DOCUMENT RESUME

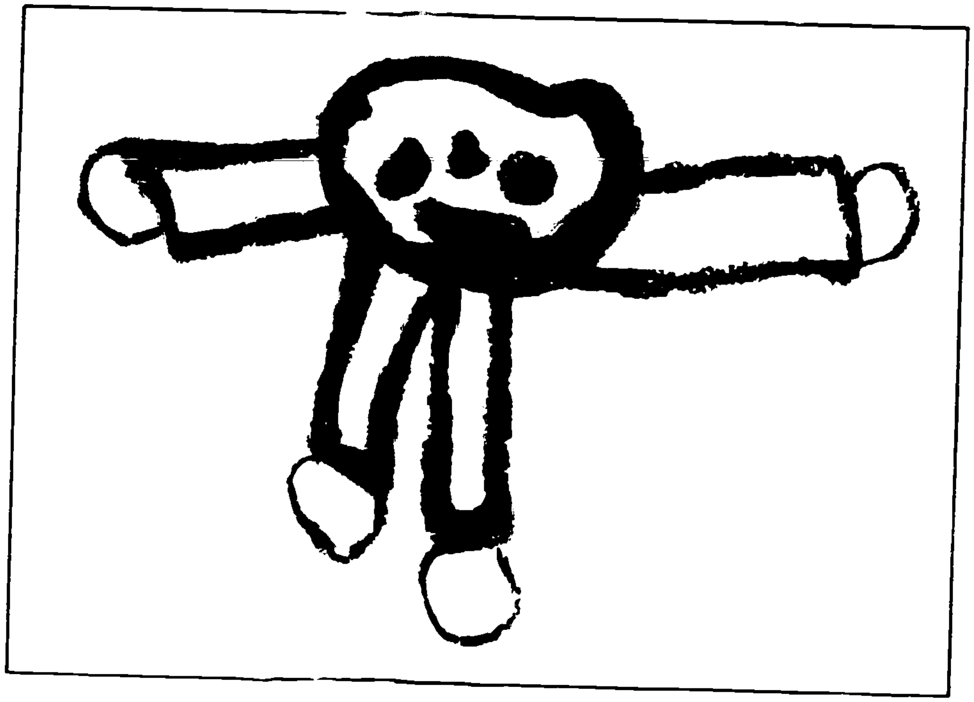
ED 171 741 TM 008 769

AUTHOR Duckworth, Eleanor
TITLE The African Primary Science Program: An Evaluation and Extended Thoughts.
INSTITUTION North Dakota Study Group on Evaluation, Grand Forks.
SPONS AGENCY Rockefeller Bros. Fund, New York, N.Y.
PUB DATE Feb 78
NOTE 145p.
AVAILABLE FROM Center for Teaching and Learning, University of North Dakota, Grand Forks, North Dakota 58202 ($5.00)

EDRS PRICE MF01/PC06 Plus Postage.
DESCRIPTORS Curriculum Development; *Curriculum Evaluation; Educational Objectives; Elementary Education; *Elementary School Science; Evaluation Methods; Experimental Curriculum; Foreign Countries; *Inquiry Training; *Intellectual Development; Learning Activities; *Manipulative Materials; *Science Instruction; Science Materials; Scientific Concepts
IDENTIFIERS Africa; *African Primary Science Program; Piagetian Tests

ABSTRACT

The philosophy underlying the African Primary Science Program, according to the author, is that the essence of science is not merely the statement of principles; it involves the struggle to find out about the material world. This program sought to develop the intellectual alertness of the children, and improve their questioning, and problem solving processes. Anecdotes describing learning activities characteristic of this program are presented, as well as a brief description of its development and underlying philosophy. The curriculum was evaluated by comparing the performance of experimental classes and non-exposed classes on a variety of tasks using manipulative materials; the observation procedures are described in detail. The results are summarized in terms of task performance, student behavior, and development of students' potential. The appendices guidelines for evaluating a child's day-to-day progress; ways to find out from teachers whether or not the unit is working; hints for writing science units; a discussion of concepts; a brief account of problem solving tasks presented in two Massachusetts fifth grade classes; and a 93-item bibliography. (GDC)



Eleanor Duckworth

THE AFRICAN PRIMARY SCIENCE PROGRAM: AN EVALUATION AND EXTENDED THOUGHTS

University of North Dakota
Grand Forks, ND 58202
February 1978

First published in 1978

North Dakota Study Group
on Evaluation, c/o Vito Perrone,
Center for Teaching & Learning
University of North Dakota
Grand Forks, N.D. 58201

Library of Congress Catalogue
Card number: 78-52229

Printed by University of
North Dakota Press

A grant from the Rockefeller Brothers Fund
makes possible publication of this series

Editor: Arthur Tobier

In November 1972, educators from several parts of the United States met at the University of North Dakota to discuss some common concerns about the narrow accountability ethos that had begun to dominate schools and to share what many believed to be more sensible means of both documenting and assessing children's learning. Subsequent meetings, much sharing of evaluation information, and financial and moral support from the Rockefeller Brothers Fund have all contributed to keeping together what is now called the North Dakota Study Group on Evaluation. A major goal of the Study Group, beyond support for individual participants and programs, is to provide materials for teachers, parents, school administrators and governmental decision-makers (within State Education Agencies and the U.S. Office of Education) that might encourage re-examination of a range of evaluation issues and perspectives about schools and schooling.

Towards this end, the Study Group has initiated a continuing series of monographs, of which this paper is one. Over time, the series will include material on, among other things, children's thinking, children's language, teacher support systems, inservice training, the school's relationship to the larger community. The intent is that these papers be taken not as final statements--a new ideology, but as working papers, written by people who are acting on, not just thinking about, these problems, whose implications need an active and considered response.

Vito Perrone, Dean
Center for Teaching & Learning,
University of North Dakota

Contents

o Dav_d Hawkins, who led me to realize that I could have some significant thoughts of my own.

Preface

This monograph is cast primarily in the form of a research report but it is much more than that. My principal purpose in this introductory note is to alert readers to the importance of attending -- not only to the findings -- but to the way of thinking about evaluation that guided the inquiry. The findings are, indeed, impressive: this is one of the first studies to demonstrate significant differences in performance on Piagetian tasks between children exposed to an experimental elementary science curriculum based on the principles of informal education and a more conventionally schooled control group. Equally significant though, from my point of view, is the great service the monograph provides by demystifying the evaluation process. In recent years, we have witnessed the creation of a new breed of professional specialists -- the evaluation experts. Many teachers have been intimidated by esoteric and technical evaluation methods and have lost faith in their own ability to think critically about the effectiveness of their teaching. Eleanor demonstrates that it is possible to devise strategies for evaluating informal education programs that are both comprehensible and faithful to the educational premises underlying those programs. She reminds us that evaluation, at its best, can serve the needs of children and teachers; it is an integral part of reflective practice.

It has become commonplace to decry the inappropriateness of conventional standardized measures of scholastic progress; yet, few informal educators have managed to go beyond that critique to the actual development of alternative evaluation strategies. Too often, we are trapped in our thinking by a false dichotomy between process and outcome. We are pleased when children seem involved in the daily life of the classroom but, at the same time, we worry that they will not -- in the end when the testers come round -- demonstrate that they have learned all that they should. But what should they have learned? The clarity of Eleanor's response to this question is instructive. Schools should teach children to use their intelligence to ask their own questions and to figure out ways of finding answers to them -- nothing more and nothing less. The answer is deceptively simple -- for embedded in this reply are a set of convictions about intellectual development grounded in years of reflection and experience. The essence of these reflections is distilled in Ch. 1 -- The Having of Wonderful Ideas -- the best account I've read on the relevance of Piagetian theory to teaching and learning.

How can we determine if children have learned to use their intelligence? Eleanor suggests we present them with an interesting, novel situation -- "an occasion for having a wonderful idea" -- and watch what they do. Left to their own resources, without any teacher at all but in the presence of an array of potentially intriguing materials, what do children do? Do they find interesting problems to work on? Do they settle down to work on these problems in concentrated and complicated ways? Do they build on each other's work? If they do, we may conclude that these children have learned to pursue their own thoughts.

"The important thing in any learning is to be able to use it, to go beyond it, in the direction of still further learning and activity." The same principles that guided the African Primary Science Curriculum evaluation can be applied by teachers to an examination of their daily teaching. When we look at our classrooms, what do we hope to find? We hope to find children working with confidence and intensity on problems of their own choosing. "The primary objective at any given moment is that the children be involved with the phenomenon -- caring about it enough to make their own effort to come to know it better." Eleanor argues persuasively that it is our concern with the significance of the experiences which the children live each day that is most likely to have significant effects in the long run. Once we fully grasp that it is a particular way of working which we are most interested in encouraging in children and in ourselves, then we can see the essential continuities between the quality of classroom life from moment to moment and the longterm effectiveness of that educational experience.

How can we evaluate our own efforts to create settings that invite productive inquiry? Appendices I, II, and III suggest a host of questions teachers and visitors can usefully ask about classrooms. I recommend them to your close attention. My favorite is the first, titled simply, "What you can look for." The message I take away with me from my reading of this monograph is that we are all capable of devising ways of looking critically at our own teaching and we would do well "to develop confidence in what we know" so that we may gather the courage "to continue to learn and revise while we teach."

Vicky Steinitz

Eleanor Duckworth teaches in the Faculte de Psychologie et des Sciences de l'Education, at the University of Geneva.

Vicky Steinitz is a Lecturer on Education in the Learning Environments Program of the Harvard Graduate School of Education and a Lecturer in the Department of Psychology at Tufts University.

Introduction

The African Primary Science Program takes the position that the essence of science is not the simple statement of principles, but rather the struggle to find out about the material world. This struggle entails both the ability to solve problems which are already articulated and the ability to *find* problems not yet articulated. The program seeks to interest children in the material world around them, so they are intellectually alert, seeing questions, and thinking about how to answer them outside, as well as during, school. My study consists then, first of all, of developing a procedure to see to what extent the program succeeds in doing the latter.

On the other hand, being "intellectually alert, seeing questions, and thinking about how to answer them" can be seen as the essence of intellectual activity in general. If this program manages to maximize such intellectual activity in these children, it is not impossible that, over a reasonably long period of time, we might find some repercussions in operational development.* So, in the second place, my study seeks to examine certain operational abilities of the children in the program compared with children not in the program.

Such a study has implications both for pedagogy and for the psychology of intelligence. The questions it deals with are the following: Can school serve to increase children's intellectual alertness? (No comparative research yet exists to show that they can). Can such "awakening" alertness contribute to the course of intellectual development? (This goes without saying in operational theory, but this, again, has not been documented in comparative studies.)

This double thesis is developed in the first chapter. The second chapter is designed to convey a sense of the pedagogy involved in the African Primary Science Program, and the third to convey how the program in question attempts to help teachers realize this pedagogy. The importance of these chapters lies in the fact that the outcomes of the pedagogy are of interest only to the extent that the nature of the pedagogy itself is understood.

The fourth chapter seeks to relate the present study to the general evaluative procedures of the program in question. The remaining chapters present the study itself.

*Throughout this monograph, "operational development" is used to mean intellectual development as described by Jean Piaget.

The author is indebted to the Kenya Institute of Education for allowing her the use of its facilities while carrying out this study, and for ensuring the cooperation of the many schools involved. She is no less indebted to the children and teachers of those schools, who submitted with great good will to the considerable disruption entailed in the visits. A. E. Yoloye, of the University of Ibadan, Nigeria, M.B.R. Savage, of the Kenya Institute of Education, and Sarah Kabetu, of the University of East Africa at Makerere, all made important contributions to the elaboration of the study, and John Macnamara of McGill University, Canada, found ways to make statistical sense of the abundant data. Michael Huberman, of the Université de Genève, was a patient and encouraging thesis director.

ON COMPARABLE PROGRAMS

Given the importance accorded to the second and third chapters, it is of interest to contrast this pedagogy with others which share some of the same points of view. During roughly the same period that the Elementary Science Study (see Chapter 2) was being developed, two other major science programs were being developed in the United States--the Science Curriculum Improvement Study and Science -- A Process Approach. In Great Britain, the Nuffield Junior Science was being developed at the same time, while the British Science 5/13 program started about 10 years later. These major programs are the focus of this comparison.

The programs share a rejection of textbooks, and of verbal summaries of current knowledge. In addition, they share an emphasis on the use of physical materials in the classroom, with each child doing his own explorations and manipulations. There are, nonetheless, important differences among them.

Science -- A Process Approach

This program, undertaken under the auspices of the American Association for the Advancement of Science, is the most strikingly different from the others. It represents a more atomic, additive, empirical view of science and of learning.

As in the other programs, there is no emphasis here on a collection of facts. But such a collection is replaced by a collection of processes, ready to be applied to problems as they arise. For children from 5 to 9, the "basic" processes are developed: Observing, Measuring, Classifying, Communicating, Using Numbers, Using Space/Time Relationships, Inferring, and Predicting. For children from 10 to 12, the following "integrated" processes are developed: Formulating Hypotheses, Defining Operationally Controlling Variables, Interpreting Data, and Experimenting. (Mayor and Livermore, 1972).

The program is described as a series of "exercises." "Skills developed in one exercise are basic to the next exercise in sequence in a particular process" (Ibid. p. 356). "A particular process skill can be developed using content from different fields. Skill in observing and describing change, for example, can be developed equally well with an expanding balloon, a melting ice cube, or a moving animal" (Ibid. p. 357). "The collection of all the objectives of exercises comprise the definition of the process of Observing in this science program. Similarly, the collection of exercises designated by any of the other processes comprises the definition of that process in the program" (Ibid. p. 359).

The analysis of learning on which this program is based is that of Robert Gagne. In *The Conditions of Learning* (1965), Gagne outlines a lesson which constitutes one of the program's exercises in Inference. This outline con-

Eleanor Duckworth teaches in the Faculte de Psychologie et des Sciences de l'Education at the University of Geneva.

veys both the atomic, empirical view of learning, and the kind of pedagogy it entails.

The Instructional Process for an Exercise on "Inferring the Presence of Water Vapor in Air"

Instructional Event	*Function*
1. Teacher directs attention to clouding of windows on a cold day; the ring of water left by a glass of ice water; the cloud left by breathing on a mirror. Questions students about why these events happen.	1. Establishment of *achievement motivation,* based on curiosity and the desire to display knowledge to other children and to parents.
2. Children are given tin cans and ice cubes.	2. Providing *stimulus* objects.
3. Students are told to put the ice cubes in the cans, and to watch what happens to the outside of the cans.	3. Completion of stimulus situation. *Verbal directions* to focus attention.
4. Students are asked to describe what they see. "Fog;" "drops of water;" "large drops running down;" "ring of water at base of can."	4. *Verbal directions* to stimulate *recall* of previously learned concepts. *Feedback* provided.
5. Students are asked what they can infer from their observations. "Liquid is water from the air."	5. Learning of a principle by discovery; for some students, this may be recall. *Feedback* provided.
6. Other alternatives are pointed out to students. Could it be some other liquid? Could it come from the metal of the can? *How can one test an inference?*	6. Verbal *directions* to inform the learner of the *expected outcome* of instruction (how to test this inference).
7. "How can we tell whether this liquid is water?" ("Taste it.")	7. *Verbal directions* requiring recall of previously learned principle.
8. "If the water comes out of the metal, what should happen when it is wiped off? ("Can should weigh less.")	8. *Verbal directions* requiring recall of previously learned principle.

Instructional Event	*Function*
9. Students are asked, if the water comes from the air, what should happen to the weight of the can after water collects on it. ("Can should increase in weight.") Direct observation is made of increase in weight of can by ice, by weighing on an equal-arm balance.	9. *Verbal directions* requiring recall of previously learned principles.
10. Students are asked to recall that steam consists of water droplets and water vapor (an invisible gas). Air can contain water vapor.	10. *Verbal directions* requiring recall of previously learned principles.
11. Students are asked to state (a) what they observed; (b) what they inferred; and (c) how they checked their inference.	11. Learning of the principles of distinguishing observation and inference, and of operations required to check inferences. *Feedback* provided.
12. Students are asked to make and test inferences in two or three other new situations, and to describe the operations and reasoning involved. These might be (a) water evaporation; (b) the extinguishing of a candle in a closed cylinder; (c) the displacement of water by gas in an inverted cylinder.	12. Additional *examples* of the principles learned, for the purpose of ensuring their recall and generalization.
13. Another new situation is presented to the students and they are asked to describe it in terms of (a) what they observed; (b) what they inferred; (c) how they checked their inference.	13. *Appraisal* providing *feedback*.

Gagné makes the following comments. "There are several reasons why this analysis should be formative for an analysis of instruction. First, it is made apparent that an exercise of this sort has an *objective* to begin with, and is completed only when that objective is reached, that is, when the students are able to display the performances implied by the objective. Second, the analysis helps to pinpoint the exact *Stage at which learning occurs*" (Ibid, p. 230).

The contrasts between this program and the African Primary Science Program will become clear in the next three chapters. Suffice it to say here that, apart from the fact that each child has some materials in hand, the resemblance is slight. Children in the AAAS program are not encouraged to pursue their own interests, to raise their own questions, or to find their own ways to answer the questions raised. The lesson is clearly an *exercise:* not the tin, not the ice cube, not even the water vapor is the subject of study. Finally, a specific analysis of the experience is the only outcome valued; no other kinds of objective are acknowledged as having a place.*

*or comparison, see pendix 4 of this ssertation.

Science Curriculum Improvement Study

This program shares with the previous one an organization around grand themes of science, but its classroom pedagogy is more organic--less based on an empirical, additive view of learning.

The grand themes in this case are "the concepts of the modern scientific point of view" (Karplus, and Thiers, 1967, p. 35). The concern is for scientific literacy, which is interpreted as developing a conceptual framework through which children can interpret phenomena that they study. The concepts are of the broadest sort--Systems, Interaction, Variation, Relative Position and Motion, Energy Sources, Models, Organisms, Life Cycles, Populations, Environments, Communities, Ecosystems (Thomson and Voelker, 1970). Each of the themes constitutes the focus of a unit of study lasting a year or half a year. In each unit of study, children's handling of materials is emphasized, as it is in all of the programs described here. From various fields (chemistry, biology, physics, geology), phenomena are chosen to contribute to the major theme of the unit. The Interactions unit, for example, includes phenomena such as changes of color of litmus paper, and the heating of a flashlight battery when a wire is attached. For each phenomenon, children are at first free to explore the materials. Then a concept is "invented" by the teacher. That is, the teacher's guide tells the teacher how the children are to talk about these phenomena. In the current example, each of the changes -- a change of color, a change of heat, or any other change -- is to be seen as evidence of an "interaction." Finally, the children are once again free to explore, but this time in order to "discover" applications to the new concept.

One recognizes here Bruner's (1960) notion of teaching the structure of a subject matter, and both Bruner, in that notion, and the developers of the Science Curriculum Improvement Study, make reference to Piaget as their psychological justification: We understand new experiences by assimilating them into the framework of the current state of our knowledge. However, in Piaget's view, such frameworks are the result of lengthy construction; a framework is not built by being told to think about things in a certain way. As Piaget (1964) has said, when asked about this approach, "The question comes up whether to teach the structure, or to present the child with situations where he is active and creates the structures himself... Teaching means creating situations where structures can be discovered; it does not mean transmitting structures which may be assimilated at nothing other than a verbal level" (p. 174).

This risk of verbalism does indeed seem to be significant in the Science Curriculum Improvement Study program. Teachers are encouraged to let the children explore on their own, but the emphasis is on having children talk about their explorations in the right way. Once again, the explorations themselves are not the focus. The focus is the curriculum developers' notion of how the explorations are to be interpreted.*

*(See, for comparison, Appendix 3, para. 6.)

Since both these programs--Science--A Process Approach and the Science Curriculum Improvement Study--insist that it is essential for children to have materials to investigate and manipulate, and thus seem to ascribe to a view of the importance of children's own activity in their learning, Millie Almy (1970) carried out a large scale and careful study of the effects of these two programs on children's operational levels.

Children of both programs were compared with children who had been in neither one. In addition, children who had been in the program during both kindergarten and the first elementary school year were compared with those who had been in the program only during the first elementary school year. Children were tested on the conservation of number, continuous quantities, and weight; seriation; class inclusion; transitivity of length; and matrices. Almy's paradoxical findings showed that, while children who had been in the programs for two years did better than those who had been in the programs only one year, the children in the experimental groups as a whole did no better than the children in the control groups as a whole.

