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Rosalind Driver

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When is a stage not a stage?

A critique of Piaget's theory of cognitive development and its application to science education

Rosalind Driver, The Centre for Studies in Science Education, University of Leeds

Summary

Piaget's theory of cognitive development, in particular his 'stage theory', is having a significant influence on thinking about school science curricula. In the trend to more informal and child-centred methods, his ideas have formed a base for many primary science programmes over the world.[1] Until fairly recently, however, the impact of his thinking has not been felt in secondary science programmes. There are now signs that this is changing. The Piagetian model, particularly the stage theory, is being used in this country and elsewhere as both a scale on which to measure scientific development[2] and an explanatory system to account for the difficulties secondary school pupils encounter in understanding scientific ideas.[3,4,5] With this growing awareness of Piaget's work and its implications among secondary science teachers and curriculum developers perhaps it is timely to take a step back and review the status of the work critically. Since it is addressing itself to the relevance of Piagetian theory to learning science at the secondary school level, the focus of this paper is specifically on studies which relate to the development from concrete to formal level thinking. The first part outlines Piaget's general epistemological position and specification of the formal level of thought. This is followed by a discussion of three areas of problem with the Piagetian analysis: problems inherent in the specification of the logical model of formal thought; assumptions underlying Piaget's research methodology; and some problems with empirical findings. The second part of the paper comments on consequent problems in attempts to apply the Piagetian ideas to secondary science education. The paper ends by assessing the aspects of Piagetian work which may contribute to science education in the future.

The formal level: a critique

What game is Piaget playing? The assumptions of genetic epistemology

Piaget is an epistemologist. As such his primary concern has been 'how can we come to know anything?' The object of his study is the 'epistemic man'. It is important to understand this focus since certain theoretical and methodological assumptions follow from it. One such central assumption or hypothesis is that of the existence of cognitive structures which are common to members of the human species. In this respect there is a similarity between Piaget's cognitive psychology and assumptions made by other structuralists (e.g. Levi-Strauss in anthropology and Noam Chomsky in linguistics). All postulate the existence of universal cognitive structures in order to explain aspects of human social or intellectual behaviour. They argue that, although our knowledge of the world is gained through our senses, perceived phenomena have the characteristics which we attribute to them because of the way the human brain is designed to order and interpret stimuli. In addition Piaget adds a developmental dimension to his hypothesis by saying that we come to *know* through the development of structures which process our perceptions of experience. We communicate and share knowledge because of similarities throughout the human

species in these structures as they have evolved through interaction with common elements in the environment.

Piaget indicates in his writings that he considers these cognitive structures as having neurophysiological status. In order to study their development he argues a form of recapitulationism, i.e. that 'ontogeny recapitulates phylogeny'.

> The fundamental hypothesis of genetic epistemology is that there is a parallelism between the progress made in the logical and rational organization of knowledge and the corresponding formative logical processes. Of course, the most fruitful field of study would be reconstituting human history – the history of human thinking in prehistoric man. Since this field of biogenesis is not available to us, we shall do as biologists do and turn to ontogenesis.[6]

Piaget's well known stage theory specifies the operations or processes characteristic of certain stages of development from birth to adulthood. At the concrete stage, for example, he specifies eight structures or 'groupements'. These operations are forms of classification and multiple groupings. He postulates that these develop into a 'structured whole' in the 'complete combinational system' during adolescence. His work with children illuminates how these structures are involved in their thinking in varying contexts: space, time, causality, morality etc.

In addition to the stage theory, Piaget postulates the mechanism by which these operations develop through the process he calls 'equilibration'. This is the process by which the learner assimilates new information into his cognitive structure and in so doing changes or accommodates that structure. In this respect his theory has an environmental component to it. In fact he suggests that the development of the cognitive structures depends not only on maturation and 'autoregulation' but on the social and cultural influences in the environment.

What is formal thought?

It is understandable how anyone coming new to the literature in this field might well be confused. Piaget's ideas concerning the formal level have been taken, used and adapted in use by various people. Each now imposes his or her own meaning on them, producing a range of significantly different elaborations. For example the work of Lunzer reflects his concern to study context-free thinking skills.[7] Lovell[8] writes about levels of abstraction from concrete referents in relation to formal thinking. Peel[9] on the other hand has focused attention on the difference between generalization and abstraction.

