work of Arlin has now given us the additional data needed to cover intelligence development up through that age. And, it is worth suggesting that along with the altered schooling should go a program of head circumference measurements designed to check the correlations inherent in the concept of phrenoblysis.

In general, the idea is that education, better called schooling, should be aimed at helping children arrive at biological and mental check points with the proper biological and mental equipment to enter the next stage and to accomplish that stage at a suitable rate. This gives an internal rhythm to schooling strategies. Once a stage has been reached, the new competencies should be extensively utilized to acquire the new and detailed understandings of many processes and subjects that have become accessible to the newly upstaged mind.

Two Further Comments

SEXUAL DIMORPHISM

It was pointed out above that the brain growth spurt of girls at age eleven years is about twice that of boys, while something like the converse is true of the brain growth spurt that occurs around age fifteen years. If we connect brain growth with mental growth, the question arises about the implications of a quantitative difference in brain growth during a spurt period. In this instance of a quantitative difference, it might be possible to discover the implications because it accompanies a sexual dimorphism so that the two classes of individuals are readily distinguished.

A simple hypothesis would be that girls need a very different, and more challenging, curriculum from that of boys at both ages, the input being far more intense and complex for girls around age eleven, and correspondingly less intense and complex around age fifteen. One can imagine that curricula developed mainly for boys could be inadequate or even harmful for girls at age eleven. Indeed, the failure to adapt educational inputs at this age to the far greater capacities of girls might be responsible for the relative lack of females in the more theoretical or abstract professions. Presumably, moreover, the inadequate program for age eleven girls would later make the girls' smaller development at fifteen even less effective.

This line of thought can be related to the famous proposition enunciated by Bruner stating that "the foundations of any subject may be taught to anybody at any age in some form."[43] Our failure to recognize the higher-level form accessible to girls around age eleven may deprive them of the needed background on which to build their subsequent intellectual growth.

A second hypothesis would be that the more substantial later brain and mind growth of boys is responsible for the differential competencies and that there is no way to make up for the relative brain growth deficit of girls at the later (and intellectually more important) age at which Arlin has shown that creative thinking emerges.

Some indications of the ramifications of the brain dimorphism might be gained from determining the fractions of males and females that show Piagetian stages 4 and 5 at their normal onset ages. A significant difference at either of these ages would signal the need for experimentation to try to discover ways of bringing the lower-ranking sex up to the fraction of the other sex showing the stage. Or, if the fractions parallel the brain dimorphism, it would give support to the inference that the sexes should be separately educated after age ten years in order to maximize each child's development of his native intellectual competence. The number of experiments that can readily be imagined is so great that there is no need to try to list them. What is needed is careful planning to do just those experiments whose results will give guidance to the later research on the functional implications of sexually dimorphic brain growth spurts.

SENSORY PROGRAMMING

If there is a stagewise character to development, perturbations are likely to be more damaging if they occur at ages of rapid development. Dobbing has already pointed out this likelihood as the basis of the extremely severe effects on *body growth* if humans or animals are undernourished during times of rapid *brain growth*; the

43. Jerome Bruner, *The Process of Education* (New York: Vintage Books, 1960).

greater effect on brain growth itself is self-evident.[44] We shall use this insight to guide our brief presentation of the appearance of sensory development in humans. Our purpose is to see if there is any reason to associate appearance of new sensory functioning with any ages or stages. The data available are for hearing/talking, language learning, and binocular vision. At birth, children do not talk or understand language; their vision is so rudimentary that it is clear that perception develops postnatally although the child can readily be shown to detect light at birth.

Few children manifest any great amount of language competence before the end of the first year of life. Therefore, if programming of the brain for language is to be shown to correlate with any brain growth spurt, the programming would have to occur during the two to four year period. The data assembled by Lenneberg give the consequences for language production of injuries to or tumors in the left hemisphere of the brain.[45] His data show that if a child suffers one of these two insults before about age twenty months, his eventual production of language is not measurably delayed or abnormal. If the insult occurs between that time and about four years of age, the child loses whatever language he had acquired, reverts to babbling, and learns language all over again. If the insult occurs after age four years, the child does not lose language and recovers whatever is consonant with the extent of the injury. Thus, we may infer that active programming of the left hemisphere for language has its onset at about age twenty months and lasts until age four years. The period is clearly similar to the two to four year period discovered from brain and cognition data.

The data for hearing/speaking refer to the problem of teaching the virtually deaf to use language. The data of interest were obtained by Wedenberg in Sweden.[46] He developed an auditory training method for handling profoundly deaf children. His success may be measured by the fraction of normal speaking vocabulary

44. Dobbing and Sands, "Quantitative Growth and Development of Human Brain."

45. Eric Lenneberg, *Biological Foundations of Language* (New York: John Wiley and Sons, 1967).

46. Erik Wedenberg, "Auditory Training of Severely Hard-of-Hearing Preschool Children," *Acta Oto-Laryngologica*, Suppl. 110 (1954).

possessed by these children at about age nine years, at which age most of the testing was done. If the auditory training was begun at any age up to two years, the children reached maximum success, which is typically 80 percent. If the training began after that age, there was a precipitous drop in success, so that by age three and a quarter years the success was down to 40 to 50 percent and reached a basal level of about 5 percent by about age four years. Thus, auditory training is effective only during the period of spurt in brain growth between ages two and four.

Recently Banks, Aslin, and Letson published the first collection of data on the age-dependence of the effectiveness of surgery in producing binocular vision in children suffering from strabismus.[47] They found that if the strabismus began at any age from birth to about two years, surgery by age two years restored about 75 percent of normal binocular vision. Surgery after age four years was useless for other than cosmetic purposes. On the other hand, if the strabismus began after age five years (there were no data between three and five years), surgery at any later age was 100 percent successful.

All these studies lead to the same conclusion: when the human brain is being programmed for the mental growth spurt correlated with the spurt in brain growth between ages two and four it is simultaneously being programmed for vision, language, and hearing/speaking. Those workers trying to help very young children to overcome physical handicaps impinging on their learning capacities should be aware of the much greater positive prognosis if their efforts are concentrated during the spurt period. It would be very interesting to know the results of similar remedial efforts during later spurt and plateau periods.

47. Martin S. Banks, Richard N. Aslin, and Robert D. Letson, "Sensitive Period for the Development of Human Binocular Vision," *Science* 190 (1975): 675-77.