In Almy's interpretation, the paradox remains unresolved, but she does offer interesting comments on the absence of any difference between the experimental groups and the control groups. (The absence of any difference here is the more striking because both experimental programs focus, in these two years, on basic logical abilities and processes like classification and measurement.) Her study included observations of four Science Curriculum Improvement Study classes to see how the program was, in fact, actualized in classrooms. The striking feature of the classes was the teachers' concern for making sure that "the lesson" was taught. Her interpretation is a classic portrait of responsible teachers seeking to do a good job with a "program" they have undertaken to teach. "The teachers did by far most of the soliciting and structuring, thus acting as the initiators of the discourse. The pupils were left to respond and react. ...This was so despite the guidance of a curriculum which sought to encourage experimentation in the presentation of activities (p. 111). "When there are no prescribed lessons ... any problem she poses or whatever explanation she makes is more likely to have the full attention of the child than is the case when there is a lesson that must be covered" (p. 147). In other words, such carefully structured programs may indeed *get in the way* of good teaching!

It is well to emphasize here that the simple fact of having materials for children to investigate does not guarantee intellectual activity. In fact, the simple presence of materials lends itself to stereotype as much as any other pedagogical gimmick. "Activity" can, in fact, be anything from running around the playground to listening attentively to music. Henriques and Coll (1976) point out that a useful way to look at the activity of the learner is the degree to which the learner does the work of structuring the activity for himself. This is one important contrast between the two programs thus far considered and the remaining ones dealt with in this monograph.

Nuffield Junior Science

This program shares with the African Primary Science Study the concern to have children pursue topics of study which are of interest to them, in ways which are natural to them. The view of pedagogy is very similar to that of the African Primary Science Program, and the study described in this monograph might well have applied to it.

The major difference is in the kind of help offered to teachers in the teachers' guides (Wastnedge, 1972). The Nuffield guides convey the pedagogy aimed at. They are largely, in fact, descriptions of investigations that various teachers and children carried out. But for a teacher who does not have a considerable familiarity with the material world, or is not already at ease with the idea of helping children learn something in a field with which he himself is not familiar, there are few specific suggestions.

This is, of course, one of the dilemmas of such a pedagogy. How can there be a "program" when the goal is to follow the children? It is an inherent contradiction. The successors of the Nuffield program in Britain have sought to resolve the contradiction with the development of the program Science 5/13.

Science 5/13

Even the briefest statement of what the developers of this program call their "educational convictions" reveals their awareness of the problems of the Nuffield Junior Science Program:

> In general, children work best when trying to find answers to problems that they themselves have chosen to investigate.
>
> These problems are best drawn from their own environment and tackled largely by practical investigations.
>
> Teachers should be responsible for thinking out and putting into practice the work of their own classes.
>
> In order to do so they should be able to find help where they need it. (Science 5/13, 1972, p.4)

This last point is elaborated in the following way:

> This project aims at helping children through helping teachers... For this purpose ....the help that is offered...must be such as to encourage teachers to put children in situations that stimulate them to ask questions and to undertake activities likely to provide answers. It must be such as helps teachers to make use of what is likely to be found in a school environment, and to reveal its possibilities as material for investigation. It must provide some insight as to how investigations may be conducted, give support when they are undertaken, and yet leave elbow-room for both teachers and children to do their own thinking and draw their own conclusions. (Ibid., pp. 6, 7).

This program also closely resembles the African Primary Science Program, as will become clear in the following chapters--although there are differences in the two programs' approaches to written teachers' guides. In the African Primary Science Study, the teachers' guides represent units of study, such as pendulums, or sinking and floating, and emphasis is given to ways of animating the whole class of children at once. Science 5/13 guides propose a much greater variety of activities, "clustered" around certain themes, but with little discussion of classroom organization, nor of a proposed ordering of activities.

The differences in the degree of "helpfulness" of these two approaches to written materials for teachers would be an interesting subject of study. But the present study does not concern itself with such differences. The overall approaches of the programs are similar, for present purposes. In fact, the present study might well have been carried out with children from Science 5/13 classes.

ON OBJECTIVES

The first and second chapters of this monograph develop the point of view, shared by the informally oriented programs, that phenomena should be studied for themselves, and not as vehicles for techniques of investigation (measurement, classification, as in Science -- A Process Approach) nor as vehicles for broad conceptual frameworks (Science Curriculum Improvement Study's system and interactions, for example). The Nobel Prize winner, Richard Feynmann (1968, p. 317), makes the same point in a different way:

> Suppose I were told to observe, to make a list, to write down, to do this, to look, and when I wrote my list down, it was filed with 130 other lists in the back of a notebook. I would learn that the result of observation is relatively dull, that nothing much comes of it.
>
> I think it is very important--at least it was to me--that if you are going to teach people to make observations, you should show that something wonderful can come from them.... I did not learn that observation was not worthwhile.

The same could be said of every other technique of investigation and means of interpretation. They derive their significance uniquely from the "something wonderful" which comes from them.

In other words, it is only if the children are interested enough that they are likely to make much effort in structuring their own intellectual activity in the sense that Henriques and Coll describe (see above). In this sense, the cognitive and affective elements of such investigations cannot be separated.

There is yet a further sense in which the cognitive and affective cannot be separated. As Kamii and Devries (1977) point out, "Qu'un individu utilise ou non son intelligence, cela depend dans une large mesure de la facon dont il se sent capable de se faire sa propre idée des choses..." (pp. 22, 23). Thus, one must both care about finding something out, and feel capable of finding something out, if one is to make an investment of intellectual effort of some significance.

This leads to a quite different type of lesson-by-lesson objective. In the informal programs described here, the primary objective at any given moment is that the children be involved with the phenomenon -- caring about it enough to make their own effort to come to know it better. Specific behaviours and specific interpretations are not going to be the objectives of a given lesson or activity.

In the Science -- A Process Approach program, the following objectives are listed at the beginning of an "exercise" in *Observing Color Changes*:

> At the end of this exercise, the child should be able to 1. IDENTIFY and NAME a colored object by comparing it with a different kind of object that has the same color. 2. STATE that the color has changed from____to____ after he has observed such a change. (Science -- A Process Approach, 1967)

Clearly, the difference between this stated objective and the primary objective referred to above is both cognitive and affective. In any one of the other four programs, if children are to be given food coloring, Congo-red dye, colored wax crayons, litmus paper, vinegar, colored paper, as they are in this Science -- A Process Approach lesson, the objectives would be something of the sort that the children should "BE SURPRISED that certain things change color, and TRY TO FIGURE OUT what kinds of things change color in what ways." (Note that the Science -- A Process Approach objective does not take into account even such rudimentary differences among children as the possibility of red-green blindness.)

These programs have taken seriously Atkin's (1968) caution that simply because it is possible to articulate objectives, and desirable to seek to attain them, their delineation should not suggest that they can be attained neatly one at a time. The four all assume that provided children are interested enough in what they are trying to find out, and confident enough in their own ability to pursue their own ideas, they will necessarily attain the sub-objectives in the process. The burden of the teacher, and the curriculum developer, then, becomes the attempt to find "entries" into the world of science that will engage children in a full range of subject matter, demanding the development of a range of abilities and ways of finding out.

Objectives *are* delineated in these four programs. However, they take the form of guidelines for teachers. It is not a matter of "today we will attain this objective." It is a matter of "watch your pupils' progress in these specific areas." A detailed example of this use of specific objectives is described in Appendix 2. The approach has been developed in much greater detail still by Science 5/13. (1972). That program has articulated over 200 specific objectives, in nine large categories. In the teachers' guides, however, specific objectives are never tied to specific activities. The activities are all centered around phenomena of interest, which children are called upon to investigate for their own sakes.

Another difference implied by the specificity of objectives tied to lessons is the approach to their eval-uation. It is clear that the Science -- A Process A[illegible] objectives stated above are at the same time a state[illegible] the evaluation. That is true of all their objecti[illegible] throughout the program. Harlen, who served as the [illegible]tor with Science 5/13, however, takes a very diffe[illegible] approach. Rather than seeking to limit the statemen[illegible] objectives to what can be readily evaluated, her pos[illegible] (1972) is that the burden is on evaluators to keep trying to extend their tools, to encompass more and more of the objectives which the educators have in mind. "For the present ... it is important to recognize that there must be valid educational objectives which cannot be validly tested" (p. 220).

ON EVALUATION

The study outlined in this monograph is one attempt to shoulder this evaluators' burden -- to extend tools in the direction of valid educational objectives which are difficult to assess. The rationale for the procedure I have developed is presented in Chapter 4. In this Introduction, I should like to place the procedure in the context of the evaluation of informal education in general -- that is, educational endeavours whose goals are not such as to allow for evaluation by testing constituent items of knowledge, because each child's development toward the overall goals might involve different constituent items.

Recently, the proponents of informal education have made excellent analyses of the inappropriateness of traditional evaluation methodologies in the evaluation of the kind of education which interests them. Shapiro (1973) points out that standardized tests, even when administered individually, sample "only an extremely narrow band of measurement" within the whole range of human enterprise with which educationists might consider themselves to be concerned. Probably the most thorough examination to date of the absence of fit between informal methods of instruction and formal methods of evaluation is Patton's *Alternative Evaluation Research Paradigm* (1975).

Using Kuhn's terminology (1962), Patton discusses the "dominant paradigm" of research in educational evaluation:

> The issue for us is that *the very dominance of the Scientific Method in evaluation research appears to have cut off the great majority of its practitioners from serious consideration of any alternative research paradigm.* (p. 6, italics his.)

The paradigm to which Patton refers as "The Scientific Method" is characterized by sophisticated statistical techniques, replicability and consistency of findings, distance from the data, focus on component parts to the exclusion of wholes. The alternative paradigm for which he seeks to establish legitimacy focuses on "a valid representation of what is happening, not at the expense of reliable measurement, but without allowing reliability to determine the nature of the data" (p. 19); a concern with understanding, rather than predicting; a closeness to the data, a concern with wholeness.

A number of authors have been developing this line of investigation, among them Bussis and Chittenden (1970), Bussis, Chittenden and Amarel (1973), Tobier (1973), Engel (1975), Langstaff (1975). The most highly developed of these approaches is no doubt that of Carini (1973 and 1975):

> Thus, in the selection and juxtaposition of observations and records, the documenter is seeking not to *exhaust* the event but to approach it, to present it vividly, intensively, and to elaborate it through its reciprocity with other events. In method, it is therefore akin to historical analysis or to biography; and as in those enterprises, it deepens and broadens as a function of the documenter's immersion in the observations and records of the events.
>
> It is a corollary to the process just described that observations or records as data are never exhausted, but rather grow more and more significant as they are juxtaposed with an ever-increasing accrual of observed events and records. Thus observations and records which were originally gathered and organized to reveal relationships in the thought and language of the young child can reveal another facet of meaning when incorporated with observations and records on the thought and language of older children, and display yet another facet of meaning when placed with other observations and records to describe the reading process. To take another example, observations and records which document a total school setting for a year can be reconsidered to describe the spontaneous interests and themes of children at given ages as these were expressed within that setting. Or the documenting of the activities of five-to-eight-year olds in a particular school setting during a year can be reorganized to reveal both the underlying processes of thought that were engaged through these activities and the emergent curriculum (1975, pp. 23, 30).

Hein (1975) emphasizes a different need in the area of evaluation for informal education. He acknowledges school administrators' concern for trends and comparative data:

It is necessary to know as precisely as possible how a particular practice affects results; that is what evaluation is all about. Unfortunately ... the information obtained from standardized testing is simply inadequate for many of the decisions for which it is used (pp. 29 and 30).

One effort to respond to the need Hein describes for a different kind of comparative data is the use of standardized tests of creative thinking (Haddon and Lytton, 1968 and 1971; Wilson, Stuckey and Langevin, 1972; Abelson, Zigler, and DeBlasi, 1974; Ramey and Piper, 1974; Ward and Barcher, 1975; Wright, 1975.) However, these tests also sample "an extremely narrow band" -- as Shapiro said of standardized achievement tests (see above). Butcher (1972) questions the relationship between creativity tests and what they claim to measure. Rieben (1974) in her careful analysis refers to these standardized tests as "des épreuves de représentation imagée divergente" (p. 139).* "Si, par créativité, on entend l'ensemble des processus superieurs qui permettent l'invention, dans n'importe quel domaine ... il n'en existe pas [d'epreuve]" (p. 138).** My own critique of the use of such tests in the present instance is developed in Chapter 1.

A more promising alternative -- because of a more obvious link between what is being measured and how it is being measured -- are the few studies on the effects of informal schooling on children's confidence in their intellectual abilities. Rappaport and Rappaport (1975) have shown the effects of such self-confidence on children's school work. An observational study by Dillon and Franks (1975) suggests that informal schooling can develop a greater sense of self-confidence. Bleier, Groveman, Kuntz, and Mueller (1972) used a simple technique to find that children in informal classrooms were more likely than children in traditional classrooms to adhere to their own opinion when it differed from the opinion of an older child.

This study is more unconventional. Within a given domain (learning about the material world), children are seen as functioning wholes, and to a certain extent a group of children is seen as a functioning whole. In support of this unconventional attempt -- and by way of apology for its weaknesses rather than of claims for its strengths -- I once again quote Hein (himself a research chemist before turning to elementary education):

There are some 'proper procedures', some 'correct' ways of carrying out anything, whether it is repairing cars, running a factory, or doing research. But these correct ways change with time, and more important, anyone who does work well knows there are times when you simply throw the rules out the window and do whatever you have to do to get the job done.

*Tests of divergent mental imagery.

**If, by creativity, one means all of the higher processes which enable invention to take place in any field...there are none [such tests].

> Moreover, particularly significant measurements sometimes require new instruments ... In many cases, the advent of a new bit of science or technology required that the new way of measuring also had to be invented and then accepted as part of the proper instrumentation (p. 13).

ON OPERATIONAL DEVELOPMENT

Harlan's article (cited above) makes the point that objectives can be expected to range farther than evaluation tools yet developed to assess them. In Phase II of the African Primary Science Program (see Chapter 6), the relationship is the reverse: the objectives were more modest than the study carried out.

It is not, of course, unusual for a program to be evaluated on objectives that it did not set for itself. On the contrary, that is precisely the complaint (already discussed) of the proponents of informal education who find themselves being evaluated with standardized achievement tests. More generally, Kamii and Elliott (1971) point out the dangers of this lack of fit in the evaluation of educational programs of all kinds. The case is different here, however. It relates to a yet more open view of educational objectives. Not only must we, as Harlen says, not exclude objectives whose evaluation is difficult, we must also be on the lookout for effects other than the stated objectives.

If an educational experience is valid, it is likely to be valid in unanticipated ways. This argument is partially developed in Chapter 1 where it is pointed out that in the African Primary Science Program the unanticipated is valued. One of the most original evaluation instruments developed by Yoloye (1969) for that program is the *Striking Incidents* schedule, where participants are invited to let the evaluators know anything that happens that strikes them as beyond the ordinary. In such a case, it becomes of interest to know not only whether or not stated objectives are attained, but what else may be happening.

It is from this point of view that the second part of this evaluation was carried out. Its aim is not so much the evaluation of the program -- Phase I is more concerned with the program's own objectives. It is rather an attempt to understand some further pedagogical and psychological relationships. The whole body of Piaget's work (see, for example, Piaget 1974, Piaget 1975) suggests that intelligence develops by being used (the phrase is mine). While this program's objectives do not include facilitating the children's operational development, it provides researchers an occasion to see whether, with ordinary teachers and ordinary resources, a pedagogical program can affect this intellectual development.

The research was aided, moreover, by the fact that the program had not set itself this goal, and that essentially no attention was paid to Piaget's work during its development. It is safe to say that none of the teachers had heard his name, and none of them were familiar with any of what have come to be known as "Piaget tasks." This outlook distinguishes, I think, this use of Piaget's work from other studies, in which the research was designed to look at programs which were based more or less closely on Piaget's work.

Lavatelli (1970) developed an early childhood curriculum based on Piaget tasks. When kindergarten children who had been in the program for five months were compared with controls on other versions of the tasks they did significantly better. This kind of study runs into the same problem which is raised by the psychological literature on "learning" concrete or formal operations. Is the progress due to a genuine intellectual restructuring, or have the children simply learned higher level responses to specific tasks by virtue of having spent a considerable amount of time thinking about these specific tasks?

In this respect, Bearison (1975) carried out an interesting school-related study, based on previous studies, showing a positive relationship between children's natural operational level and school achievement. Kindergarten children were trained to an operational level on a number of Piaget tasks. Control groups were, on the one hand, children who had attained that operational level naturally, and on the other hand, children of the pre-operational level who were given no special training. Three years later, school achievement of the trained children resembled the second of the control groups more than the first. "Although children's performance on operational tasks is positively related to their school achievement, it does not follow that teaching children operational concepts improves their achievement" (p. 579). Bearison concludes that while natural attainment reveals operational structures, attainment can be trained without affecting the essential structures. This study is actually the opposite of Lavatelli's, but it is a telling complement.

Bredderman (1974) studied children who had completed the Science -- A Process Approach "exercises" on controlling variables -- 80 children in grades 4, 6, 8 and 10. Although they had successfully completed the exercises in the program, there was no difference between these children and two control groups on clinically administered Inhelder and Piaget (1955) tests of the combinatorial and controlling variables (a modification of the flexibility experiment). Like Bearison, Bredderman doubted whether these exercises had affected their operational structures. "One could speculate that, during the Science -- A Process Approach instructional sessions, the child may have acquired a rule or procedure ... which enabled him to cope successfully with the instructional exercises and their associated evaluations" (p. 486).

Lovell (1961) did a replication study of 10 of the Inhelder and Piaget tests with children who had had instruction in four of the subject matter areas. The results on the four areas studied correlated highly with the results on the six areas not studied. He quotes a comment by one of the children (12; 8) which speaks for itself: "I know they should be the same. I'm trying to remember what the science teacher told us, but I've no memory for weights and things. We were told they were equal, and we did work it out and he did show us the reason" (p. 151).

In a fascinating study, Kamii and Derman (1971) did clinical interviews with pre-school children who had been trained by Engelmann to explain the floating and sinking of objects in water by the application of a verbal formula ("It is heavier (lighter) than a bit of water the same size"). They found that the children applied the verbal formula in totally inappropriate situations, such as to explain why one object displaced a greater volume of water than another, and engaged themselves in contradictions such as that a large block of wax weighs the same as a small flake of wax.

Linn and Thier (1975) carried out a nationwide study of children in all classes that had completed the Science Curriculum Improvement Study unit on Energy Sources, comparing them with classes of children who had not been involved in the Science Curriculum Improvement Study program. They applied a group test which involved the compensation of two factors (friction and height) in determining the distance reached by an object rolled down an inclined plane. The problem was presented on film, and the children's responses were written. Results were significantly in favor of the experimental group. The authors conclude that the science program had a significant effect on the "logical thinking" of the children. However, one does not know whether the children in the energy unit studied inclined planes (although it seems unlikely that they would have chosen this test if they had), nor whether emphasis was placed (as it is likely to have been in this program) on compensation of two factors. More seriously, the authors themselves interpret the better results from girls than from boys as being due to girls' traditionally greater verbal ability. If verbal ability affects the results, the significance of the study as a whole is brought into question.

Espejo, Good, and Westmeyer (1975) claim to have found a higher operational level in kindergarten and Grade 1 children in a "child-structured" science curriculum compared with controls. However, the tests were modifications of Piaget's procedures, and most of them are based on figurative rather than operational aspects of the tasks.

McKinnon and Renner (1971) quote three studies in which science programs have significant effects on performance on Piaget tasks. In one of these, Stafford found that children who were involved in the first grade Science Improvement Curriculum Study program were found to have "achieved the ability to conserve much more rapidly" than controls. (This is in contrast to Almy's findings quoted earlier.) In another, Friot found that seventh, eighth, and ninth grade science students in "courses placing emphasis upon the inquiry approach" were able to "function at a much higher level of logical thought" than controls. In the third study, McKinnon looked at "the effect of an inquiry-centered science course on entry into the formal operational stage of concrete operational freshman college students" (p. 1050) and found a significant difference. No details on the programs or the testing procedures are given.