Here I shall comment only on what I understand as Piaget's interpretation of formal thought as outlined in *The Growth of Logical Thinking.*

Far from being a vague notion about 'being able to think in the abstract', formal level thought for Piaget was characterized by the existence of 'integrated structures' which could be modelled mathematically. The detailed descriptions of these mathematical models are documented elsewhere.[10]

One characteristic of this level of thought clearly stated by Piaget was its independence of context. 'At the formal level, in contrast with the preceding level, the operational form is entirely dissociated from thought content. We see concepts of proportions and especially combinatory considerations appearing at the same level in the most diverse areas.'[11]

Problems of specifying formal level structures

A problem exists here at two levels. First there is the question of the internal validity of the mathematical models suggested by Piaget as descriptors of the formal thinking structures. Secondly there is perhaps the more subtle and difficult question of relating the formal model to specific behaviours, i.e. what criteria should be used to identify formal thought 'in action'.

On the first level, problems internal to Piaget's mathematical model itself have been identified, notably by the logician Parsons.[12]

Problems of the second kind have also been identified. In a recent critique, Ennis[13] analyses Piaget's writings and identifies four criteria used to determine instances of formal operational thought: that the subject uses the language of propositional logic (which at other places Piaget himself states is not an adequate criterion); that the subject uses suppositional reasoning; that subjects can distinguish one operation from another; and that subjects can isolate variables.

Ennis takes each criterion in turn and concludes that it is either irrelevant to the formulation of the formal level (as in the case of the ability to isolate variables), that it is not sufficient proof (as in the

case of the use of the language of propositional logic) or that young children can also perform the task (as he argues is the case with suppositional reasoning). He concludes: 'No matter what the interpretation, I have concluded that the claim (Piaget's formulation of the formal level structures) is either false, or untestable or not about deductive logic.'[14]

We are left to conclude, then, that not only are there fallacies in the mathematical formulation of the structure of formal thought, but that the criteria for detecting its existence either do not relate correctly to the structure, or lead to untestable situations, or indicate skills which children much younger than adolescents can master.

Where does this place the status of the formal level structures postulated by Piaget? Might the problem be more tractable if one were prepared to abandon the elegance of the notion of a 'structured whole' and instead look for separate, more identifiable skills which appear to develop during adolescence? There is some empirical evidence, for example, that skills such as handling problems involving ratio and proportion, or the ability consciously to control variables in an experiment may be such skills.[15,16,17] However, postulating that these skills develop during adolescence is very different from suggesting that they are indications of a stage of thought, with the implication of unity of operations that comes with it.

Assumptions underlying Piaget's reaearch methodology

The way *The Growth of Logical Thinking* was written is an example of the role that theory plays in Piaget's work. It is the *a priori* in his work; structures such as the INRC group or the additive grouping of classes, arising as they do no doubt from his very wide experience of working with children, are the focus of the work around which the data are collected and selected. Piaget is by no means unique in presenting his theory in this *a priori* fashion; the approach has parallels in the so-called 'hard' sciences. However, where the difference lies is in the relationship between the theory so presented and the data. First, the experiments performed in Geneva are selected and shaped to reflect the underlying structures being studied, as opposed to possibly putting their existence to a critical test. Secondly, the data collected are reported in a selective way by Piaget so that they are shown to be consonant with the theory. Even the instances Piaget does report have been shown to be open to alternative interpretations.[18] Thirdly, perhaps the most powerful mechanism of self-perpetuation arises in the way the replication studies are done.

Here we see the limitations of the Piagetian theoretical framework most clearly manifested. The procedure adopted is usually to follow as closely as possible the procedure Piaget has given for administering the tasks. The responses are then scrutinized using the criteria Piaget specifies. Implications are drawn as to whether or not certain structures do or do not exist and at what ages they develop. The question is 'do the children have a certain cognitive structure?' (for example hierarchical classification, or conservation of number) as opposed to asking the more open-ended question 'what structures of thought do the children use to handle problem situations?'.

As a result of such studies, bold statements are made about the universality of such structures. One might ask, however, whether this is very surprising in view of the way data have been collected. If you approach a child with two equal balls of clay, roll one out into a sausage and ask, 'Is there more now, the same, or less than in the ball?', what are the possible responses the child can make? He is either a 'conserver' or not. The ways in which the task is set up and the data are processed mean that the structures underlying the formulation of the stage theory are not questioned. The data do not radically question the kinds of structures the children are using, but simply check whether or not the structures suggested by Piaget are present or not and at what ages they develop.

We see this problem particularly in relation to cross-cultural Piagetian studies where inferences are made about children going through the same stages but perhaps at different rates depending on their cultural environment.[19,20] Again might we not ask whether, or to what extent, such findings are a function of our research methods rather than a reflection of the children's dominant cognitive structures? Are we not defining the possible responses by the inherent structure in the tasks? Particularly in cross-cultural situations might not a more profitable research question be 'what structures or cognitive strategies do people use in certain problem situations?' rather than 'what evidence is there that they use certain specified structures?'.[21,22] In their recent work *Culture and*

Thought Cole and Scribner[23] outline a methodology for research involving the co-operation of anthropologists, linguists and psychologists in unravelling the complex issues underlying the study of culture and cognition. Although the need for such a team effort is more obvious when people from the western culture and western science study people with a different background, there might be value in turning a sceptical eye on the methodology in this field employed within our own society.

In summarizing the argument here, what needs to be emphasized is that it is the interpretation of the data, not the data themselves, that is being called into question. In fact the phenomenon of the interesting responses children make to certain situations has been verified time and again, in some cases by very sceptical experimenters. What can be acknowledged is that Piaget's theoretical interpretations have served a purpose as heuristic devices in generating the very rich collection of data on children's behaviour.

So far the issues raised have been those which question the relation between the data and the theory. Another methodological question arises relating to Piaget's selection of children for the tasks. Here we see how an implicit assumption in Piaget's thinking affects the way he selects children for the tasks and the implications he draws from the results.

We have already mentioned that Piaget's concern has been the search for universal structures of thought: the pursuit of the 'epistemic man'. With such a concern, the question of sampling is an irrelevant one; any child is as good as any other as an example of the cognitive structures at work. When developing his hypotheses on the nature of the developmental process Piaget has used children from local schools in Geneva, and little attempt has been made to study the same child's response in different situations or to do longitudinal studies of the same child.

The way the population has been sampled by Piaget, therefore, is in keeping with the search for universal structures, and underlines the fact that documenting variability is not his concern. Although replication studies have paid more attention to the question of sampling, these have still tended to be cross-sectional studies. Studies of the longitudinal development of individual children are very few (perhaps for obvious practical reasons). When such studies have been done, for example by Wallace,[24] they indicate that children do not follow identical paths in their cognitive development.

So far the discussion has focused on limitations of Piaget's work as an empirical exercise. One could, of course, assert that Piaget's work is not in the tradition of empirical science. He does not make operational definitions nor does he specify criteria by which children's thinking can reliably be assessed (though other researchers have attempted this). Piaget's way of working and of handing on his insights takes on the form almost of induction into a practice. As medical students follow the specialist on his ward rounds, learning through example the subtleties of diagnosis, so those involved in Piagetian work first need a period of apprenticeship in order to develop their subjective judgements, this apprenticeship being served in the clinical interview and analysis of many children's behaviour. If this is so, it is perhaps irrelevant to criticize Piaget's work as falling short of a model he does not pretend to adopt. The criticisms, however, should be made against those who attempt to use his work and interpret it within the empirical tradition.

Empirical results

As mentioned earlier in the paper, in *The Growth of Logical Thinking* Piaget clearly indicates that the acquisition of formal thinking differs from that of concrete thought in that the operations do not depend on the context of the task: 'The development of concrete operations, unlike that of at least the more elementary formal operations, can never be dissociated from the intuitive content to which such operations need to be applied.'[25] (It is perhaps worth commenting here that this inference by Piaget was made without data on the performance of the same subjects on different tasks.)[26]

Replication studies following the publication of Inhelder and Piaget's work immediately threw some doubt on this statement.[27,28] They showed that even on the formal level tasks children operate at different levels in different contexts; although the logical structure of two tasks may be identical, that one is easier than the other is evidenced by children successfully solving the task earlier.