In contrast with Stafford's study just cited, and in accord with Almy, Neuman (1969) found no difference in conservation of weight and quantity between first-grade children in the Science Curriculum Improvement Study program and controls.

The significant aspect of the present study, distinguishing it from all of the above, with the possible exceptions of Friot and McKinnon, is the theoretical link between Phases I and II. That is, Phase II, the operational tasks, were carried out not because children had had specific experiences in classification, seriation, isolating variables, and so on, but because they had learned to take an interest in the intelligibility of the material world, as Phase I revealed, and for up to three years this interest had been giving them occasions to use their intelligence. I think it is no doubt *because* the African Primary Science Program did not set out to teach operational structures, nor particular intellectual procedures, but instead put its emphasis on engaging teachers and children fully in the ways that were natural to them, that it was able to have far-reaching effects on the children.

"Sufficient unto the day is the joy thereof," said F. Hawkins (1969, p. 95), of a day when her deaf four-year-olds were especially caught up in their explorations. One might want to be more explicit about what gives value to a single day's experience (as Appendix 1 attempts to be). But it seems to me, paradoxically, that it is indeed the concern with the sufficiency of the day -- the concern with the significance of the experiences which the children live each day -- that is most likely to have significant effects in the long run.

1

The Having of Wonderful Ideas

Kevin, Stephanie, and the Mathematician

To look at the relationship between pedagogy and the development of intelligence, let me start with an example. I had cut 10 cellophane drinking straws into different lengths and asked the children to put them in order, from smallest to biggest (Piaget and Szeminska, 1941). The first two 7-year-olds did it with no difficulty and little interest. Then came Kevin. Before I said a word about the straws, he picked them up and said to me, "I know what I'm going to do," and proceeded, on his own, to seriate them by length. He didn't mean, "I know what you're going to ask me to do." He meant, "I have a wonderful idea about what to do with these straws. You'll be surprised by my wonderful idea."

It wasn't easy for him. He needed a good deal of trial and error as he set about developing his system. But he was so pleased with himself when he accomplished his self-set task that when I decided to offer them to him to keep (10 whole drinking straws!), he glowed with joy, showed them to one or two select friends, and stored them away with other treasures in a shoe box.

The having of wonderful ideas is what I consider to be the essence of intellectual development. And I consider it the essence of pedagogy to give Kevin the occasion to have his wonderful ideas and to let him feel good about himself for having them. Two main influences were were at play to bring me to this point of view, and I would like to say something about the relationship between them, since reconciling them was for me a struggle of some years' duration.

The first was Piaget. I had never heard of Piaget when I first sat in a class of his in Paris in 1957. I had just received a bachelor's degree in philosophy, and it was the adolescent philosopher in me that responded to his ideas. I went on to spend two further years in Geneva, as a graduate student and research assistant.

It was in 1962 that I encountered the second influence. As a Ph. D. drop out, casting about for a job, I joined the staff of an elementary science curriculum program, and found myself in the midst of an exciting circle of educators.

The colleagues I admired most got along very well without any special knowledge of psychology. They trusted their own insights about when and how children were learning, and they were right. Their insights were excellent.

*This chapter is published with the permission of Basic Books. It appears in *Piaget in the Classroom*, M. Schwebel and J. Raph (ed.), New York: Basic Books, 1973.

Moreover, they were especially distrustful of Piaget. He had not yet appeared on the cover of *Saturday Review* or *The New York Times Magazine*, and they had their own picture of him: a severe, humorless intellectual confronting a small child with questions that were surely incomprehensible, while the child tried to tell from the look in his eyes what the answer was supposed to be. No wonder the child couldn't think straight. (More than one of these colleagues first started to pay attention to Piaget when they saw a photo of him. He may be Swiss, but he doesn't look like Calvin! Maybe he can talk to children after all.)

I myself didn't know what to think. My colleagues did not seem to be any the worse for not taking Piaget seriously. Nor, I had to admit, did I seem to be any the better. Schools were such complicated places compared with psychology labs that I couldn't find a way to be o any special help. Not only did Piaget seem to be irrelevant, I was no longer sure that he was right. For a couple of years, I scarcely ever mentioned him and simply went about the business of trying to he helpful, with no single instance, as I recall, of drawing directly on any of his specific findings.

The lowest point came when one of my colleagues gleefully showed me an essay written in a first grade by 6-year-old Stephanie. The children had been investigating capillary tubes, and were looking at the differences in the height of the water as a function of the diameter of the tube. Stephanie's essay read as follows: "I know why it looks like there's more in the skinny tube. Because it's higher. But the other is fatter, so there's the same."

My colleague triumphantly took this statement as proof that 6-year-olds can reason about the compensation of two dimensions. I didn't know what to say. Of course, it should have been simple. Some 6-year-olds *can* reason about compensations. The ages that Piaget mentions are only norms, not universals (Piaget and Inhelder, 1941). Children develop at a variety of speeds. Some children develop slower and some develop faster. But I was so unsure of myself at that point, that this incident shook me badly, and all of that only sounded like a lame excuse.

I do have something else to say about that incident later. For now, I shall simply try to describe my struggle.

Even if I did believe that Piaget was right, how could he be helpful? If the main thing that we take from Piaget is that before certain ages children are unable to understand certain things -- conservation, transitivity, spatial coordinates -- what do we do about it? Do we try to teach the children these things? Probably not, because on the one hand Piaget leads us to believe that we probably won't be very successful at it; and, on the other hand, if there is one thing we have learned from Piaget, it is that children can be left to their own devices in coming to understand these notions. We don't have to try to furnish them. It took a few months before that was clear to me, but I did conclude that this was not a very good way to make use of Piaget.

An alternative might be to keep in mind the limits on children's abilities to classify, conserve, seriate, etc. when deciding what to teach them at certain ages. However, I found this an inadequate criterion. There was so much else to keep in mind. The most obvious reason, of course, was that any class of children has a great diversity of levels. Tailoring to an average level of development is sure to miss a large proportion of the children. In addition, a Piaget psychologist has no monopoly here. When trying to approximate the abilities of a group of children of a given age, able teachers like my colleagues could make as good approximations as I.

What I found most appealing was that the people with whom I was working judged the merits of any suggestion by how well it worked in classrooms. That is, instead of deciding on a priori grounds what children *ought* to know, or what they *ought* to be able to do at a certain age, they found activities, lessons, points of departure that would engage children in real classrooms, with real teachers. In their view, it was easy to devise all-embracing schemes of how science (as it was in this instance) could be organized for children, but to make things work pedagogically in classrooms was the difficult part. They started with the difficult part. A theory of intellectual development might have been the basis of a theoretical framework of a curriculum. But in making things work in a classroom, it was but a small part compared with finding ways to interest children, to take into account different children's interests and abilities, to help teachers with no special training in the subject, and so forth. So, the burden of this curriculum effort was classroom trials. The criterion was whether or not they worked, and their working depended only in part on their being at the right intellectual level for the children. They might be perfectly all right, from the point of view of intellectual demands, and yet fall short in other ways. Most often, it was a complex combination.

As I was struggling to find some framework within which my knowledge of Piaget would be useful, I found, more or less incidentally, that I was starting to be useful myself. As an observer for some of the pilot teaching of this program, and later as a pilot teacher myself, I found that I had some good insights into intellectual difficulties that children encountered. I had a certain skill in being able to watch and listen to children and figure out how they were really seeing the problem. This led to a certain ability to raise questions that made sense to the children or to think of a new orientation for the whole activity that might correspond better to their way of seeing things. I don't want to suggest that I was unique in this. Many of the excellent teachers with whom

I was in contact had similar insights, as did many of the mathematicians and scientists among my colleagues, who, from their points of view, could tell when children were seeing things differently from the ways they did. But the question of whether or not I was unique is not really pertinent. For me, through my experience with Piaget of working closely with one child at a time and trying to figure out what was really in his mind, I had gained a wonderful background for being sensitive to children in classrooms. I feel that a certain amount of this kind of background would be similarly useful for every teacher.

This sensitivity to children in classrooms continued to be central in my own development. As a framework for thinking about learning, my understanding of Piaget was invaluable. This understanding, however, was also deepened by working with teachers and children. I may be able to shed some light on that mutual relationship by referring again to 6-year-old Stephanie's essay on compensation. Few of us, looking at water rise in capillary tubes of different diameters, would bother to wonder whether the quantities are the same. Nobody asked Stephanie to make that comparison and, in fact, it is impossible to tell just by looking. On her own, she felt it was a significant thing to comment upon. I take that as an indication that for her it was a wonderful idea. Not long before, she believed that there was more water in the tube in which the water was higher. She had recently won her own intellectual struggle on that issue, and she wanted to point out her finding to the world for the benefit of those who might be taken in by preliminary appearances.

This incident, once I had figured it out, helped me think about a point that had bothered me in one of Piaget's anecdotes. You may recall Piaget's account of a mathematician friend who inspired his studies of the conservation of number (Piaget and Szeminska, 1941). This man told Piaget about an incident from his childhood, where he counted a number of pebbles he had set out in a line. Having counted them from left to right and found there were 10, he decided to see how many there would be if he counted them from right to left. Intrigued to find that there were still 10, he put them in a different arrangement and counted them again. He kept rearranging and counting them until he decided that, no matter what the arrangement, he was always going to find that there were 10. Number is independent of the order of counting.

My problem was this: In Piaget's accounts of his subjects, if 10 eggs are spread out so they take more space than 10 egg cups, a classic nonconserver will maintain that there are more eggs than egg cups, even if he counts and finds that he comes to 10 in both cases. Counting is not sufficient to convince him that there are enough egg cups for all the eggs. How is it, then, that for the mathematician, counting was sufficient? If he was a nonconserver at the time, counting should not have made any difference. If he was a conserver, he should have known from the start that it would always come out the same.

I think it must be that the whole enterprise was his own wonderful idea. He raised the question for himself and figured out for himself how to try to answer it. In essence, I am saying that he was in a transitional moment, and that Stephanie and Kevin were, too. He was at a point where a certain experience fit into certain thoughts and took him a step forward. A powerful pedagogical point can be made from this. These three instances dramatize it because they deal with children moving ahead with Piaget notions, which are usually difficult to advance on the basis of any one experience. The point has two aspects: First, the right question at the right time can move children to peaks in their thinking that result in significant steps forward and real intellectual excitement; and, second, although it is almost impossible for an adult to know exactly the right time to ask a specific question of a specific child -- especially for a teacher who is concerned with 30 or more children -- children can raise the right question for themselves if the setting is right. Once the right question is raised, they are moved to tax themselves to the fullest to find an answer. The answers did not come easily in any of these three cases, but the children were prepared to work them through. Having confidence in one's ideas does not mean, "I know my ideas are right;" it means, "I am willing to try out my ideas."

As I put together experiences like these and continued to think about them, I started developing some ideas about what education could be and about the relationships between education and intellectual development.

UNCOVERING, NOT COVERING, A SUBJECT

It is a truism that all children in their first and second years make incredible intellectual advances. Piaget has documented these advances from his own point of view, but every parent and every psychologist know this to be the case. One recurring question is, why does the intellectual development of vast numbers of children then slow down? What happens to children's curiosity and resourcefulness later in their childhood? Why do so few continue to have their own wonderful ideas? I think part of the answer is that intellectual breakthroughs come to be less and less valued. Either they are dismissed as being trivial -- as Kevin's or Stephanie's or the mathematician's might have been by some adults -- or else they are discouraged as being unacceptable -- like discovering how it feels to wear shoes on the wrong feet, or asking questions that are socially embarrassing, or destroying something to see what it's like inside. The effect is to discourage children from exploring their own ideas and to make them feel that they have no important ideas of their own, only silly or evil ones.

But I think there is at least one other part of the answer, too. Wonderful ideas do not spring out of nothing. They build on a foundation of other ideas. The following incident may help to clarify what I mean.

Hank was an energetic and not very scholarly fifth grader. His class had been learning about electric circuits with flash-light batteries, bulbs, and various wires. (ESS, 1968a). After the children had developed considerable familiarity with these materials, the teacher made a number of mystery boxes. Two wires protruded from each box, but inside, unseen, each box had a different way of making contact between the wires. In one box the wires were attached to a battery; in another they were attached to a bulb; in a third, to a certain length of resistence wire; in a fourth box they were not attached at all; etc. By trying to complete the circuit on the outside of a box, the children were able to figure out what made the connection inside the box. Like many other children, Hank attached a battery and a bulb to the wire outside the box. Because the bulb lit, he knew at least that the wires inside the box were connected in some way. But, because it was somewhat dimmer than usual, he also knew that the wires inside were not connected directly to each other and that they were not connected by a piece of ordinary copper wire. Along with many of the children he knew that the degree of dimness of the bulb meant that the wires inside were connected either by another bulb of the same kind or by a certain kind of resistance wire.

The teacher expected them to go only this far. However, in order to push the children to think a little further, she asked them if they could tell whether it was a bulb or a piece of wire inside the box. She herself thought there was no way to tell. After some thought, Hank had an idea. He undid the battery and bulb that he had already attached on the outside of the box. In their place, using additional copper wire, he attached six batteries in a series. He had already experimented enough to know that six batteries would burn out a bulb, if it was a bulb inside the box. He also knew that once a bulb is burned out, it no longer completes the circuit. He then attached the original battery and bulb again. This time he found that the bulb on the outside of the box did not light. So he reasoned, with justice, that there had been a bulb inside the box and that now it was burned out. If there had been a wire inside, it would not have burned through and the bulb on the outside would still light.

Note that to carry out that idea, Hank had to take the risk of destroying a light bulb. In fact, he did destroy one. In accepting this idea, the teacher had to accept not only the fact that Hank had a good idea that even she did not have, but also that it was worthwhile to destroy a small piece of property for the sake of following through an idea. These features almost turn the incident into a parable. Without these kinds of acceptance, Hank would not have been able to pursue his idea. Think of how many times this acceptance is not forthcoming in the life of any one child.

But the main point to be made here is that in order to have his idea, Hank had to know a lot about batteries, bulbs, and wires. His previous work and familiarity with those materials were a necessary aspect of this occasion for him to have a wonderful idea. David Hawkins has said of curriculum development, "You don't want to cover a subject; you want to uncover it." That, it seems to me, is what schools should be about. They can help to uncover parts of the world which children would not otherwise know how to tackle. Wonderful ideas are built on other wonderful ideas. They do not occur contentless. In Piaget's terms, you must reach out to the world with your own intellectual tools and grasp it; assimilate it yourself. All kinds of things are hidden from us -- even though they surround us -- unless we know how to reach out for them. Schools and teachers can provide materials and questions in ways that suggest things to be done with them; and children, in the doing, cannot help being inventive.

There are two aspects to providing occasions for wonderful ideas. One is being willing to accept children's ideas. The other is providing a setting that suggests wonderful ideas to children -- different ideas to different children -- as they get caught up in intellectual problems that are real to them.

WHAT SCHOOLS CAN DO

The African Primary Science Program was, to my mind, an application of Piaget in the best sense. Although it happened to be set in Africa, for the purposes of this discussion it might have been set anywhere. The assumptions that lay behind the work correspond well with Piaget's views of the nature of learning and intellectual development. In fact, they correspond with the ideas I have just been developing. The program set out to reveal the world to children. They sought to familiarize the children with the material world -- that is, with biological phenomena, physical phenomena, and technical phenomena -- flash-lights, mosquito larvae, clouds, clay. When I speak of familiarity, I mean that the child should feel at home with these things: He should know what to expect of them, what can be done with them, how they react to various circumstances, what he likes about them and what he does not like about them, and how they can be changed, avoided, preserved, destroyed, or enhanced.

Certainly the material world is too diverse and too complex for a child to become familiar with all of it in the course of an elementary school career. The best that one can do is to make such knowledge, such familiarity, seem interesting and accessible to the child. That is, one can familiarize him with a few phenomena in such a way as to catch his interest, to let him raise and answer his own questions, to let him realize that his ideas are significant -- so that he has the interest, the ability, and the self-confidence to go on by himself.

Such a program is a curriculum, so to speak, but a curriculum with a difference. The difference can best be characterized by saying that the unexpected is valued. Instead of expecting teachers and children to do only what was specified in guide books, the program hoped that children and teachers would have so many unanticipated ideas of their own about the materials that they would never even use the guides. The purpose of developing guides at all was that teachers and children start producing and following through their own ideas, if possible getting beyond needing anybody else's suggestions. This is unlikely ever to be completely realized, of course. However, as an ideal it represents the orientation of the program. It is a rather radical view of curriculum development.

It is just as necessary for teachers as for children to feel confidence in their own ideas. It is important for them as people and it is important in order for them to feel free to acknowledge the children's ideas. If teachers feel that their class must do things just as the book says, and that their excellence as teachers depend upon this, they cannot possibly accept the children's divergence and creations. A teachers' guide must give enough indications, enough suggestions, so that the teacher has ideas to start with and to pursue. But it must also enable the teacher to feel free to move in her own directions when she has other ideas.

For instance, the teachers' guides for the African Primary Science Program include many examples of things children are likely to do. The risk is that teachers may see these as things that the children in their classes *must* do. Whether or not the children do them becomes a measure of successful or unsuccessful teaching. Sometimes the writers of the teachers' guides intentionally omit mention of some of the most exciting activities because they almost always happen even if they are not arranged. If the teacher expects them, she will often force them, and they no longer happen with the excitement of wonderful ideas. Often the writers include extreme examples, so extreme that a teacher cannot really expect them to happen in her class. These examples are meant to convey the message that "even if the children do that it's OK! Look, in one class they even did this!" This approach often is more fruitful than the use of more common examples whose message is likely to be "this is what ought to happen in your class."

The teachers' guides dealt with materials which were readily available in or out of schools, and suggested activities that could be done with these materials so that children became interested in them and started asking their own questions. For instance, common substances all around us are the basis of chemistry knowledge (African Primary Science Program, 1969b). They interact together in all sorts of interesting ways that are accessible to all of us if only we know how to reach out for them. Here is an instance of a part of the world waiting to be uncovered. How can it be uncovered for children in a way that gives them an interest in continuing to find out about it, that gives them the occasion to take their own initiatives and to feel at home in this part of their world?

The teachers' guide suggests starting with salt, ashes, sugar, cassava starch, alum, lemon juice, and water. When mixed together, some of these cause bubbles. Which combinations cause bubbles? How long does the bubbling last? How can it be kept going longer? What other substances cause bubbles? If a combination bubbles, what can be added that will stop the bubbling? Other things change color when they are mixed together, and similar questions can be asked of them.

Written teachers' guides, however, cannot bear the burden alone, if this kind of teaching is totally new. To get such a program started, a great deal of teacher education is necessary as well. Although I shall not try to go into this in any detail, there seem to be three major aspects to such teacher education. First, teachers themselves must learn in the way that the children in their classes will be learning. Almost any one of the units developed in this program is as effective with adults as it is with children. The teachers themselves learn through some of the units and feel what it is like to learn in this way. Second, the teachers need to work with one or two children at a time so they can observe them closely enough to realize what is involved for the children. Last, it seems valuable for teachers to see films or live demonstrations of a class of children learning in this way, so that they can start to feel that it really is possible to run their class in such a way. A fourth aspect is of a slightly different nature. Except for the rare teacher who will take this leap all on her own on the basis of a single course and some written teachers' guides, most teachers need the support of at least some nearby co-workers who are trying to do the same thing, and with whom they can share notes. An even better help is the presence of an experienced teacher to whom they can go with questions and problems.

REPRISE

I am hypothesizing that intellectual alertness is the motor of development in operational thinking. No doubt there is a continuum. No normal child is completely unalert. But some are far more alert than others. I am also hypothesizing that a child's alertness is not fixed. By opening up to children the many fascinating aspects of the ordinary world and by enabling them to feel that their ideas are worthwhile having and following through, I believe that their tendency to have wonderful ideas can be affected in significant ways.

Another way of putting this is that I think the distinction made between "divergent" and "convergent" thinking is over-simple. Even to think a problem through to its most appropriate end-point (convergent) one must create various hypotheses to check out (divergent). When Hank came up with a closed end-point to the problem, it was the result of a brilliantly imaginative -- that is, divergent -- thought. We must conceive of the possibilities before we can check them out.