In a review of several more recent studies by Brown and Deforges[29] the authors suggest that far from formal level structures being task inde-

pendent, the level of inter-task correlation reported by various studies is of the order of 0.4. This means that a child can use formal level thought in one situation but not in another. Also, not only does a child operate at a different level (according to the stage model) depending on the context of the task, but there is considerable variability on the level of operation on a given task for a particular age group. Such results not only call into question Piaget's assertion about formal thought but also suggest limitations of the utility of the theory. Brown and Desforges comment that 'if the stage theory is to have utility there must be a substantial degree of homogeneity within the behaviours of most children for the greater part of each stage. If on the other hand heterogeneity is characteristic of most children's performances most of the time, predictions cannot be made for behaviour or educational tasks beyond assessed areas.'[30]

Reasons for this lack of homogeneity have been discussed by Lunzer.[31] He suggests that tasks, though identical from the structural point of view, may differ in their complexity and in the degree of familiarity of the subject with the terms and ideas in the task. The most powerful reason for the comparative difficulty of tasks he suggests as being due to the degree of consonance or dissonance with previously existing notions (i.e. their credibility). 'Such an emphasis on content as opposed to structure finds less support in the works of Piaget, but seems to be required by the facts.'[32] This suggestion by Lunzer has since been supported by evidence in the elegant studies by Wason and Johnson-Laird.[33] In one set of experiments in this sequence, the authors are studying the extent to which subjects' familiarity with the subject matter affects their reasoning. They comment: 'The experiment confirmed our view that the individual tends naturally to think in a causal fashion, and that if this tendency is set into opposition with the logical requirements of an inference, it is extremely difficult for the correct deductions to be drawn.'[34]

Later the authors compare the difficulty of abstract problems as compared with those set with concrete material:

> (Concrete material) confers upon (a subject) a natural facility in making assumptions and deductions, but whether such facility is to be turned to advantage depends precisely upon the structural requirements of the task. When the two coincide, as in the vast majority of our studies and those of others (e.g. Inhelder and Piaget, 1958), then the reasoning is relatively easy. When the two conflict, then causality tends to win, to the detriment of logical performance.

The authors conclude with the following comments concerning the usefulness of formal logic in constructing psychological models of reasoning:

> From some considerable time we cherished the illusion that ... only the structural characteristics of the problem mattered. Only gradually did we realise first that there was no existing formal calculus which correctly modelled our subjects' inferences, and second that no purely formal calculus would succeed. Content is crucial, and this suggests that any general theory of human reasoning must include an important semantic compenent.[35]

However appealing it might be to look for content-independent structures in human thought, this study should serve as a cautionary note.

Problems of application

Problems of specifying formal level thinking: is it an entity or a collection of skills?

It has proved difficult enough for theorists to agree on their specification of criteria of assessment of the level of subjects' thinking. The apparently simple idea of formal level thought as being described as the subject performing operations on operations, or second order operations is not easy to identify in practical situations. There is therefore a problem in selecting tasks which are valid tests of formal thought as a whole. Since, as was argued earlier, formal operations may not be a 'structured whole', any task may test only a specific skill, and thus make the drawing of inferences of the subjects' ability on other tasks problematical. To make predictions on the overall level of performance of pupils in a range of curricular activities appears completely unjustified. Many people working in the area of cognitive development admit that the phenomenon of 'formal thinking' exists, yet like a spectre it eludes capture.

If, then, there are general cognitive skills which develop during adolescence, such skills need identification and analysis as separate entities. Only when this is done will it be possible to articulate science content with cognitive skills in the degree of detail which is necessary. Some studies on the relationship between proportional reasoning and the understanding of specific curricular areas such as chemical equations[36] or using the concept of speed[37] indicate the degree of specificity needed.

Problems in analysis of the conceptual demands of subject areas

One of the reasons given for assessing pupils' levels of thinking is to enable a match to be made between the level of cognitive functioning of the learner and the demands of the curriculum. This, therefore, involves submitting curriculum materials to an analysis for the level of demand they make. The technique for doing this which has been developed by Shayer[38] is now well known.

The problems associated with assessing pupils' level of thinking apply equally well to the analysis of the demands of curriculum materials, in that we may not be concerned with a unique level but a collection of skills each with their developmental pattern.

In addition there is a further problem in that implicit in the analyses of the conceptual demand of curriculum materials is the assumption that all subjects need to think through a problem in a certain way in order to solve it. On the contrary, what may be solved by one subject using formal operational thought, may be approached by another by concrete operations.