I am suggesting children do not have a built-in pace of intellectual development. I would temper that suggestion by saying that the built-in aspect of the pace is minimal. The having of wonderful ideas, which I consider the essence of intellectual development, would depend instead to an overwhelming extent on the occasions for having them. I have dwelt at some length on how important it is to allow children to accept their own ideas and work them through. I would like now to consider the intellectual basis for new ideas.

I react strongly against the thought that we need to provide children with only a set of intellectual processes -- a dry, contentless set of tools that they can go about applying. I believe that the tools cannot help developing once children have something real to think about; and if they don't have anything real to think about, they won't be applying tools anyway. That is, there really is no such thing as a contentless intellectual tool. If a person has some knowledge at his disposal, he can try to make sense of new experiences and new information related to it. He fits it into what he has. By knowledge I do not mean verbal summaries of somebody else's knowledge. I do not urge a return to textbooks and lectures. I mean a person's own repertoire of thoughts, actions, connections, predictions, and feelings. Some of these may have as their source something he has read or heard. But he has done the work of putting them together for himself, and they give rise to new ways for him to put them together.

The greater the child's repertory of actions and thoughts -- in Piaget's terms, schemes -- the more material he has for trying to put things together in his head. The essence of the African Primary Science Program is that children increase the repertories of actions that they carry out in ordinary things, which in turn gives rise to the need to make more intellectual connections.

Let us consider a child who has had the world of common substances opened to him, as described earlier. He now has a vastly increased repertory of actions to carry out and of connections to make. He has seen that when you boil away sea water, a salt residue remains. Would some residue remain if he boiled away beer? If he dissolved this residue in water again, would he have beer again -- flat beer? He has seen that he can get a colored liquid from flower petals if he crushes them. Could he get that liquid to go into water and make colored water? Could he make colored coconut oil this way? All these questions and the actions they lead to are based on the familiarity the child has gained with the possibilities contained in this world of common substances.

Intelligence cannot develop without matter to think about. Making new connections depends on knowing enough about something in the first place to provide a basis for thinking of other things to do -- of other questions to ask -- that demand more complex connections in order to make sense. The more ideas a person already has at his disposal about something, the more new ideas occur and the more he can coordinate to build up still more complicated schemes.

Piaget has speculated that some people reach the level of formal operations in some specific area that they know well -- auto mechanics, for example -- without reaching formal levels in other areas. That fits into what I am trying to say. In an area you know well, you can think of many possibilities, and working them through demands formal operations. If there is no area in which you are familiar enough with the complexities to work through them, you are not likely to develop formal operations. Knowing enough about things is one prerequisite for wonderful ideas.

Moreover, the wonderful ideas that I refer to need not necessarily look wonderful to the outside world. I see no difference in mind between wonderful ideas that many other people have already had, and wonderful ideas that nobody has yet happened upon. That is, the nature of creative intellectual acts remains the same, whether it is an infant who for the first time makes the connection between seeing things and reaching for them, or Kevin who had the idea of putting straws in order of their length, or a cook who conceives of a new combination of herbs, or an astronomer who develops a new theory of the creation of the universe. In each case, new connections are being made between things already mastered. The more we help children to have their wonderful ideas and to feel good about themselves for having them, the more likely it is that they will some day happen upon wonderful ideas that no one else has happened upon before.

2

"The Phenomena Have to be Enjoyed . . ."

Since the Elementary Science Study, the program to which I referred early in the previous chapter, was an important antecedent to the African Primary Science Program, I would like to outline the origins of its approach before going on.

A six-week conference in the summer of 1962 under the aegis of Educational Services, Inc. (later Education Development Center) in Newton, Mass., was the real beginning of this program, although some preliminary work had been done during the previous winter. The conference was attended by about 60 people -- scientists, philosophers and historians of science, high school science teachers, educators involved in training teachers of science, writers of science books for elementary school children, elementary school teachers, cognitive psychologists. I was present at that beginning, as a member of this last category.

The first week of the conference, frustrating though it was to live through, served to make an extremely significant point. Laboratories and school children were to be available for the last five weeks, but the first week took place at a conference center, and was for the purpose of planning. It was an illustrious group that had gathered and -- for the sake of protocol as much as for any other reason, I should guess -- chairmanship of the sessions rotated. Now each chairman sought to engage the group in a consideration of his own vision of elementary school science teaching -- his own rationale for its organization. ("His" it was, each time, I am afraid to say; this was the early 1960s, and none of the session chairmen was a woman.)

For one session, there was a physicist, whose rationale was that the basic notions of physics are, clearly, the basic notions of all science. Any elementary science program, to be rational, must be organized around the basic notion of physics. So the assembled body spent that session outlining these notions and deriving the rest of science from them -- in this way producing a framework on which to hang a curriculum.

For another session, the chairman was a biologist who was (already in 1962) profoundly concerned about ecology. He began the session with a very moving statement of man's place in his environment, and how crucial, to mankind and to each individual, an understanding of this relationship is. To his mind there was no question but that elementary school science should be organized around this understanding. So the assembled body spent that session outlining a child's immediate ecological environment, and the lines that can grow out of that to encompass all of science.

A psychologist chaired yet another session, and impressed upon the group the importance of basing a curriculum on the developing mind of the child. The stages of a child's intellectual development were well documented; science instruction should be devised in such a way as to furthur this development, presenting children with intellectual challenges of just the right sort and difficulty to take them to the next stage.

Yet another session was chaired by an historian of science, who saw this field as the obvious basis for organizing a science curriculum in elementary schools.

And so it went. Each system taken by itself was as rational and coherent as any planner could hope for. But by the end of the week we were no nearer to general agreement on a unified working plan. The problem -- and this was the significant thing about that frustrating time -- was not that none of those curricular skeletons was good enough. The problem was that *all* of them were good enough. It was all too easy to produce a convincing curricular skeleton. Clearly, the difficult work lay somewhere else.

The change of locale the following week, bringing with it working spaces and the availability of children, came as a relief. The group was impatient to do something other than talk. They were ready to roll up their sleeves and start finding ways to engage children and teachers in the kind of science they themselves enjoyed doing. Small groups of participants felt each other out about what they would like to do with children. Those of us who did not really know much about the material world ourselves, and thus had few ideas of starting points, found a small group to latch on to.

One group of physicists was passionately fond of the elegance of physical phenomena such as pendulums, balances, and inclined planes. They called themselves the Playground Physics Group, and started by looking at swings, seesaws, and slides. I remember being invited in when the group thought they had a good beginning set of materials and questions for balances, and were gathering courage to try them with children. (As I was naive in matters of science, I was soon found to be a first-rate sample child for people to try things on.) A footlong ruler was balanced on a rounded piece of wood, and a few metal washers were placed along it, preserving its balance. Someone held on to the stick and moved one of the washers; I was to move another of the washers, so that my move compensated theirs, and the ruler would remain balanced when they let go.

I was getting quite good at it. If they moved one to the left, I had to move one an equal distance to the right. Then they set up a situation like the one on page 30, and they moved washer number 3, four inches to the left. I was to compensate with washer number 2. The rule I had developed for myself suggested that I move it four inches to the right. But that would mean crossing the middle. Surely it wouldn't stay balanced if I took washer number 2 across the middle; I did know, after all, what a special place the middle is. I puzzled a while, but I could not come up with any other sensible way to decide how to move. Feeling extremely tentative, and rather daring, I decided to try the rule I had created for the other cases -- and I did move washer number 2 across the middle four inches to the right. It worked! The balance group was delighted, and soon started trying the same kinds of problems with children. (See *Balancing and Weighing*, Elementary Science Study, 1969.)

It was not the only group capable of intriguing the naive. Another took as its starting point the classic experiment used to "demonstrate" that the atmosphere is 20 percent oxygen. They stood a small candle in some clay in about an inch of water in a small dish, lit the candle, and put a closed tube over it. As expected, the candle would go out, and water would come up into the tube. This team was devising an imaginative set of variations on that experiment designed to explore why the water *really* rises in the tube. For example, in one variant, an open tube was used, closed at the top only by a balloon. In this case, before the candle goes out, the balloon stands abruptly upright; when the candle goes out, it collapses again. And almost no water rises in the tube. This and many more variants succeeded in convincing one that, although a candle may well use up oxygen when it burns, and although oxygen may well make up 20 percent of the atmosphere, the classic demonstration is no proof of either one of these claims. In fact, it's a hoax. Still more variants helped one figure out what really is going on when a tube is placed over a burning candle in a dish of water.*

[See *Gases and Airs*, lementary Science Study, 965.)

Another group worked with light and shadows and other matters of optics. I remember seeing two dozen drinking straws, all set into the ground within a couple of square yards, and all at identical angles. Children had placed them quite independently of each other, but so as to cast no shadow -- (that is, pointing directly at the sun.) It was impressive to see this order, created essentially by the rules of the world itself. (See *Daytime Astronomy*, Elementary Science Study, 1969.)

At least one group was working with the microscopic world, and some of their efforts were directed toward designing a microscope which would be cheap and good -- even if it did not look much like a microscope. Efforts were concentrated, that summer, on penlights -- pen-sized flashlights whose bulbs were excellent small lenses. The hope was to have microscopes easily accessible in any elementary classroom, at less cost than a set of textbooks. (See *Small Things*, Elementary Science Study, 1965.)

A group working on animal movement crossed back and forth between biology and physics. I remember the idea which has made Newton's "action and reaction" law vivid for me ever since. Each time we take a step, we push ourselves forward, pushing the ground backward at the same time. What if, one woman proposed, everyone in the world, at the same time, faced east and started to walk? Would we manage to push the world so it would start turning east to west, instead of its habitual west to east?

Yet another group was growing mold gardens -- flourishing growths on apples, bread, jelly, old shoes. (See *Microgardening*, Elementary Science Study, 1966.)

I myself finally got caught up with trying to make as many layers as I could of colored liquids, and then finding particles (rice, plastic bits, wood chips) that floated between the layers. I gradually moved from beakers to closed pill bottles, and started focussing on the motions the liquids made as they were turned over, or stirred up. My favorite was (and still is) corn oil sitting on red-dyed glycerine, with a few radish seeds at the interface. (See *Floating Color Tubes*, Duckworth, 1964.)

The first director of the Elementary Science Study, David Hawkins, later wrote about this kind of experience in the following way ("Introduction", 1964, pages 3, 4):

> Along with the growth of intuition and understanding goes a necessary component which can only be called aesthetic; an enjoyment, a sheer enjoyment, of the phenomena themselves. Make up a few color tubes and play with them. What is this good for? Is it going to lead to an understanding of density or surface tension? Probably not. Well, then, what is it good for? I think part of the answer is that the tubes are just good and one doesn't have to ask immediately what they are good for, or, indeed, whether they are good for anything at all. Try them out and just see if they generate further ideas for exploring the curious behaviours of different sorts of liquids.
>
> Or think about butterflies. Here is much richer scientific fare. But would it have the richness if it were not for the marvellous colors and shapes and movements of these little animals? Every part of science has its own characteristic phenomena and gives rise to characteristic -- one is tempted to say -- art forms. Contrast the style of the caterpillars and butterflies with the elegant motion of a ten-foot pendulum. The phenomena have to be enjoyed, because if they are not enjoyed it means they have not been seriously attended to for their own sake; and if they have not been seriously attended to, then the ground work of later intellec-

tual understanding, and still later return to new sorts of phenomena, will not have been laid.

For my own part, after I had been working in this spirit for a year or so, getting caught up in many phenomena for their own sakes, I began to see how this groundwork was indeed leading to intellectual understanding, in quite unpredictable ways. What I knew of buoyancy, from the floating color tubes; of balancing, from rulers and washers (and mobiles, by that time); and of gases, from candles, tubes, and balloons, came together in the following way. On one end of a balance hung a plastic bag, deflated, and closed air tight; inside it was a small amount of water, at the bottom, and an Alka Seltzer tablet stuck by a piece of clay near the top. On the other end of the balance was some weight, just enough to create equilibrium. The question was what would happen when the plastic bag was shaken so the Alka Seltzer tablet fell down and landed in the water? I do not remember how that unlikely problem arose. But I do remember that I was able to tell -- because the "science" I had learned by then, unorthodox and limited though it was, did nonetheless thoroughly belong to me -- that the plastic bag end of the scale would rise. It did. The bubbles released when the Alka Seltzer fell into the water filled out the bag, so it took up more room while not increasing its weight -- and thus became more buoyant in the surrounding air.*

*The difficult challenge faced by the Elementary Science Study educators, of course, was finding ways to enable teachers and children in hundreds of thousands of ordinary classrooms to enjoy this same kind of experience. The way the Elementary Science Study went about it, and the degree of its success, are not the subject of this study. But for those who wish to learn about it in greater detail, I'd recommend reading the Study's teacher's guides (published by McGraw-Hill); numerous articles (notably Morrison, 1964a; Morrison, 1964b; Hawkins, 1965a; Hawkins, 1965b; Elementary Science Study, 1970; Hein, 1973;), and a volume which traces the history of the program from 1961 to 1972 (Elementary Science Study, 1973).

3

African Primary Science

At its beginnings, the African Primary Science Program shared with the Elementary Science Study the tendency, among other things, to leap into the fray without starting from a detailed statement of goals and objectives. There were only phrases such as, "to plan for possible major changes in the teaching of beginning science in Tropical Africa" (Zacharias, 1965, p. 1); "to combat the deadening effects of rote and memory" (Ibid., p. 2); "building a new curriculum and training teachers in its use" (Educational Services, Inc., 1965, p. 2).

Yoloye, who since 1967 has coordinated evaluation for the African Primary Science Program and for its successor, Science Education Program for Africa, made the following observation about the first two years (1965 to 1967):

> There appeared to be a remarkable reluctance, or was it inability, on the part of these people to verbalize what they were trying to do. Yet there was little doubt that they were doing something promising and exciting. (Yoloye, 1971, p. 21)

Another statement by David Hawkins, referring to the Elementary Science Study, expressed something of their attitude also:

> After the work is done and is ready to be set before its potential users and critics, then indeed it must be set forth in such a way as to communicate the educational purposes which it is intended to serve and by which we would have it be judged. But the goals of such a venture are not things which can be set down easily and economically at the beginning. They are, in a sense, its final outcome. (Hawkins, 1964, p. 1)

During the first two summer conferences, in Entebbe, Uganda, in 1965, and in Dar es Salaam, Tanzania, in 1966, some participants did concern themselves with evaluation. Their documents convey the same heady feeling as characterized the other participants; they revel in the scope of this program, sketching out evaluation possibilities of many sorts and many levels. (Elite, 1965; Chin, 1966). Their intriguing suggestions in fact gave rise to no systematic evaluation efforts until after 1967, when a permanent, though part-time, evaluation group was formed under Yoloye's leadership.

By that time, there were African and non-African staff members in each of seven countries -- Ghana, Kenya, Malawi, Nigeria, Sierra Leone, Tanzania, and Uganda. They had by then done a lot of work with children, drawing on the vast traditional African knowledge about the material world, and on the knowledge of modern science, which served largely for ingenious designs of tools and equipment to be made with materials available in every village. They were starting to find ways to animate whole classes of children, and to fire non-specialist classroom teachers with some of their own excitement. They were also starting to put some of their ideas for materials and activities into written form, and to develop short courses or workshops for groups of teachers. The work wasn't done yet, to take David Hawkins' phrase, but it was far enough along that Yoloye felt ready to try to articulate the goals that seemed to underlie it:

> In 1967 at the Akosombo workshop, the evaluation group adopted an indirect technique of getting the curriculum developers to clarify their objectives. On the basis of direct observation and analysis of materials and activities of the program since the two years of its existence, a list was prepared of the objectives at which the program seemed to be aiming. This list was compiled into a rating scale which was then circulated among participants at the workshop. Each participant was required to rate the degree of his agreement with each stated objective on a five-point Lickert-type scale. Space was provided for explanatory comments and additional suggestions. (Yoloye, 1971, p. 22)

One of my own first tasks, as a member of Yoloye's evaluation group that summer, was to draft a statement based on the responses to this rating scale that conveyed the broad goals with which all participants seemed to agree. First and second drafts of this statement were again submitted to the participants for comments on thoroughness and accuracy. The final draft, adopted by the program that summer, was as follows:

A. The chief goal of the African Primary Science Program is to contribute to the following characteristics in children during primary school years:
   1. First-hand familiarity with the material world -- both natural and man-made.
   2. Interest in further exploration of the world around them on their own initiative.
   3. Ability to find out for themselves -- to see problems and to be able to set about resolving them for themselves.

4. Confidence in their own ability to find out for themselves and do things for themselves.
5. Ability to share in a common development of knowledge, through collaborating on problems, telling, listening, and discriminating use of second-hand sources.

The above characteristics should help prepare children for what they do after primary school insofar as

-the great majority of primary school leavers who will have no further formal education will be better prepared to continue their own learning in their everyday encounters with the world, more especially in the work they do every day, e.g., farming, food preparation, house building, health techniques.
-children who go on to secondary school will have a foundation of knowledge, experimental ability and confidence which will help them in their science studies. *What they have learned in primary school will have been well learned, and not soon forgotten.*
-a few children will ultimately play an active role in the technological developments of their countries, and perhaps make international contributions. *A good basis in science in primary schools may help create a wider interest in the profession of scientist, engineer, and technologist and may better prepare children to be accepted as students in local and international institutions of higher learning.*

B. Primary school science, in order to accomplish these ends, should have the following characteristics:
   1. *The focus of study should be the phenomena themselves* -- e.g., plants, animals, stones, liquids, stars, shadows, etc. First-hand experience with materials is essential. The phenomena of the natural and man-made world are complex. They have different significance for different people. Telling about them does not carry all their complexities and fascination. Nor does "the telling about" them alone allow opportunities for children to develop ability and confidence in finding out for themselves.
   2. *The materials selected should capture and hold the attention and interest of children.* In some cases, the materials may be sufficient in themselves to suggest things to do. In some cases, questions and suggestions

from the teachers are necessary to reveal interesting possibilities which the children may not have thought of themselves. In some cases, alternatives should be available for children with different interests.

3. *The materials should reveal that there is not always one right answer.* This can be at a variety of levels. At one level, children may arrive at different answers to the same question and all answers may be equally acceptable. At another level, the teacher will often not be able to answer questions that arise, and there is no other way to find out in the classroom, except by carrying out an investigation. At another level, questions may arise to which no one can find an answer, and to which, indeed, no one in the world yet knows the answer!
4. *Materials should allow opportunities for a variety of different ways to find out.* Some patient watching, some resourceful tool-making, some clever experimental design, some sudden insight, some constant repetition, some imaginative guessing, some tight logical thinking, some trying out a tentative idea, some frustration; some recourse to other people, books, radio, film, etc.
5. *The classroom experiences should lead to social interaction among children* -- where they develop a body of common experience; accept and respect other points of view; attempt to substantiate their own points of view; cooperate to solve problems together.
6. *To a large extent, the materials should be simple and familiar* -- so the children's experiences are met here in a fresh way. This in itself may develop the awareness that the children can continue their investigations on their own in everything they do.

C. Teaching science in this way in primary schools requires certain approaches at the level of administration and teacher-training:

1. Materials should be developed which correspond to the above characteristics.
2. Tutors in teacher training colleges and ministry officials who work directly with teachers should be familiarized with the materials and encouraged to participate in the development.
3. Teachers must be taught in the same way they are expected to teach, in that they must be given the occasion to find out for themselves, to develop confidence in what they know, to

appreciate that there are many unanswered problems, and to realize that they can continue to learn and revise while they teach.

4. Teachers must be supported through follow-up visits, advisory services, discussions among teachers, and the provision of concrete and written materials.
5. Primary school science curricula should be made flexible enough to allow for continued change and improvement as the program and the teachers develop. (Duckworth, 1967.)

WRITTEN MATERIAL

The "materials" referred to above take the form of booklets that serve as teachers' guides. Something of their character has already been suggested in Chapter 1. More specifically, the booklets for teachers are divided into those for teachers of lower primary classes -- the children's first three years of schooling -- and those for teachers of upper primary classes -- the remaining three or four year of primary school.

On Activities

Lower primary booklets consist of a series whose general title is *Activities for Lower Primary* (African Primary Science Program, 1978a.) An introductory booklet presents the notion of an "activity period;" each of the other booklets deals with one kind of activity which can be incorporated into an activity period: *Arts and Crafts, Water, Wet Sand, Dry Sand, Woodwork, Construction, Cooking, Games, Exploring the Local Community* (African Primary Science Program, 1968b). Science is not given special emphasis in these booklets. The approach is general, dealing with many aspects of young children's learning. The following excerpts from the Introduction might best convey the approach:

> Before he goes to school a young child has already learned a great deal. For example he has learned to talk. He has learned to talk fluently with no one teacher expecially to teach him. He learns by doing things and by seeing what happens when he does things. An activity period is a time when the teacher tries to provide this sort of learning situation in her classroom...
>
> Your activity period is a time when your children will be moving around in the classroom. Sometimes to see what another child has done, sometimes to ask you to come and see their work because they are so delighted with it.
>
> The activity period is a time for laughing, for talking, even for running. There will be times when your room is noisy, times when it will be

quiet. Your activity period is a time when, in a friendly, relaxed atmosphere your children are gaining experiences that are valuable in their understanding of science, maths, language and other subjects in the curriculum. Indeed, you will find that some of the things you would normally be teaching in those subjects come up in the activity period...

Many teachers have found that when they introduce an activity period, the interest and enthusiasm of the children spill over into other parts of the day. Children begin to ask more questions. You will notice that children's attitude to school changes as they begin to feel that learning is something alive and exciting, and something that they can do for themselves. In many parts of Africa parents have noticed this change in their children and have come to school to congratulate the teachers.

It is important that children work with materials that can be used in more than one way. As he works, he learns what can and cannot be done with each material. He develops his physical control over the materials and his ability to think and reason about them. This sort of learning cannot be taught with words.

Children are capable of doing much more than we think. Too often teachers and parents over-protect children and do too much for them. It is impossible to find out what any child really can do unless he is given a chance to show us.

You will be able to see much more readily than in a formal classroom situation the individual problems each child really is facing in his science, number and language work.

The activity period is a time when children work with materials, with each other, *and with the teacher.* Once the room is set up and the children at work, your role is very important. Above all, you must observe the children and try to understand how they work and what they are doing.

Grouping children for their work focusses their attention on their activity and each other rather than on you. You will find that you will have to move from group to group or individual to individual. You won't be able to get to everyone and you will not realize all that goes on, but you will gradually become aware of specific groups and children who need your help. It is more important for you to work intensively with an individual or group who need you, rather than to try to see all the children every day.

Children need your encouragement and interest. Try to take the time to discuss the work they are doing. Show the child that you are interested in the way he has thought and worked. It is important to understand why a child works the way he does. Sometimes his reasons are difficult for you to see, but he will have a reason. You are not looking for errors he has made, but rather trying to understand. He must see you as an ally and not as a critical observer or inspector of his work.

Sometimes children may bring you into their work and conversation. Let them lead you in the discussion. There will be times when the children come to you for help or to ask questions. Try to discuss the questions or problems with children and lead them to work out their own solutions. For example, a child may ask you to saw a piece of wood. Start it, to show him how, but let him finish the sawing. Another child may ask you what he can draw. Don't tell him directly. Ask him about things he saw on his way to school, or animals he likes. Talk to him about anything that might give him an idea of what he might want to draw.

Very often the best time to talk with children is after they have finished working at an activity. Ask them to tell you about what they have been doing.

Another role for the teacher is that of adding new materials. Try to make sure that you add the right thing at the right time. Watch the children carefully to see if they need anything new. Perhaps the lorries they are making need new wheels. Ask your children what they might use for wheels or add a few round bits of wood the following day. Perhaps they have been using containers to fill bottles in their water play. Next time make sure that there is a funnel in the box. Children should not be told how to use something new. Put it out and let them discover how to use it themselves. A child might think of some uses that come as a surprise both to himself and the teacher.

If children seem to have lost interest in an activity, or in a piece of equipment, you might remove it for a while. It will often be taken up again in a new way when you put it back. (African Primary Science Program, 1968a, p. 1-16)

Within each specific activity, teachers are given suggestions of materials to use, what to look for in the children's activities, what kinds of questions to ask, what kinds of suggestions to make.

The following excerpts are taken from the booklet, *Water:*

Water is an exciting and lasting material for children. It is familiar and attracts them naturally, yet at times water can fill children with wonder. Water play provides children with an opportunity for much mathematics and language work and it is an experience that forms a basis on which future science can be built.

Water is dangerous in many areas. If you cannot disinfect water that has germs, you will not be able to do this activity. If you can, water play is best done outside the classrooms. You will have to collect containers and, if possible, make a few pieces of equipment. However, you will find that with only some of the materials listed, interesting work will go on. Start with just a few simple containers and a tin with lots of holes in the bottom. Children will enjoy the things they can do with these for a long time. As new opportunities arise, and as you and the children find new materials, add them to the water play. Sometimes children will lose interest in a piece of equipment. Remove it for awhile. When you put it back it will arouse new interest.

Give the children a split piece of bamboo or banana stem. They may use this to get water from one place to another. If you have tubes or hollow stems they will use these too. After much play with the materials some children might use many pieces of equipment at once to carry water from one place to another.

Some children might be familiar with boats. They might pretend that a tin is a ship floating on the river. They will need a quiet container for a lake or an ocean. Can your children suggest things that float like boats? Do they have to be a special shape? Bring things in that float. Flat tins, seed pods, leaves, cigarette paper, many things will do. Do your children load their boats with stones or clay figures?

If some of your children are losing interest in the water play, add some ordinary soap and a few hollow reeds or straws. Children can spend hours blowing bubbles. Some may blow into their tins of soapy water and produce a mass of frothy bubbles. Others may try to blow big, single bubbles. Do your children notice the colours in the bubbles? Do they use their hands, pieces of grass or wire to try to blow bubbles? Do they notice how the bubbles arrange themselves when they are together in a mass?

Do your children even wonder what happens to the water they spill? Draw round a puddle after it has rained. Look at it the next day. Where does the water go to? You could ask the children. Give your children big paint brushes. Have them paint all sorts of different surfaces to find out if water disappears faster from some places than others.

When children spill water in the classroom, sometimes give them different things to dry the water with. Do your children notice that only some things absorb the water?

Bubbles come out of a bottle when it is dipped into water. Children may look at the bubbles and listen to them. Bubbles rise in a bottle when it is emptied and children will find the fastest way to fill and empty their bottles. Slowly tip a bottle filled with water containing a small bubble. It is fascinating to watch this bubble as it moves. Watch and see when your children discover this bubble.

Try to find a bottle with a very small hole. How do your children fill and empty it?

Do any children push tin cans straight down into the water? Let them try pushing a tin with holes in the bottom into the water. Do they feel the difference?

Listen to the children talk to each other about their play. Look for occasions when you can enter in. If they are pretending to sell milk or tea or paraffin, ask to buy some. Do you notice children pretending to wash, or to fetch and carry water as they do at home? Are they going to a well, a tap, or a river? Do any children pretend to make rain? You can join into these situations and encourage other children to do so.

Situations will arise when you can introduce new words and phrases. These might come up: bubbles, dry, wet, soaked, damp, how many times. Other phrases that might arise are: twice, two times, how much, how little. What do your children mean by full, a half, a quarter, a drop, float, sink?

Do children pretend to bottle various drinks? Help your children to label the bottles. For example, "Coca-Cola", "Mirinda", "Beer", might all be labelled. As children sell water, drinks, milk or paraffin they could make paper money and keep records of their sales.

Children know many songs about rain, water falls, rowing, etc. You could tell the stories of how people in different regions get water and how they carry it. Do you and your children know any stories of droughts or floods? Let children try to carry various containers of water on their heads. This will give them lots to laugh and talk about. (African Primary Science Program, 1968b, p. 1-11)

On Topics of Study

Upper primary booklets are organized around topics of study, such as ant lions (a common insect), musical instruments, sinking and floating, inks and papers, buds and twigs, measuring time, balancing and weighing, construction with grass, making a microscope with a waterdrop lens. The study of the ant lion is a good example of the approach taken. The booklet is entitled, *Ask the Ant Lion.* Here are some passages from its brief introduction:

> A little creature, often ignored, succeeded in keeping forty children happily busy for many days.
>
> How was this possible?
>
> Well why not ask the little creature? Why not ask the ant lion?
>
> Where is it to be found?
>
> Almost everywhere in the soil. In dry and sometimes shady places, such as under overhanging roofs, along the walls under verandahs, or even between the buttress roots of trees. In fact, in most dry and sandy places there are tiny conical-shaped pits where, at the bottom of each one, lurks a drab little creature -- the ant lion.
>
> The children, when they observed this insect, and saw what it did, were stimulated to ask many questions.
>
> What is it?
> What does it do?
> How does it move?
> What does it eat?
> How does it catch its food?
> How does it live in these little sand pits?
> How does it eat?
> How does it make these little pits?
> Can it make pits in gravel? In flour? In sugar?
> In ashes? Does it prefer sand to gravel?
> How does it throw things out of its pit?
> How big a thing can it throw out of its pit?
> Can it see where it goes?
>
> These and many, many more questions were asked. And invariably the same answer was given to the children: Ask the ant lion; it will give you the answer.
>
> This is the leading phrase throughout the unit. By "asking the ant lion," the children find answers to their questions, and the teacher to many of his. The exciting thing about it is -- the ant lion is always right. The children -- or the teacher -- may predict incorrectly.
>
> In order to "ask the ant lion" the children had to think out and set up all sorts of experiments. They placed the ant lion in different kinds of situations. The ant lion would never fail to respond and provide an answer.
>
> The teacher played the role of organizer. As

leader, he listened to the ideas of the children and encouraged them to come forward with new ones. He led them to discuss their questions, and he hinted at some ways to find the answers. He saw to it that enough materials were available, or that the children would bring more. The teacher told them nothing about the ant lion, but gave them only one lead: Ask the ant lion.

It will be of great help to you, as the teacher, to become familiar with the ant lion before teaching this unit. Reading through the unit will give you ideas for a starting point. Ant lions can readily be found along the wall of your house or the school. Watch them; see how they react to the different conditions you create for them. Observing the ant lion for yourself will give you the confidence you need to present it to your students. You will be better able to guide the children's explorations. You will be able to share your excitement with them, and will soon share theirs.

As a teacher, are there doubts in your mind? Is the study of an insignificant insect really worthwhile? Is it a valuable learning experience?

Well, why not find out for yourself? Why not ask the ant lion? (African Primary Science Program, 1966, p. 4-6)

The following passage comes later in the text:

> The above illustrates that, in fact, the children can direct the lesson. Raising the problem of the ant lion's food was convenient at this early stage; once the children had discovered what the ant lion eats, they could better care for their ant lion specimens.
>
> If there are tins or other containers with undisturbed ant lion pits available, the children can drop ants into them and observe how the ant lion responds. They should be allowed to try anything they think it will eat. One little boy in the trial class caught a fly and fed it to his ant lion.
>
> Some children will drop things in the ant lion pits and watch what happens, but others may soon want to see how the ant lion catches its food. They may dig their specimens out of the sand, put them on to the desk, and confront the ant lions with ants or a variety of things. This may lead to other discoveries. Ants may not take too kindly to an ant lion. The ant lions, being disturbed, may not respond too eagerly. They may even do quite unexpected things.
>
> This exercise may look unruly, but in fact it is very valuable because the children will learn how difficult it is to experiment with living things.

They may also learn how to solve the problem of setting up a situation in which the ant lion really shows them how it eats.

It is advisable for the teacher to keep a box with ant lions which are not to be disturbed too much. If children cannot succeed in feeding trials with their ant lions, perhaps some of the undisturbed specimens might be substituted.

During their observations of the ant lion feeding on ants, the idea that the pit, in fact, is a trap out of which it is very difficult for an ant to escape, may become apparent to the children.

It may be useful to draw the attention of the children to the struggling ant, whenever this is appropriate. For instance, by asking the question: "Why does the ant not try to get away?"

Again, give the children plenty of time for their observations. If they keep records, fine. If not, coach, but do not force them. (African Primary Science Program, 1966; p. 12, 13)

Further information on the development of these booklets, including the constant contribution of classroom trials, can be found in Chaytor (1971) (Also see Appendices 2 and 3 of this monograph.)

TEACHER EDUCATION

As I suggested in Chapter 1, the other major aspect of this program, as important as the written materials, is teacher education. From the beginning, the participants assumed that the booklets' major use would be as support for their work with teachers in short courses or in teacher training colleges. Since 1971, in fact, the Science Education Program for Africa, successor to the African Primary Science Program, has concerned itself entirely with teacher education, showing as much thought and careful trial to the development of ways to work with teachers as had already been shown in the development of ways to work with children. Its efforts to date are conveyed in a detailed *Handbook for Teachers* (Science Education Program for Africa, 1976). An excellent account of this approach to teacher education can be found in Elstgeest's article, "Teachers or Instructors?" from which the following extracts are taken:

> Modern Science Education relies very much on simple, understandable, and every-day materials found in the immediate environment. The successful employment of these materials depends very much on the resourcefulness of the teacher. Almost anything taken from the environment can become a gate which opens into a wide field of serious study. The problem is: where to find the key to this gate?

The key can only be found in the person's own enthusiasm, sense of wonder, confidence, resourcefulness, and inquiring mind. Unfortunately these qualities are systematically killed in a rote system of learning. The key turns easier, and the gate opens wider according to the abilities and skills acquired to investigate, to explore, to observe, to ask, and to experiment...

* * *

A fresh look at things is required: a look that sees possibilities and potentialities. For example, a bush of bamboo becomes more than a long-forgotten Latin name. Within the bamboo there are hidden balances, cages, containers, battery holders, telescopes, pumps, bows and abacus rings. Bamboo is a fascinating, fast-growing giant grass with a hollow structure of high strength; it has a typical way of propagation; it is a home for many animals. It is a bush full of maths and science...

* * *

It is difficult to swallow the thought that the old, safe, successful answers no longer stand up to the test. It is hard to begin to learn the subject that you had imagined you had learned so well before. It demands courage to concede that a seemingly easy problem beats you. It is much easier to say, "This is kid-stuff!" and leave it at that. It needs confidence to tackle a problem to which there is no answer in the book. Snorting: "What is the use of all this?" is an escape from the imagined danger of making a fool of one's self; it is the fear of not being able to give a tutor the presumed "right answer"...

* * *

The original resistance does wear off when the surprises come, when they find satisfaction in their work, and thus gain confidence. I introduced a group of students to the use of the small and simple bead microscope. They rejected it as a useless substitute: "We can only work with real, big microscopes!" Of course, the cheap bead microscopes do have their limitations, but sixty cents for a sixty-power microscope has its attractions, too. But no, "they were of no use". However, three weeks later, five of these boys worked four hours with me designing and improving a microscope made of used detergent packets. They became so excited that they invited everybody who happened to pass by to come and have a look at the hairs on a fly wing through their waterdrop microscope of which they were now very proud.

Because teachers often teach the way they were taught themselves, it is useless to let them rote-learn so-called "methodology." The policy in Modern Science Education is to teach them in exactly the same way as they will be expected to teach in the schools. This can be accomplished by introducing the students to a variety of serious scientific studies. These must have a direct relationship to the immediate environment. Every environment lavishly supplies ample opportunity for serious study in depth.

The main objective for these studies is to help them realize that science is not merely an amount of more or less recent inventions and discoveries, but rather a process of investigation that can lead to a deeper understanding of the world in which they live...

* * *

There is no reason why some of the units that have been prepared for the primary schools cannot be used in training colleges. The often-raised argument, that one cannot force adults to "go back to children's topics," holds absolutely no ground. Whatever looks sophisticated in adults' studies is not the topic, but the depth to which a certain investigation has been pursued. All the intricacies of modern astrophysics have started with a plain look at the sky at one time...

* * *

Once the revelation dawns that science is to be found between the questions and the answer, between the problems and its solution; once the first barrages of resistance have been endured and overcome; once a new attitude toward science begins, the students are taken a step further. From now onwards, connected with their activities, constant reference is made to children in the schools, to the environment in which they live, and to the basic goals and objectives of an effective Science Education. This is often done in discussions which arise from the studies made, from difficulties encountered, and from successes booked. The art of asking the right questions is something that takes a long time to learn. Personal investigation of many materials, however, soon sorts out the unanswerable from the answerable questions....

The time comes when the students may work with children. After they have gained sufficient experience in scientific investigation and in self-confidence, they can turn their attention to the involvement of real primary school children. This can give difficulties of organization, but it is worth all the trouble. It pays to give students ample opportunity to observe children who are carrying out their own

> explorations. Apart from observing the children, our students can participate in providing the materials and ideas necessary to place children in interesting problem-solving situations. (Elstgeest, 1971; p 86-89)

ASSUMPTIONS ABOUT THINKING

In keeping with the statement of goals, the assumption is made throughout the African Primary Science Program that there are many aspects to finding out about the material world--some of which do not, on the surface, look very much like science as we usually understand that term.

Sometimes children have specific questions in mind and think of experiments that will help them find the answers to these questions. For instance, they may wonder whether the brightness of a small bulb will change if they make the wire longer or shorter, and they can answer this question by using a single bulb and a single battery, with the wire always attached in the same way, and varying only the length of the wire.

Other times they may not have a specific question in mind but may think of something to do just to see what will happen. For instance, they might think of trying to boil a piece of bark from a tree with no particular idea in mind ahead of time about what might happen.

Other times they may simply watch what happens aroun them. For instance, they might watch an insect going back and forth carrying food, and they might pay attention to how it moves, or how it picks up the food, or the path it takes, or what kind of foods it eats, or whether it pays attention to any other insects around it.

On other occasions, they may not seem to be interested in finding out anything but simply in accomplishing some practical aim, like trying to make an egg roll in a straight line; or trying to build some symmetrical pattern In cases like this, they learn as they realize that certain ways do not work and as they look for other ways that might work.

Still other times they may simply be trying to consolidate what they seem to know already. For instance, a child may use spools for wheels and sticks for axles, and scraps of wood for a cart. As he tries to put these together so that the wheels really do turn, he will be reproducing and consolidating what he understands of wheel and axles.

Even playing at storekeeping is seen to serve the same purpose for young children. The more children strive to make representational play correspond to the real world the more they are thought to understand that real world.

Two main tendencies run through these various ways of learning. On the one hand, children need to have lots of ideas -- of questions to ask, of practical things to do of experiments to do just for fun, of ways to try to represent something. On the other hand, they need to develop some rigor in order to judge when indeed they have learned something, or when their representation is adequate.

Neither of these types of thinking can develop in a vacuum. Children need to know enough about materials to produce ideas about interesting things to do with them, as well as to judge which are the most appropriate ideas. This program, then, attempts to have children know about the material world in a way that enables them to produce many ideas about it, and to judge their ideas.

Those who have been involved in the program believe that in order to know the world in this way, with a knowledge that leads out beyond itself, it is more important for children to investigate a small area thoroughly than to skim superficially over many phenomena. The materials are presented in such a way that children become intrigued with doing things with them that they had not done before, and in finding out more about them. Thus, they are encouraged and helped to pursue their lines of interest.

It is not considered important that each child learn the same things as every other child. What is considered important is that each child be involved in learning for himself, day by day. This is seen as the best way for children to be prepared to continue doing their own learning, outside school, and after they leave school.

4

Evaluation Study: The Setting

The evaluation group headed by Yoloye has, since its inception in 1967, touched on many different aspects of this program. A good summary can be found in Yoloye's *Evaluation for Innovation* (1971). *Handbook for Teachers* (Science Education Program for Africa, 1974) also contains a lengthy and useful section on evaluation procedures. A variety of my own contributions are included in the Appendices of this dissertation. In addition, during my full year as program evaluator, I was able to carry out a study that attempted a comparison between children who had been in the program and other school children. The question that interested me was whether this kind of science teaching does give children a good basis for going further on their own.

RATIONALE

To develop the rationale for my approach, let us take the example mentioned in Chapter 2 -- the unit of study concerned with chemical reactions of common substances.

In most primary science programs, if such a topic was studied at all, it would merit perhaps one lesson. The various kinds of chemical interactions would probably be outlined, some of them might be demonstrated, and perhaps some of the children would be given opportunity to carry out some of the demonstrations, according to directions they were given. In this program, however, the children were likely to spend up to 10 or 12 lessons on the topic. They would be mixing and combining the various substances, finding different reactions, comparing their findings, trying to analyze the mixture of powders by studying their reactions, developing ways to record their results, etc.