The dependence of thinking skills on the context of the task

We have seen the extent to which the level of children's thinking depends on the context of the tasks given, rather than on the logical structure of the task. This obviously calls into question our ability to test children and make statements about the level at which they are operating.[39] Related to this, and perhaps even more important, it calls into question how useful such information is to teachers since they will not be able to predict the level of the child's thinking in a new context from his scores on those tasks.

If the aim of this type of research is to help teachers match the pupils' thinking abilities to the educational programme offered, it appears from the points raised earlier in this paper that we are far from being able to be prescriptive in this way (even if it were considered educationally beneficial).

Influence of Piagetian structures on curriculum

The danger indicated here is to assume that the only structures of thought necessary to develop are those discussed by Piaget. In the case of formal thinking this implies developing pupils' abilities to separate and control variables, to understand proportionality etc. This can lead to teaching schemes such as 'Science 5/13' where it might be argued that activities are at times somewhat artificially included because they enable such thinking skills to be used. Here we see psychological processes of thought (of questionable standing) taking a dominant place over the science content in the curriculum. Is the tail wagging the dog?

Further practical considerations

Because of the ability of research workers to influence thinking of teachers on curriculum matters, there is a danger that curriculum materials will be prepared based in too uncritical a manner on the prescriptions of such research. It may indeed be the case that such an approach may produce counter educational effects by labelling children and running the danger of pupils perpetuating teachers' expectations of them: children being labelled as clearly only capable of logical thought when manipulating concrete material may be relegated to the science laboratory's equivalent of the sand tray and water play.

A distinction needs to be made between those who see in Piaget's work a quasi-scientific theory which will enable educators to construct more effective instructional systems, and those who see in it a rationale for a more child-centred education.

Can we separate the baby from the bath water?

Having reviewed what I see as fallacies, dangers or difficulties, it is important to emphasize that there are aspects of Piaget's work about which we can be positive. First, we must separate the phenomena concerning children's thinking from the suggested interpretation of it. Many initially sceptical researchers have found that Piaget's experiments have given repeatable results.

However these data are interpreted, the immense volume of work of Piaget and his co-workers documents the range of children's perceptions and interpretations of experience. Implicit in this is the need therefore to consider what children bring to a new learning experience. Here I would argue not for coarse diagnostic tests of levels of thought but for much more weight on the need for diagnosing problems in specific content areas, and in particular for teachers to be their own diagnosticians: to be aware that part of their teaching function is to understand how a pupil interprets a situation in order to lead him or her to a fuller or different understanding. Secondly, a case has been made to question both the idea of a stage of formal thought and the structural representation suggested by Piaget. However, this does not imply a rejection of the search for underlying patterns in cognitive development. Finally, Piaget's idea of learning as equilibration and the related idea of operation knowledge is a reminder that each learner has to think old thoughts anew and tread well-trodden paths again; that far from being a boring repetition this can be an interesting journey for each individual.[40]