Clearly, the children in this program would in the long run have more ideas about common substances than most children would. Clearly, too, children in other science programs would have studied about a larger number of topics than children in this program. How can two programs as different as these be compared?

Let us assume that the children in the other program have spent a total of 10 lessons on the general topic of elementary chemistry, while the children in this program were spending 10 lessons studying the reactions of common substances. The elementary chemistry in the other program might include reactions of other less common substances, such as sulphur, and powdered iron; it might include reactions of metals with acids; it might include the production of certain gases. Then, to compare the value of each of these approaches, we could give each group of children a new area of chemistry to study, and see how they could use what they have learned so far to find out about this new area on their own.

Similar comparisons could be made in other areas. Children who spent eight weeks studying pendulums in this program could be compared with children who spent eight weeks on the general area of physical mechanics by seeing how able each group was to investigate, on their own, some new phenomenon of mechanics. Children who spent eight weeks studying ant lions could be compared with children who spent eight weeks studying insects in general, in their ability to find out about an insect equally unfamiliar to both. The assumption, in making such comparisons, is that the important thing in any learning is to be able to use it, to go beyond it, in the direction of still further learning and activity.

Although the comparisons I made were based on this same assumption, they were not exactly of the sort outlined above. For one thing, the experimental classes had dealt with a great variety of different topics. In the limited amount of time available, I could not develop a comparison procedure for each topic. For another thing, there were no comparison classes which had studied related topics to the extent that would have been necessary for these comparisons, and there was not time to establish such courses as controls.

I tried to develop a procedure which would enable us to compare children who had been in this program -- whatever the topics they had studied -- with children who had not been in this program, those who might have had no science or who might have had science of a different sort.

In order to make such a comparison, my first thought was to devise a short lesson that would take only one class period, and use it as a standard lesson, concerning an area not involved in any of the units in the program. This new "mini-unit" could then be used as a standard situation in which to compare classes of children. I had in fact already done a pilot study of this sort, as a member of the Elementary Science Study staff (see Appendix 5). However, the need to have the same teacher do the teaching would have put severe limits on the use of such a procedure. One person would be indispensable each time one was interested in comparing two classes. Specifically, the comparisons would then be limited to classes whose language that teacher knew. Furthermore, even the same teacher, speaking the same language, can vary enough from day to day or week to week so that his/her influence would not in fact remain constant.

A simple variant of that original idea was suggested by a physics examination given to students at Cornell University by Philip Morrison (see Appendix 6). His examination was held in the laboratory. The students were given sets of materials, the same set of materials for each student, but they were given no specific problem. Their problem was to *find* a problem and then work on it. For Professor Morrison, the crucial thing was finding the question, just as it was for Kevin, Stephanie, and the mathematician, as I described it in Chapter 1. Indeed, in this examination, clear differences in the degree of both knowledge and inventiveness were revealed in the problems the students set themselves and the work they did was only as good as their problems. The major difficulty with Professor Morrison's procedure, from our point of view, was that we could not expect the children to write up what they found. At the ages we were dealing with, as young as five years old, we could not even quite expect them to articulate specific questions. In our case, it would have to be a matter of watching what children did with the materials throughout the time available to them, and noting what they did throughout, rather than expecting them to offer us some conclusions at the end. It was tantamount to the first idea, simply leaving out the teacher.

This, then, was the procedure I adopted in Phase I, with the additional modification of providing a considerable variety of materials to allow scope for a similar variety of knowledge, ideas, and abilities children might have developed.

It is perhaps worth mentioning that one line of psychological research never was in contention in my planning of this study, namely the literature on "creativity," or "divergent thinking." To my knowledge, all of this research is confined to pencil studies; many of them deal with play with words. (See Wallach, 1970, for an article which, summarizing the research, mentions no technique of any other kind.) For my purposes, even tests such as *Uses of Common Objects* (see Torrance, 1966) remain much too distant from the kinds of ideas involved in making productive use of materials; the subjects are never given an object. On the one hand, this allows for flights of fancy that might be totally unrealistic -- revealing a literary imagination, but not necessarily a materially productive one; on the other hand, a child who had few ideas when asked to sit and think of them, might well find, if he had a tin in his hands, to take one example, and other materials available, too, that his hands would, as it were, think for him. Hudson (1968, p. 48), moreover, concedes that in his studies of "divergent thinking" in exceptionally bright youngsters, the test (all paper and pencil) "failed to catch the fancy of inventive scientists and technicians."

Hudson goes on to say (Ibid., p. 50) that "the relation of convergence and divergence to originality in science will prove complex." As I suggested in Chapter 1, I think the two go hand in hand, since science is, by its very nature, a creative affair. Having questions and ideas grows out of the same kinds of knowledge as does the ability to pursue those questions and ideas to a productive end. It was this thought that gave rise to Phase II of my study.

The rationale for Phase II is complete in Chapter 1. As I said in that chapter, my hypothesis was that intelligence develops by being used and the African Primary Science Program looked to me a likely ground for trying out that hypothesis. The work involved in the program makes constant demands on children to work intelligently, rather than by rote. It also aims to influence children's approach to the material world around them, outside school hours. Such intellectual activity might, over a long enough period of time, make a difference to the intellectual development of some of the children. In Phase II, then, we presented individual children with specific intellectual problems to be solved.

THE CLASSES STUDIED

Experimental Classes

The study described here was carried out in Kenya, where the African Primary Science Program was developed under the auspices of the Kenya Institute of Education. Most of the teachers involved in the program in Kenya had attended workshops sponsored by the Kenya Institute of Education either at the Institute itself in Nairobi or at one of the two sub-centers in Siriba or in Kagumo.

In all three of these centers, courses were given initially to some teachers from Standards I and IV in surrounding rural or village schools. In addition to giving the initial course, educators from the centers visited the teachers as they taught, encouraging them, and helping them with problems they encountered. Meetings were held as the year progressed, where teachers discussed their progress and difficulties. The teachers were provided with written teachers' guides, and were given help in assembling the necessary materials.

After the first year, the main center, in Nairobi, stopped giving courses to teachers and concentrated on other aspects of the program, such as developing more teachers' guides. However, in one school where two Standard I teachers had been involved, these teachers moved up with their classes and helped the new Standard I teachers to use the program with the new Standard I children. The following year, the four teachers using the program moved up again and helped a new pair of Standard I teachers. After three years, these six classes of children had all been in the program for all of their school years, and four of the teachers had had no special training from anyone outside their own school. The original help given to two teachers in that school multiplied by three in three years.

In the two other sub-centers, this multiplier effect was also at work, but in a slightly different form. In each case, one teacher who had become enthusiastic about the program was released from his own classroom teaching and spent the year giving courses to other teachers in his district, helping them in the same way that he had been helped. At a cost to the Ministry of one extra teacher's salary, 12 other teachers were introduced to the program.

From these three centers we examined 15 different classes. The school year is divided into three terms and we did the investigation at the end of the second term. Since most of the teachers moved up with their classes from year to year, the Standard I and Standard IV children had been in the program for two terms; the Standard II and Standard V children had been in the program for one year and two terms; the Standard III children for two years and two terms. The single exception to this was one Standard V class, whose teacher did not move on with them from Standard IV. They were no longer in the program at the time they were examined, but had been in the program for all of Standard IV.

The children in one Standard V class were older than most Standard V children, and are referred to as Standard VII throughout this report.

One of the experimental classes (a Standard V) was the lower of two streams of its school. None of the other experimental classes was in a school with streamed classes. Four of the classes -- one Standard I, one Standard II, and two Standard IV's -- were taught by teachers who were trained by other teachers. All the classes were from largely illiterate communities.

The distribution of the experimental classes was as follows:

Standard I	2
Standard II	6
Standard III	1
Standard IV	2
Standard V	3
Standard VII	1

Comparison Classes

For the experimental classes, all the teachers were considered by the local science educators to be doing a good job within the program. Thus, in selecting comparison classes, we tried to find classes that were in comparable communities, with teachers who were also considered to be doing a good job teaching. At the Upper Primary level, we sought classes whose program included science as it existed in the syllabus at that time, which was a matter of rote memory of briefly stated facts and principles. At the Lower Primary level, we sought classes which were involved in Kenya's New Primary Approach. This meant that the teachers had had extra training in new methods of teaching and that the medium of instruction was English. The New Primary Approach also involved activities of a sort similar to the Lower Primary Activities of the African Primary Science Program. That is, the teachers were asked to allow time for activities, but they were given little help in what kind of activities to do, or how to help their children make productive use of the activities period.

In most cases, the comparison classes came from similar rural areas. When there was difficulty in finding a close comparison, we selected a class that would be from a more privileged, rather than a less privileged situation, i.e., closer to the paved road or to an urban center. In two schools where the classes were streamed, we took the upper stream.

The older Standard V experimental class (which I refer to as Standard VII) was put to an expecially severe comparison. The experimental class came from an illiterate community well off the paved road. The comparison class was a Standard VII from a city twenty miles away. The children in the comparison class were the same age, but they had had two more years of schooling in a well-equipped school, with a specialized science teacher. The families were literate and, for the most part, middle-class.

In one instance, we were able to make a very close comparison between two schools. Standards I, II, and III in one school were all involved in this program and were among the experimental classes we studied. A few miles down the road was another school of a similar size, attended by children of essentially the same community. Many children of the two schools were friends and cousins, as were many of the teachers. The comparison school was involved in the New Primary Approach. As a double check on the comparability of the two schools, we did our evaluation not only in Standards I, II, and III, but in Standard IV as well, neither of which was in any special program. We found that, indeed, the two Standard IV classes were essentially indistinguishable on the measures involved in our procedure.

The distribution of comparison classes was as follows:

Standard I	2
Standard II	4
Standard III	2
Standard IV	2
Standard V	2
Standard VII	1

Except for the teacher in the comparison Standard VII class, none of the teachers in either group had more than eight years of formal schooling.

The same classes and same children were involved in both Phase I and Phase II of this study.

5

Phase I: Procedure

Phase I was designed to provide an opportunity for children to show their ideas about what to do with materials. If experience in this program really helped children to know the material world, to know how to find out about it and how to use it, to know how to work together to build on one another's ideas, and to be confident in trying out their own ideas, then they ought to be able to make profitable use of unstructured time available to them to do what they wanted with materials.

A large variety of different materials was chosen so children who had developed in different ways would all be able to bring to bear their knowledge, ideas, and abilities. The final list consisted of the following:

1. *Bilo* - a commercial building toy for children. Bilo consists of strips and blocks of wood from one to 12 inches long, with holes placed at intervals of one inch, and plastic nuts and bolts to attach them together. Some plastic wheels and gears are also included, as well as a plastic spanner, with a plastic Philips screw driver on the other end. We used the size 44, 121-piece set.
2. *Playplax* - another commercial building toy. Playplax consists of two-inch squares of colored plastic, with a half-inch slit in each side. The pieces can be joined together by means of the slits. The plastic is transparent, and children could look through the pieces to see what effect they had on the colors of the world around them. The plastic pieces are red, yellow, blue, green, or clear.
3. *Pattern Blocks* - a set of flat wooden blocks of different shapes and colors. The basic piece is a green equilateral triangle. The other pieces are a blue diamond, equivalent to two triangles; a red trapezoid, equivalent to three triangles; and a yellow hexagon, equivalent to two trapezoids. There were about 200 pieces in the set. With these pieces, we provided three outlines of shapes that could be filled in with the blocks in various ways. No pieces were placed within these outlines, nor was there any suggestion of what the outlines might be for.
4. *Cuisenaire rods* - a set of wooden rods sometimes used to teach arithmetic. The basic piece is a cubic centimeter. The next piece is twice as long, as

if two of the cubic centimeters were placed side by side -- and so on up to a rod ten centimeters long. Each size of Cuisenaire rod has its own color.

5. *Materials for making electric circuits:*
   - eight D-sized 1 1/2 volt batteries
   - eight "battery holders" -- blocks of wood into which are hammered six nails such that a battery can be wedged between them; at each end, a nail is in contact with the terminal, and a wire is attached to each of these nails.
   - 12 flashlight bulbs
   - six commercial plastic sockets, with a wire screwed into each terminal.
   - copper wire of different lengths and thicknesses, including two four-foot lengths of triple strand insulated wire*
6. *Two home-made pan balances*, and a selection of materials that would lend themselves to weighing:
   - tins of different sizes
   - plastic containers with covers, about 3" cubed
   - a dozen empty match boxes of different sizes
   - a few ounces of commercial oil-based clay
   - scraps of metal
   - several dozen bottle tops
   - two dozen metal washers
   - half a pound of maize and half a pound of rice
   - 24 blocks of wood, about six different shapes and sizes, made of two different kinds of wood
7. *Other general materials:*
   - cigarette foil
   - string
   - paper clips
   - several dozen pieces of reed-like grass that can be pinned together
   - pins
   - eight cotton spools, of four different sizes
   - a wire scouring pad
   - two pieces of wire screening
   - four empty plastic reels for 8 mm. cinema film paper
   - eight rings cut from inner tubes, ranging in width from 1 cm. to 3 cm.
   - two metal mirrors, 7 cm. x 10 cm.
   - two plastic mirrors, 5 cm. x 7 cm.

---

*For one experimental class that had studied batteries and bulbs, this material was omitted.

PRESENTATION OF MATERIALS

We set up the materials in an empty room. If there was an extra room in the school, we used it. If not, teachers were very cooperative in moving the children out of a classroom for us; the children continued their work outdoors, or were distributed around in other classes.

We moved desks together so there were three major working surfaces. On one of these surfaces we displayed the Bilo materials. We left two simple objects already constructed -- a cart and a small duck-shape, and we provided four photographs of simple constructions, one of them a photograph of the duck-shape.

On a second surface we displayed the Playplax and the Pattern Blocks. Five Playplax pieces were attached together in a row, by means of the slits. The other pieces were spread out, without any system. Three cards with outlines of shapes which could be made with the Pattern Blocks were left near the blocks, but no pieces were placed within the outlines.

On the third working surface was everything else. The Cuisenaire rods were placed near the balancing materials. The cigarette foil, wire scouring pad, wire screening, and pieces of metal were placed near the electric circuit materials; two complete circuits were set up, using a battery holder, and a socket, joined with crocodile clips -- the bulbs were lit. A few pieces of grass were pinned together in a simple construction, and the pins were placed near the grass.

Where materials were pr sented suggestively, we had judged that it would be more . resting to see how and how far the children would pursue an activity, once it was suggested to them, rather than to see whether they managed to hit upon that way of using the materials themselves. Our preliminary trials had shown us, for example, that if a single child happened to see how to use a battery holder and a socket to light a bulb, several children would become engaged in interesting work, whereas if nobody happened to see that, the entire electric circuit area tended to be ignored. Setting up two circuits ahead of time put classes on an equal footing, in this respect. It would, of course, have been interesting to know in which classes a child did happen upon these particularly productive ways to use materials. However, the other materials gave ample scope for individual initiative. So we chose to take the first step ourselves, in the few cases where our presentation was suggestive, in the interests of seeing where these suggestions led.

To clarify this point still further it might be worth mentioning that in our first trials we included some materials which were very interesting if one of us showed children what could be done with them. There was no way to arrange these materials suggestively; it involved taking them in our own hands and showing what could be done with them. But we found that when we did this, they understood, despite our protestations, that we really preferred them to work with these materials, over the other materials which we did not touch. As a result, they neglected most of the other materials. We therefore eliminated these materials, but we kept the materials mentioned, where suggestions could be made in the display.

When all was ready, we chose 12 children from the class we wanted to test. Twelve children were enough to give us an idea of the whole class, and they were few enough for us to be able to watch quite closely. We asked each child in the group to write his name and age on a piece of paper. Then we gathered the papers, and chose twelve at random from the pile. We put an upper age limit as follows:

Standard I	-	younger than 9
Standard II	-	younger than 10
Standard III	-	younger than 11
Standard IV	-	younger than 13
Standard V	-	younger than 14

Each of these children was assigned a number, from 1 to 12. This number was pinned on him, both on the front and back.

When the children were ready, with their numbers, they were given the following instructions, in their own language: "On the desks (tables) in this room there are many things. You may do whatever you wish with these things. You do not have to sit down. You may walk from place to place. You may talk with your friends, and you may work together." For the next 35 minutes they were left without further instructions. Their teacher was not present.

RECORDING SYSTEM

Two observers watched each group of children -- the same two observers throughout the study. Each observer had twelve recording sheets, one for each child, attached to a clipboard, so they could make notes as they stood and watched the children work. An example of a recording sheet is shown here. The sheet is divided from top to bottom according to the kind of material the child was working with when he/she was being observed. The shorthand names for these materials have the following interpretations:

"B & W"	-- batteries, bulbs, and wires
"General"	-- all the general familiar objects
"Bal"	-- balances
"Bilo"	-- the Bilo materials
"Cuis"	-- Cuisenaire rods

(so abbreviated in reference to Edward Prenowitz, who developed them for the Elementary Science Study)

"Plast" -- Playplax plastic pieces
"Ed's" -- the Pattern blocks*

The sheet is divided from left to right according to our ways of categorizing what the child was doing at the moment of observation. The column heads have the following interpretations:

Mix -- the child was working with more than one kind of material at a time
N -- the child was doing nothing relating to the materials -- for example, he/she was looking out the window, looking at us, or paying attention to something else in the room
W -- the child was watching some other child working with the materials, without participating or contributing ideas
H -- the child was handling materials, rather abstractly without seeming to be paying any attention to them
S -- the child was sorting objects, as if to see better what was available, or simply out of an interest in introducing some visual order
Inv -- the child was examining, or investigating a single object, as if trying to find out about it, or to get some idea of what to do with it
S -- the child was working with materials at a simple level, other than handling, investigating, or sorting
M -- the child was working with materials at a moderate level
E -- the child was working with materials at an elaborate level
X -- the child was working with materials at an extraordinary level
(This category was not anticipated; it was introduced when we found that the work of a few children in one class went beyond any level of elaborateness that we had seen in the preliminary trials. Subsequently, children in a few other classes did work of this level. On the original scoresheet, this column had been left for judgments we wished to discuss with one another afterward.)

The blank area at the right of the sheet was used to make notes of the work the child was doing, giving us some qualitative points of reference, to complement the information contained in our simple time-checks. This was necessary for compiling diversity scores, and also comparing judgments, about how we classed an activity.

Not all the distinctions across the page were maintained in our scoring counts. Rather, they simplified our job as we recorded. One observer started the session with child number 1, and the other started with child number 7. After a pre-established period of time, each would move on to the next child, following the order of the numbers pinned on their shirts. Each observer made the complete round of the twelve children six times during the session. For the first and last rounds, she observed for 10 seconds before moving on to the next child. For the second and third rounds, she observed for half a minute.

The most interesting information was obtained during the observation periods of half a minute. In our preliminary trials, however, we realized that we could create an untrue picture of a child's work if we sampled half a minute of that work at the very beginning. A child's approach to the materials, in the first few minutes, was not necessarily representative of his work as the session proceeded. By starting with a very brief observation period on the first round, we did a complete round in two minutes. By the time we started our more thorough observation, the work the children were doing was representative of their work throughout the session.

The final 10-second round was added in order to get a quick picture of the work of each child during the very last two minutes. The children did not know that these were the last two minutes, but we thought it important to know their level of work at the end, since some children ran out of things to do, while others had time by then to develop their work to a higher level of complexity.

During the six rounds taken together, each child was thus observed for almost two and a half minutes by each observer, or almost five minutes altogether. In principle, the six rounds took 28 minutes to complete. In practice, the total time was longer than that, because the observers would always spend a few seconds locating the next child they were to observe. We always started the final round when 33 minutes had elapsed. This meant that we sometimes waited a minute or two between the fifth and sixth rounds..

The sequence of the observations was recorded with the help of color-coding. The first round was recorded with a black pen, the second and third with a green pen, the fourth and fifth with blue, and the sixth with red.

A mark was made every 10 seconds, representing what the child was doing during the most part of the preceeding 10-second interval. Numbers were used to indicate sequence within a single color-code. If, for example, a child did the same thing for the entire half-minute, during the second round the green marks would read -- 1 1 1, and the third round would start with a green. If, however, he/she did one thing during 20 seconds, and then changed for the next 10 seconds, the green marks would read 1 1 2, and the third round would start with a green 3. These marks could then serve as reference numbers to notes made on the right-hand part of the page.

Thus, by looking at the black mark, then the green marks in order, then the blue marks in order, and finally the red mark, a child's activities can be traced in one observer's records. By interspersing the records of the other observer, a sequence of 12 time-spots can be recreated, during the child's 35 minutes of work.

SCORING SYSTEM

The "complexity" dimension -- simple, moderate, elaborate -- can best be characterized by referring to a remark by W. U. Walton, a physicist who was a staff member of the African Primary Science Program for two years, and one of the most inventive people I know with materials. Asked how he managed to assemble such a repertoire of productive uses for unlikely materials, he replied that sometimes the use came first, and sometimes the material came first. That is, sometimes he had an idea of something he would like to do, which he would keep in the back of his mind, perhaps for years, until one day he came across some object or material which he could recognize as being just what he needed to realize that idea. Other times, he would have a material which he would recognize as having unique characteristics, without knowing how those characteristics might best be used. After a time, he would come up with an idea of just what could be done with that material. In other words, sometimes the idea came first, and he eventually found a material way to realize that idea; and sometimes a material came first, and he eventually found an idea that could take advantage of that material.

Needless to say, Walton's ideas depend on knowing a great deal about how things behave; and this knowledge about things was hard won -- dependent a great deal on previous ideas he had about the way other things behave, and on explorations derived from these ideas. This same interplay of materials and ideas is what we were looking for in our "complexity" dimension.

The specific criteria for each category -- simple, moderate, elaborate -- were first roughly established on the basis of our own knowledge of the materials involved, of how children generally approached them, and of the cognitive abilities in certain activities. Preliminary trials in 10 classes enabled us to refine our original criteria.

An activity which was the obvious and easy thing to do with a given material was coded as simple -- picking things up, comparing two things, rolling a ready-made cart, trying to copy a model we presented, piling flat-sided objects on top of one another, turning an object around in one's hands, collecting together all similar objects (washers, for example), looking at oneself in a mirror.

Activity was coded as moderate if it went beyond the obvious in any one of a number of different ways. It was moderate if what was obvious was not easy to do, and required some determination -- pinning several pieces of grass together at one point, for example (obvious because the model already did that). If piling of blocks developed into a pattern, or a representation, or, in the case of Cuisenaire rods, took advantage of the differences in length, it was scored moderate. Choosing some specific colored object to look at through the colored plastic became moderate. Putting objects on the balance with some system other than loading each side with diverse objects would be moderate -- for example, comparing objects in pairs. Trying to make an electrical circuit other than the model -- even if the bulb did not light -- was moderate.

To be coded as elaborate, a good deal more planning was involved, and/or understanding of the nature of the materials. An axle would be assembled which allowed the wheels on a cart to turn. A mirror would be used to look for an image other than the child him/herself. Optical effects of two or more colored plastic pieces would be systematically compared. Constructions would cope with some structural problems, or include representational detail, or mathematical patterns.

The activities scored as extraordinary -- going beyond anything we had anticipated -- were the following:

1. A "walking" cotton spool made by passing a rubber band through the center hole, and winding it on bits of stiff grass, strung with string to make a braking mechanism.
2. A solidly built chair, of pinned grasses, standing firmly on four legs, and strong enough to hold any weight that would fit on it.
3. Lights arranged to illuminate a number of different rooms in a plastic house.
4. Filling one of the pattern black card outlines in four different ways, based on the shape relationships among the pieces.

5-8. Four different Bilo constructions, tightly assembled, each involving more than a dozen pieces, and each having working parts, either wheels mounted on bearings, or gears properly engaged.

For the "diversity" dimension, some distinctions were obvious: lighting a bulb is a different activity from weighing blocks. Some distinctions were a good less obvious.

We accorded a "different" activity for the following kinds of distinctions: each different technical device -- for example the use of the spanner in the Bilo materials; each different representation -- building an airplane was marked as a different activity from building a goat; each different combination of materials -- building with Playplax and Cuisenaire rods combined was different from building with Cuisenaire rods and pattern blocks combined; each different kind of exploration of materials -- reversing the battery in the model circuit was different from replacing the bulb.

In the case of this dimension, more than in the case of complexity, our criteria were affected by what we saw in the preliminary trials. It might seem strange, for example, that we called building with Pattern Blocks standing up a different activity from making patterns with them lying down. However, we saw classes who did only one or the other. They seemed, in fact, to be two distinct ideas about appropriate uses for those blocks. At the other extreme, many of the children in the younger classes used materials for representational activities whose general theme was shopping. Many different kinds of materials were brought into the shopping activity, and many different kinds of shopping were represented. But the basic idea was shopping, and it was a very common idea; we scored it as a single activity. Unusual details were reflected in the "complexity" dimension, giving evidence of thoroughness in thinking through the representation, and of the number of relationships involved. Similarly, any number of houses or towers built with one kind of material counted as a single activity, as did any number of Bilo carts, and any number of chairs or tables built with Cuisenaire rods. Other objects, however -- animals, machines, people, for example -- each counted as different activities.

This much general description should facilitate reading the following guidelines to the scoring. Separate guidelines are shown for each material. Each "different" activity is listed at the left. Where the number of different possibilities is open-ended, this is indicated by "1, 2, 3, etc." The distinctions between simple, moderate, and elaborate versions of each activity are outlined across the page.

General

	S	M	E
sorting objects	class	>1 class	multiple classes
investigate	no transforming	1 transformation	>1 transformation
1			
2			
3			
etc.			
use as tool		based on 1 property	based on >1 property
1			
2			
3			
etc.			
shopping	<3 elements	3, 4 elements	>4 elements
cooking	<3 elements	3, 4 elements	>4 elements

General (Cont'd)

	S	M	E
other representational play 1 2 3 etc.	<3 elements	3, 4 elements	>4 elements
pin grass	attempting	few pieces achieved	recognizable 1 2 3 etc.
clay	forming	recognizable 1 2 3 etc.	detail
build, by piling	few pieces	tower or house	structural complication or detail
		other, recognizable	structural complication or detail
build, not by piling 1 2 3 etc.	few pieces	>1 relationship	>2 relationships, or detail

Bilo

copy any model	few pieces loose or 3 pieces and 1 bolt	more than half	completed
copy any photo	few pieces loose or 3 pieces and 1 bolt	more than half	completed
cart other than model		>3 pieces, bolted tight, or >6 pieces, loose	>2 angles bolted, and >6 pieces
each other object 1 2 3 etc.		>3 pieces, bolted tight, or >6 pieces, loose	>2 angles bolted, and >6 pieces

Bilo (Cont'd)

	S	M	E
build by piling	few pieces	house or tower Other, recognizable 1 2 3 etc.	structural complication or detail
arrange pieces flat		pattern or recognizable form	detail
use spanner		X	
use Philips screw driver		X	
combinations with other materials 1 2 3 etc.	few pieces	>1 relationship	>2 relationships or detail

Cuisenaire Rods

flat	no pattern	pattern or representation	pattern based on unit length differences; or detail
built up - house or tower	no length relationships	length relationships	unit length relationships, or structural complication, or detail
built up - chair or table	no length relationships	length relationships	unit length relationships, or structural complication, or detail
built up - each other representation 1 2 3 etc.	no length relationships	length relationships	unit length relationships, or structural complication, or detail
combinations with other materials 1 2 3 etc.	few pieces	>1 relationship	>2 relationships, or detail

Pattern Blocks

	S	M	E
flat patterns	few pieces	repeated patterns	repeated patterns, >1 shape and >1 relationship
built up patterns	few pieces	repeated patterns, or balance	>1 shape and >1 relationship
representation		<10 pieces, or letters and numbers	>10 pieces, and other than letters or numbers
filling card		attempting	completed
building around card outline	attempting	completed	
combinations with other materials	few pieces	>1 relationship	>2 relationships, or detail
1			
2			
3			
etc.			

Playplax

	S	M	E
joined	<10 in row, or <7 in two dimensions	>10 in row, or >6 in 2 or 3 dimensions	>10 in 2 or 3 dimensions, tight
flat	no pattern	pattern	
on edge, not joined	attempting	successfully balanced	
combination, joined and not joined		1 relationship	>1 relationship
use as color filter	1 piece at a time, at work in general	1 piece at some specific object, or pieces superimposed, at world at large	comparing distance, colors, etc.
combinations with other materials	few pieces	>1 relationship	>2 relationships, or detail
1			
2			
3			
etc.			

Balances

	S	M	E
balancing and weighing	loading pans haphazardly	trying to preserve equilibrium; or comparing weights of two objects	ordering >2 objects by weight; or quantifying comparisons; or comparing the two balances
other	criteria not defineable in advance		
1			
2			
3			
etc.			

Batteries and bulbs

Many African children know how to light a bulb this way

	S	M	E
copy model circuit	attempting	successful	
make classic circuit*	attempting	successful	
explore bulb in circuit	screw and unscrew	exchange	
explore battery in circuit	shake, push, remove	reverse or exchange	
explore wires in circuit	undo, tighten	change contacts	
try other conductor	wire-type	not wire-type	
make own connections	1 bulb, 1 battery	>1 bulb or >1 battery	>2 bulbs or >3 batteries
1			
2			
3			
etc.			
combinations with other materials	criteria not defineable in advance		
1			
2			
3			
etc.			

Mix	N	W	H	S	Inv	S	M	E	X	NOTES
										B & b
										General
										Bal
										Bilo
										Cuis
										Plast
										Ed's

Phase II: Procedure

The specific problems presented for Phase II of the study are drawn from the areas of classification, seriation, and spatial relations. A major factor in the selection of the problems was the time available to us. The three that are derived from Piaget's studies were done on a one-to-one basis and could be done relatively quickly. The other three, which relate less directly to Piaget's work but share similar concerns, took more time. But several children could be doing them at once, at different places in the room, without the investigator's constant presence.

The problems were always presented to the children in their own language. The solutions all took the form of nonverbal activity.

The first four problems presented below were used with the children in lower primary classes. Each child did two of them. Half the children did the Missing Piece and the Brick Corner; the other half did the Bilo Model (a) and the Straight Line. In the upper primary classes, each child did one problem; half the group did Ordering Weights, and the other half did Bilo Model (b). The children were assigned randomly to these treatments, with the following exception: children who had worked with Bilo materials in Phase I were not assigned to the Bilo Model problem in Phase II.

MISSING PIECE

This problem was derived from Piaget and Inhelder's work on children's ability to classify groups of objects according to two criteria at once. The technique is not identical to any used by Piaget himself. We developed this technique in order to make it as playful as possible, as well as to eliminate as much as possible any difficulties of verbalization -- both in making ourselves understood, and in understanding the children's justifications.

We took care to avoid presenting the problem in such a way that children could resolve it perceptually. Piaget and Inhelder point out that, "there is a figural, or quasi-perceptual way of solving matrix problems..." (Inhelder and Piaget, 1964, p. 155.) "The younger subjects start from spatial form and treat it as a incomplete pattern which helps them fill the gaps in terms of symmetries (Ibid. p. 157). Piaget and Inhelder distinguish between this approach and a conceptual approach on the basis of the justifications the children give for their answers. In our technique, on the contrary, the "good form," or matrix, is not given to the children. They must create it themselves, either by arranging the pieces, or by organizing the information in their heads.

It is, of course, incumbent upon us to make sure the children know that the 24 objects (six colors, four sizes) *can* be arranged by double classification, without however laying out the four by six matrix for them. Our technique endeavors to do that.

Materials

Plastic rectangles, 24 (from Lego building set): red, blue, yellow, white, clear, black, small, medium, medium-large, and large.

Procedure

(A) Six pieces are set out in the following array:

large red	large white	large black
medium red	medium white	medium black

The experimenter (E) says, "I am going to mix these up and take one away. Close your eyes." E takes away the medium red. E: "Now open your eyes. Which one did I take away?" E congratulates him on right answer. (This much is simply a way of explaining the task to the children. It is simple enough so that every child examined found the correct answer with no difficulty.)

(B) E produces the complete set of pieces and lays them out in four messy rows, according to size. Within each row, the colors are random -- differing from row to row. E says, "This time there are big ones, smaller ones, and smaller ones, and very small ones (indicating the appropriate row each time). In this row there are (E points to each color in turn, in one of the rows, and names them). "There are all the same colors in each row, yellow ones, red ones, black ones, plain ones, blue ones, and white ones. Now we'll do the same thing again. It will be harder this time, won't it. Close your eyes."

E mixes all the pieces, and removes smallest blue.

E: "Open your eyes. Which one did I take?" (Said with a big friendly smile.)

If the child names only a color, E says, "Show me how big it is."

(C) After the child's answer (which might be "I don't know, or some equivalent), E says: "Move the pieces and put them so you can see better whether you are right" (or, if he hasn't made a guess, "So that you can see better which one it is").

(D) After the child seems to have finished moving the pieces, if he has not yet confirmed or changed his guess, E asks, "Now what do you think?"

Scoring

Piaget and Inhelder do not describe stages in the solution of matrices. Instead, they allot a point score, based on the number of criteria adhered to. They also take into account the first answer, compared with later answers, and the reasons the child gives. In our own point scores, we have taken into account the two criteria (size and color), the initial answer and the final answer, and the ability to make an arrangement of the pieces that serves to justify the answer.

We awarded points in the following way:

correct size on first answer	1
correct color on first answer	1
correct size on final answer	1
correct color on final answer	1
systematic arrangement either by color or by size or both	1
systematic arrangement accomplished spontaneously, before E's suggestion	1

This gives a highest possible score of 6. The various possible types of protocols resulting in each score are the following:

0 no arrangement of the pieces, even after suggestion to do so: final answer wrong in both size and color
Note: If the first answer is right, in whole or part, but the child changes to a wrong final answer, the earlier right answer is considered to have been coincidence, and no credit is given for it.

1 first guess wrong in both size and color
no arrangement of the pieces
final guess half-right (either size or color, but not both)

1 arrangement by size or color or both, after suggestion
final answer wrong in both size and color

2 first guess wrong
successful arrangement after suggestion
final answer half-right

2 spontaneous arrangement of pieces
final answer wrong

2 first answer half-right
no arrangement
half-right answer maintained in final answer

2 wrong first answer
no arrangement
right final answer

3 spontaneous arrangement
final answer half-right

3 half-right first answer
no arrangement
right final answer

4 wrong first answer
suggested arrangement
right final answer

4 right first answer
no arrangement
right final answer

5 half-right first answer
suggested arrangement
right final answer

6 right first answer
arrangement (spontaneous or suggested)
right final answer

STRAIGHT LINE

This problem was derived from Piaget and Inhelder's work on children's spatial representation (Piaget and Inhelder, 1948). To build a straight line, when there is no edge to follow, children have to have an overall idea in mind as they proceed. Doing this depends upon having constructed a notion of a consistent point of view -- one of the foundations of spatial relations.

Procedure

(A) E asks child to draw a straight line on the table with his finger in order to establish that they both agree as to what is meant. E then places two grains of maize, about six inches apart, along the table's edge, and asks child to place eight other pieces between them, "so they make a straight line." If child has any difficulty, E again helps to establish that they both know what is meant. All of this is by way of introduction.

(B) E then places the two grains of maize on a piece of paper in such a way that the straight line will not be parallel to a side of the paper, but will be slanted across the paper. E marks with a pen the placement of the grains and insists that those grains must remain where she has put them. E asks the child to place the other eight grains between those two end-points "so they make a straight line." Any time the child is tempted to move the end-points, E insists they must remain where the penmarks are.

(C) When the child finishes, E asks if it is "a good straight line," and offers the child the occasion to change it as much as he wishes.

Scoring

0 grains are placed such as to ignore one or both of the designated end-points, and in nothing resembling a straight line

2 the line is more or less straight, but ignores one end-point

2 the line goes from one end-point to the other, straying far from a straight line -- either a broad curve, or a zig-zag

4 the line goes from one end-point to another, managing to come quite close to a straight line through a continuous correction process

6 the child takes both end-points into account right from the start, and keeps the direction in mind as he places each grain

A few children were given scores of 1, 3, or 5, if their approach was intermediate between two of the results described above.

BRICK CORNER

This was one of the problems we devised that could be done without the experimenter's presence, given the limitations on our time.

It does not derive directly from the work of Piaget. Spatial relationships are clearly involved, but not in any form that Piaget has studied. The child must keep in mind the overall shape of the object and relations of up-down, left-right, front-behind; but he must do this in conjunction with grasping the idea of overlapping the bricks, so the construction holds together mechanically. This mechanical element to the problem serves as a self-corrective device -- as long as he has not grasped it, his construction will not hold together, and he knows that it is not yet like the model. On the other hand, it complicates the spatial relations involved, since several of the bricks can only be partially seen, and this disguises their orientation.

Materials

Lego bricks are made of plastic and about two centimeters long and one centimeter wide. Bumps on the top surface and grooves on the undersurface enable them to stick together firmly.

Procedure

The child is given a construction made of six Lego bricks (three white and three red) arranged in three layers, overlapping, and making a right-angled corner. He is given six loose bricks and asked to build a corner just like the model. Two children worked on this test independently, in opposite corners of the room, while the experimenter did one of the other tests with other children. Each one worked alone and was allowed to work as long as he wished until he felt he had finished.

Scoring

Although this test was not based on any one of Piaget's investigations, there was a clear division into stages. The turning point was the construction of a single corner, two-layered, consisting of three bricks. Any construction attaining at least this level scored 4, 5, or 6. Any construction not attaining it scored 0, 1, or 2. There is such a clear distinction that no protocol was accorded a mark of three.

Points were assigned as follows:

0 no L-shape, no overlap (simply some bricks piled or stuck together)

1 L-shape, but no over-lap (simply two unattached wings)

1 overlap, but not stuck together, no L-shape

2 overlap, stuck together, but no L-shape

2 L-shape, overlapped, but not stuck together

4 L-shaped, overlapped, stuck together -- two layers

5 L-shaped, overlapped, stuck together -- three layers, but some bricks out of place

6 perfect (or mirror image)

BILO MODEL (A)

This problem involves the construction of a three-dimensional model from a colored photograph. While a coordinate system of spatial representation comes into play, the mechanical problems of assembling the model are significant also. As in the case of the Lego corner, the mechanical difficulties serve as self-corrective devices to some degree. The model will not hold if the mechanics are not done correctly. At the same time, they make trial and error an extremely arduous procedure. Each connection takes a certain time to do, and as long again to undo. This combination makes it an appropriate problem for children to do on their own, without the constant presence of the experimenter. Only with a systematic approach could a child's construction closely resemble the model.

Procedure

The child is given the photograph and the exact pieces needed to make the object. If a child asks for additional pieces, he is given them any time throughout his work. He is allowed to work until he feels he is finished.

Scoring

Two of the six points were accorded for mastery of the use of screws and bolts. Four of the six points were accorded for reconstruction of the spatial relations. This resulted in the following scale:

0 no screws used; no resemblance to the model

1 no screws used; one or two correct Euclidean relationships constructed

1 some screws inserted loosely, unbolted; no resemblance

2 some screws inserted loosely, unbolted; one or two correct Euclidean relationships constructed

2 some screws bolted; no resemblance

3 some screws bolted; one or two correct Euclidean relationships constructed

4 screws bolted; basic form correct

5 screws bolted; all relationships taken into account; some errors of angle or direction

6 perfect, or perfect except for one detail

ORDERING WEIGHTS

Materials

One pan balance.

Eight objects of different weights and different sizes. (The weight differences were small enough, given the shapes and sizes, that sure judgments between adjacent objects could not be made without using the balance.) The objects were the following, listed from lightest to heaviest:

a matchbox weighted with paper*
a piece of wood, 3 1/2" by 2 1/2" by 1/4"

a D-sized dry cell
a steel roller-skate wheel
a ball of oil-based clay
a matchbox weighted with clay and nails*
a piece of wax, 1" by 2 1/2" by 1 1/2"
a matchbox weighted with nails*

Procedure

(A) E routinely introduces child to the use of the balance as a way to compare weights of two objects, using two objects that are not among the eight to be used in the seriation. (For no child did this present any problem.)