References

1. ESS and SCIS in America; 'Science 5/13' in England; 'SEPA Science' in Africa.
2. 'Progress in Learning Science.' A Schools Council Project at the University of Reading, directed by Dr Wynne Harlen.
3. SHAYER, M. (1970). 'How to assess science courses', *Education in Chemistry*, 7, 5, 182–6.
4. LAWSON, A. and RENNER, J. (1975). 'Relationships of science subject matter and developmental levels of learners', *J. Res. Sc. Teaching*, 12, 347–58.
5. SAYRE, S. and BALL, D. (1975). 'Piagetian cognitive development and achievement in science', *J. Res. Sc. Teaching*, 12, 165–74.
6. PIAGET, J. (1970). *Genetic Epistemology*, p. 13. Columbia University Press.
7. LUNZER, E. A. (1973). 'The development of formal reasoning: some recent experiments and their implications'. In FREY, and LANG, *Cognitive Processes and Science Instruction.* Bern: Hans Huber.
8. LOVELL, K. (1974). 'Intellectual growth and understanding science', *Studies in Science Education*, 1, 1–19.
9. PEEL, E. A. (1971). 'Generalising and abstracting', *Nature*, 230, 5296, 600.
10. FLAVELL, J. H. (1963). *The Developmental Psychology of Jean Piaget.* London: Van Nostrand Reinhold.
11. INHELDER, B. and PIAGET, J. (1958). *The Growth of Logical Thinking from Childhood to Adolescence.* New York: Basic Books. 265.
12. PARSONS, C. (1960). 'Inhelder and Piaget's *The Growth of Logical Thinking, II:* a logician's viewpoint', *Br. J. Psychol.*, 51, 75–84.
13. ENNIS, R. (1975). 'Children's ability to handle Piaget's propositional logic: a conceptual critique', *Rev. Educ. Res.*, 45, 1, 1–41.
14. Ibid., p. 39.
15. BRAINERD, C. J. (1971). 'The development of the proportionality scheme in children and adolescents', *Dev. Psychol.*, 5, 469–76.
16. LUNZER, E. A. and PUMPHREY, P. D. (1966). 'Understanding proportionality', *Mathematics Teaching*, 34, 7–12.
17. LOVELL, K. and BUTTERWORTH, I. B. (1966). 'Abilities underlying the understanding of proportionality', *Mathematics Teaching*, 37, 5–9.
18. See, for example, the alternative analysis of the protocol reported by Inhelder and Piaget in *The Growth of Logical Thinking* which they present as an example of the 16 binary operations. WEITZ, L. J. *et al.* (1973). 'Piaget's system of 16 binary operations: an empirical investigation', *J. Genet. Psychol.* 123, 279–84.
19. ASHTON, P. (1975). 'Cross-cultural Piagetian research: an experimental perspective', *Harv. Educ. Rev.*, 45, 4, 475–506.
20. BERRY, J. W. and DASEN, P. R. (Eds) (1974). *Culture and Cognition: Readings in Cross-Cultural Psychology.* London: Methuen.
21. A well known study which reflects the former type of approach is that of GAY, J. and COLE, M. (1967). *New Mathematics in an Old Culture.* New York: Holt, Rinehart and Winston.
22. Further issues in cross-cultural Piagetian work are explored in a paper by KAMARA, A. I. and EASLEY, J. A. (1976). 'Is the role of cognitive development uniform across cultures? A methodological critique with new evidence from Themne children'. In: DASEN, P. R. (Ed.) *Piagetian Psychology: Cross-Cultural Contributions.* New York: Gardner Press.
23. COLE, M. and SCRIBNER, S. (1971) *Culture and Thought: A Psychological Introduction.* New York: Wiley.
24. WALLACE, J. G. (1972). *Stages and Transition in Conceptual Development.* Slough: NFER.
25. INHELDER, B. and PIAGET, J., op. cit.
26. More recently Piaget has revised his view. PIAGET, J. (1972). 'Intellectual evolution from adolescence to adulthood', *Hum. Dev.*, 15, 1–12.
27. LOVELL, K. (1961). 'A follow-up study of Inhelder and Piaget's *The Growth of Logical Thinking*', *Br. J. Psychol.*, 52, 143–53.
28. JACKSON, S. (1965). 'The growth of logical thinking in normal and subnormal children', *Br. J. Educ. Psychol.* 35, 255–8.
29. BROWN, G. and DESFORGES, C. (1977). 'Piagetian psychology and education: time for revision', *Br. J. Educ. Psychol.*, 47, 7–17.
30. Ibid.
31. LUNZER, E. A. (1965). 'Problems of formal reasoning in test situations', *Monograph of Society for Res. in Child Dev. No. 100*, 30, 2, 19–46.
32. Ibid., p. 45.

33. WASON, P. C. and JOHNSON-LAIRD, P. N. (1972). *Psychology of Reasoning: Structure and Content.* London: Batsford.
34. Ibid., p. 74.
35. Ibid., pp. 244–5.
36. WHEELER, E. A. and KASS, H. (1977). Proportional Reasoning in Introductory High School Chemistry. Paper presented to the fiftieth Annual Meeting of the National Association for Research in Science Teaching, Ohio.
37. BOULANGER, D. F. (1976). 'The effects of training in the proportional reasoning associated with the concept of speed', *J. Res. Sci. Teaching,* 13, 2, 145–54.
38. SHAYER, M. (1970). 'How to assess science courses', *Education in Chemistry,* 7, 5, 182–6.
39. The type of survey research being undertaken in this country is reported in SHAYER, M., KUCHEMANN, D. E. and WYLAM, A. (1976). 'The distribution of Piagetian stages of thinking in British middle and secondary school children', *Br. J. Educ. Psychol.,* 46, 164–73.
40. See DUCKWORTH, E. (1972). 'The having of wonderful ideas', *Harv. Educ. Rev.,* 42, 2, 217–31.