(B) E then indicates the objects to be seriated (except for object number 6). These are, of course, disposed randomly. E: "Would you try to put the very lightest one over here, the one that doesn't weigh very much at all, and then the one that's a little bit heavier, and then the one that's a little bit heavier, right up to the very heaviest over here. Put them so they get heavier and heavier and heavier, right up to the very heaviest over here. You can use the balance to be sure." For children whose initial actions indicate that they may not have understood the instructions (one or two in our sample), E repeats or rephrases the instruction.

(C) After child has arranged the objects to his satisfaction, E asks him if there is anything he would like to check, suggesting that he may change anything he thinks needs to be changed. If child has not used the balance, E asks him to use the balance to check what he has done.

(D) Finally, E presents object number 6, and asks child to find its place in the line.

Scoring

The scoring was done in accordance with Piaget and Inhelder's analysis of stages, described in *Le Developpement des Quantites Physiques chez l'enfant* (1941, pp. 220-243).

Piaget and Inhelder describe four different techniques in which children seriate weights. (A fifth technique is essentially verbal.) In three of their four techniques, Piaget and Inhelder ask the children always to compare two weights at a time. This eliminates the possibility of "pseudo-seriation by unconscious memory or immediate perception," and obliges the children to depend upon logical operations of transitivity if they are to infer the correct relationships involved in a series of comparisons. In these techniques, the number of objects ranges from three to six. Only in one technique do Piaget and Inhelder allow the children to manipulate the weights freely. In this technique there are 10 balls of the same size and shape, differing only in weight. No perceptual illusions are thus involved, and no balance is necessary.

In our technique, the children were allowed to manipulate the objects freely, but perceptual illusions arising from differences in size and shape make it necessary to make two-by-two comparisons on the balance. The coordination of these two-by-two comparisons allows us to see the children's operational level.

Where children do not use the balance, believing that they can trust their hands, as is the case with some of the children in the lower stages, we can compare their procedures with those in Piaget and Inhelder's free manipulation technique.

Points were accorded as follows:

6 Piaget and Inhelder's stage IIIb: The children proceed totally systematically, seeking the lightest of all, the lightest of those that remain, then the lightest of those that remain, and so on.

5 The overall approach is as above, but the system is still tenuous enough that it leads to one or two errors.

4 Piaget and Inhelder's stage IIIa: The child succeeds in making one or two partial series, or three or four elements, by coordinating several pairs, but without proceeding by a comprehensive system.

3 The child seeks to make some partial series by coordinating pairs, but does not succeed.

2 Piaget and Inhelder's stage II: The child systematically compares two objects at a time, but does not attempt to coordinate pairs. Or, without using the balance, the child manages an intuitive ordering of four or five weights.

1 The child makes some comparisons of weight, but tends generally simply to follow the order of his own actions -- the order in which he picks them up is the order in which he places them in the row.

0 The child simply follows the order of his own actions.

BILO MODEL (B)

The same comments apply as for Bilo Model (a).

The model in this case was more complicated. The basic shape involved the same relationships, but more pieces were necessary to realize them. All pieces and relationships were visible in the photograph. Interpreting the relationships, especially the minor connecting pieces, required a surer system of coordinates, especially in the depth dimension.

Scoring

At this age level, no credit was given for mastering the technique of nuts and bolts. If they presented difficulty for a child, this was reflected in his final construction.

There were two major organizational ideas involved -- the basic form, and the function of the connecting pieces. Each of these scored one point. The remaining four points were accorded for additional relationships of length, position, orientation, or angle. The various combinations are too many to list in detail.

7

Results

PHASE I

Chapter 1 touched on the qualitative differences between experimental and comparison classes. To make the contrasts more explicit, let me describe what happened in the two best experimental classes and the two best comparison classes.

One of the experimental classes in Standard I was remarkable for the variety of their ideas. Much of their inventiveness took the form of symbolic play: using something to pretend it was something else. Several children pretended that the plastic pieces were eye-glasses, and "wore" them on their faces, or bought and sold them to one another. Several children bought and sold other things, too, weighing them on the balance, and using washers or small blocks as money. One girl made a handbag by pulling strands in a wire scour; she put pretend money in the handbag and went shopping with it. One child used tins and spools to build a stove inside a house made of Cuisenaire rods, and cooked corn and rice on her stove. Several children made other kinds of stoves, cooked on them, and pretended to serve the cooked food to others. A few children made various wheel-and-axle arrangements, using spools, film reels, or Bilo wheels as wheels, and grass or metal or Bilo screws as axles.

Several children used the plastic pieces as color filters, to look through, at everything around them. One child looked specifically at some lit light bulbs, and then used a battery and bulb circuit to illuminate a plastic construction. Five of the children worked at the Bilo set to the point of building an interesting construction. Four children worked with the batteries and bulbs, making circuits and doing small experiments. They made circuits with two or three batteries, and two or three bulbs, and they tried attaching wires in different ways to see what would happen. One child made designs with the pattern blocks, where he made use of the geometrical relationships between the shapes of the different blocks. He built some symmetry into his pattern, and he pursued his interest in symmetry by using a mirror to reflect what he had built. One child made a construction with Cuisenaire rods, where he made use of the different length relationships of the rods. One child made constructions with the Playplax pieces. One child used a piece of metal as a mirror to look at himself, and another tried to see how good a re-

Each set of results is irst discussed qualiatively, and then anayzed statistically. everal paragraphs in he chapter are addressed pecifically to readers ith a background in staistics. Other readers an limit themselves to he qualitative discusions.

flector the back of the mirror was.

In the best Standard I comparison class, four children who showed the most concentration all worked most of the time with batteries and bulbs. They tried many different ways to light a single bulb on a single battery -- touching wires in different places, using clips to attach wires together, tapping, pushing and shaking the battery and bulb to see what effects that would have. One child made a moderately elaborate arrangement with the Cuisenaire rods. One child made a small cart out of two pieces of the Bilo construction set, two axles and two wheels loosely bolted on. One child spent a few minutes balancing tins of maize and rice and Cuisenaire rods on a balance. He also used a block from the Bilo construction set to pretend it was a car and pushed it along a table making the appropriate noises. Two or three of the children put together one or two pieces of the Bilo set without pursuing it long enough to make anything significant. Three children put together a few pieces of the plastic construction set. Four children spent most of the time simply handling the materials or watching the other children.

In the experimental Standard VII class, we could scarcely keep track of the activities. Six children made constructions with the Bilo materials, and several of them made two or three different things. Their constructions included four- and three-wheeled carts, onto which they loaded things to be carried and some of which they tied together with string, into a train. They also included a balance. Other children made complicated circuits with batteries and bulbs and various conductors. Two children collaborated to make a telephone system that crossed the room with string for the wires, and three tins for the receivers. It was a working system, not just make-believe. With the Cuisenaire rods, five different children made constructions that made use of the numerical nature of the lengths of the pieces. They built houses with them, and outlined letters with them, and the boy who made a balance from Bilo pieces also used the Cuisenaire pieces to make a picture of a balance. Three children made catapult arrangements from spools, pieces from an inner tube, and pieces of stiff grass. One child made a cart from spools, grass, string, rubber, and wood. Children made elaborate towers with the plastic pieces. Others worked with the geometry pattern blocks, making flat patterns or filling in outlined shapes in a variety of ways, or making pictures with the blocks or building towers with them. One made a staircase of them for his plastic tower. One child compared weights of Cuisenaire rods of various numerical relationships; he also spent some time trying to fix one of the balances which was not working very well. One child tied a piece of string to the spanner from the Bilo set and swung it like a pendulum.

In the comparison class most children spent their time with either the Bilo construction set or the geometry pattern blocks. With the pattern blocks, six different children spent their time making symmetrical and repeated designs. There was a good variety of different designs, but no child used the blocks in any other way. Seven different children made elaborate constructions with the Bilo. All but one of these took the form of a chart, most of them resembling one another. The one exception was a four-sided figure in the form of a flat trapezoid. Five children used the string and the spools to make a pulley rig; there was very little difference from one to another in these rigs. The most interesting construction of all was a wagon made of wood with metal rods as axles and spools as the wheels. However, it was put together in such a way that the wheels would not turn. One child used two mirrors to see the effects of double reflections; one child made an elaborate tower with the plastic pieces; two children built houses with the Cuisenaire rods.

Without any question, the classes which showed the most complexity and diversity working with the materials were experimental classes. Similarly, without any question, the classes with the fewest ideas and the least initiative were comparison classes. In the middle range, most of the experimental classes worked at a higher level than all of the comparison classes, but there were some comparison classes which worked at a higher level than some of the experimental classes. Differences in the way that children in this study functioned would be clear to any observer. Anyone who wanted to see for himself could simply set up these materials, as we did, and watch children work with them. After watching a few classes which had been well involved in this program and a few other classes which had not at all been involved in it, the observer would have a good idea of the differences.

Quantifying these differences is a somewhat more complicated matter. As indicated in Chapter 4, two dimensions were quantified -- the complexity of the activities, and the diversity within a class.

We decided to discard from the analysis the Phase I results of a Standard II experimental class, and a Standard IV comparison class. The Standard II experimental class was greatly influenced, during Phase I, by three children who spent the time asking each other the English names for the various objects involved. By the end, all the children were doing only this. We did not know how to take this kind of activity into account. The Standard IV comparison class seemed to be angry at school in general, and many of them refused to allow themselves to get involved for a while. By the end all of them were simply standing and looking at us. It seemed to us that their lack of activity was due not to a lack of ideas of what to do, but to some protest they were making. (In Phase II both these groups of children became involved in the problems they were set, so we have kept their results for that phase.)

Analyzing the results of the remaining classes, we made two different kinds of comparisons. The first kind deals with the diversity and complexity of activities done by a class as a whole. The second kind deals with the number of children in a class who were involved in work of a high complexity.

Kinds of activities done by a class

Table 1 summarizes the results of the first comparison. The classes are listed at the left, by grade level; in every case the experimental classes, indicat[illegible] by an E, precede the comparison classes, indicated by a [illegible]

The first column, labelled D, indicates the total number of different kinds of things done in that class, of whatever level of complexity. The second column, labelled M, indicates how many of these different things were at least moderately complex. The third column, labelled Elab, indicates how many were at least elaborate. The fourth column, labelled X, indicates how many were extraordinary. Thus, the totals work cumulatively from right to left. (Any one *kind* of activity done in a given class scores only once for the class, no matter how many different children might have done it.)

The last column is a score we devised which would combine the number of different things done (column D) *and* the degree of complexity involved in these things. The Diversity/Complexity score is simply a totalling of the columns D, M, Elab, and X. (This amounts to scoring 1 for each different activity of a simple level, 2 for each of a moderate level, 3 for each of an elaborate level, and 4 for an extraordinary level.) We found it important to have such a score, reflecting both diversity and complexity, since the amount of time a child spends pursuing one activity enough to develop some complexity in it must necessarily take away from the time he has to undertake a number of different activities.

9[illegible]

TABLE I *Class scores for diversity and complexity of work*

	D	M	Complexity Elab	X	Diversity/Complexity Score
Standard I					
E1	36	21	2	0	59
E2	34	7	0	0	41
C1	24	5	0	0	29
C2	21	4	0	0	25
Standard II					
E1	36	13	3	0	52
E2	30	14	1	0	45
E3	28	13	0	0	41
E4	21	10	0	0	31
E5	17	11	2	0	30
C1	27	11	1	0	39
C2	28	8	2	0	38
C3	21	5	0	0	26
C4	17	5	0	0	22
Standard III					
E1	29	14	1	0	44
C1	28	10	0	0	38
C2	18	8	1	0	27
Standard IV					
E1	33	15	4	0	52
E2	25	13	4	0	42
C1	24	12	2	0	38
C2	22	13	1	0	36
Standard V					
E1	37	23	12	2	74
E2	39	20	6	1	66
E3	27	16	7	3	53
C1	29	10	3	0	42
C2	16	9	5	0	30
Standard VII					
E1	40	26	15	2	83
C1	26	22	8	0	56

D=Number of different things done in the class
M=Number of moderate things done in the class
Elab=Number of elaborate things done in the class
X=Number of extraordinary things done in the class

A few especially remarkable classes can be identified in this table. Standard I class E1, for instance, with 36 different activities, of which 21 were moderate or better and 2 were elaborate, has a higher Diversity/Complexity score than any of the comparison classes right up through Standard VII. Its Diversity/Complexity score resembles those of experimental Standard V's, although, as would be expected from young children, very few of its points come from elaborate activity.

Experimental classes E1 in Standard V and E1 in Standard VII were remarkable for the number of different activities of an elaborate complexity.

Looking at the results as a whole (Table 1), we can see that at every grade level but one, all the experimental classes scored higher than all the comparative classes of the same level, and even higher than all the comparative classes one year older. (The exception is in Standard II where the two lowest experimental classes did less well than the two highest comparative classes, and less well than the best Standard III comparative class. They nonetheless still scored better than the lowest Standard II comparative class.)

Table 2 presents the average scores in each standard. Here we can see, as the preceding comments have already implied, that the average of the experimental classes is in every case higher than the average of the comparison classes of the same standard. But what is striking in this table is that all experimental standards, even the youngest, have better averages than any of the comparison standards, except for Standard VII.

TABLE 2 *Average diversity/complexity scores by standard*

Standard	*Experimental*	*Comparison*
I	50	27
II	39.8	31.25
III	44	32.5
IV	47	37
V	64.3	36
VII	83	56

To perform tests of statistical significance, we considered the results of 12 classes from each group, one each from Standards III and VII, two each from Standards I, IV, and V and four from Standard II. Referring to Table 1, the classes we eliminated were E5 in Standard II, C1 in Standard III and E1 in Standard V. In each case, we eliminated the class which was least well matched with any class in the other group.

In analyzing the total Diversity/Complexity scores for these classes (the last column from Table 1), we found that the difference in favor of the experimental group yields a t (22) = 3.47, which is significant at the .01 level.

We also analyzed the number of different things done in these classes of at least moderate complexity (the sum of the scores for each class in columns 2, 3 and 4 of Table 1). This yields a t (22) = 2.88, which is once again significant at the .01 level.

An analysis of the number of different things done of at least elaborate complexity (the sum of the scores for each class in columns 3 and 4 in Table 1) yields a t (22) = 1.74, which is not significant at the .05 level.

Table 3 isolates the results for the two highly comparable schools (as described below) where Standards I, II, and III from one school were all in the program. The results of the Standard IV from each school have been included and their nearly-identical results strengthen our assumption that the two schools were closely matched. In the other three standards, the experimental classes scored higher than the equivalent comparison classes, and also higher than the comparison class one year older. Experimental Standard I did even better than the Standards III and IV classes which had not been in the program.

TABLE 3 *Class scores of two closely-matched schools for diversity and complexity of work*

	D	*M*	*Complexity* *Elab*	*X*	*Diversity/Complexity Score*
Standard I					
E	34	7	0	0	41
C	21	4	0	0	25
Standard II					
E	21	10	0	0	31
C	21	5	0	0	26
Standard III					
E	29	14	1	0	44
C	18	8	1	0	27
Standard IV					
C(E)	24	12	2	0	38
C	22	13	1	0	36

Standard IV results are included to indicate comparability of the two schools. Neither of the Standard IV classes was involved in the experimental program.

Number of different children in each class

The second major kind of count we made was the number of different children who were engaged in work of these various levels of complexity. Table 4 summarizes these results. The classes are listed in the same order as they were in Table 1. The first column indicates the number of children in each class who did something extraordinary. The second column indicates the number of children in each class whose best work was elaborate. The third column in[illegible] the number of children whose best work was modera[illegible] The fourth column indicates the number of children who did not go beyond the simple level. The last column is a score attributed to the class, calculated by assigning three points for every child who did something extraordinary, two points for every child whose best work was elaborate, and one point for every child whose best work was moderate. The highest possible score for a class would be 36 -- if each child in the class did something extraordinary.

TABLE 4 *Number of children in each class who did work of various levels of complexity*

	X *(3 pts)*	*E* *(2 pts)*	*M* *(1 pt)*	*S*	*Calculated Point Score*
Standard I					
E1	0	2	9	1	13
E2	0	0	6	6	6
C1	0	0	6	6	6
C2	0	0	4	8	4
Standard II					
E1	0	2	10	0	14
E2	0	1	10	1	12
E3	0	0	10	2	10
E4	0	0	9	3	9
E5	0	2	9	1	13
C1	0	1	9	2	11
C2	0	2	4	6	8
C3	0	0	6	6	6
C4	0	0	4	8	4
Standard III					
E1	0	1	10	1	12
C1	0	0	9	3	9
C2	0	1	7	4	9
Standard IV					
E1	0	7	5	0	19
E2	0	4	8	0	16
C1	0	1	10	1	12
C2	0	1	0	2	11
Standard V					
E1	2	5	5	0	21
E2	1	6	5	0	20
E3	3	6	3	0	24
C1	0	3	8	1	14
C2	0	4	6	2	14
Standard VII					
E1	2	10	0	0	26
C1	0	8	4	9	20

X=Number of children who did something extraordinary
E=Number of children whose best work was elaborate
M=Number of children whose best work was moderate
S= Number of children whose work remained simple

96

TABLE 5 *Point scores for degree of complexity attained by individual children, by standard*

Standards	Experimental	Comparison
I	9	5
II	11.6	7.25
III	12	9
IV	17.5	11.5
V	21.67	14
VII	26	20

TABLE 6 *Number of children in closely-matched schools who did work of various levels of complexity*

	X (3 pts)	*Elab* (2 pts)	*M* (1 pt)	*S*	*Calculated Point Score*
Standard I					
E	0	0	6	6	6
C	0	0	4	8	4
Standard II					
E	0	0	9	3	9
C	0	0	6	6	6
Standard III					
E	0	1	10	1	12
C	0	1	7	4	9
Standard IV					
C(E)	0	1	10	1	12
C	0	1	9	2	11

Standard IV results are included to indicate comparability of the two schools. Neither of the Standard IV's was involved in the experimental program.

A result that is significant at the .05 level could happen by chance less than 1 time in 20; it is quite likely that it did *not* happen by chance.

We eliminated the same three classes -- E5 in Standard II, Cl in Standard III, and El in Standard V -- in order to do a statistical test of the significance of the overall difference in scores in favor of the experimental classes (the right-hand column of Table IV). This analysis yielded a value for t (22) = 2.28, which is significant at the .05 level.

For two other analyses, we were able to keep the scores of all the classes. At the upper primary level (Standards IV, V, and VII), we did a X^2 analysis of the numbers of children who did something of at least elaborate complexity (combining the first two columns of Table 4). There were significantly more such children in the experimental classes (X^2 (2) = 15.08, which is significant at the .001 level).

A result that is significant at the .001 level could happen by chance less than 1 time in 1,000, it is almost *certain* not to have happened by chance.

At the lower primary level (Standards 1, II and III), it is more instructive to look at the number of children whose work did not go beyond the simple (the 4th column of Table 4). There are many fewer such children in the experimental classes than in the comparison classes -- X^2 (2) = 18.01, which is, once again, significant at the .001 level.

We also counted the number of times a child scored as doing nothing, or watching other children work. These counts are presented in Table 7 where we, once again, eliminated the results of the same three classes, so that we could have an equal number of experimental and comparison classes at each grade level. Any one child might have had from 0 to 28 marks in this category. 0, of course, is ideal. A score of 28 means that a child was never doing anything at any time either observer was watching him.

Ninety-one of the 144 children in the experimental classes had "doing nothing" scores of 0 or 1 -- essentially negligible -- compared with 66 of the 144 children in the comparison classes.

Only 4 of the 144 children in the experimental classes had "doing nothing" scores higher than 6, and the highest such score of any child in the experimental classes was 10. Twenty children in the comparison classes had scores higher than 6, and their scores ranged as high as 21.

We did a means test on the "doing nothing" scores of all the children within each standard. In Standard I, this gave us an X^2 (1) = 5.343, significant at the .05 level. In Standard II, it gave us an X^2 (1) = 4.729, also significant at the .05 level. In the other standards, the difference was not significant, although it was in the right direction.

TABLE 7 *Distribution of frequency of "doing nothing" observations*

Number of times children observed "doing nothing"	*Number of experimental class children*	*Number of control class children*
0	57	46
1	34	20
2	19	22
3	12	16
4	7	9
5	5	6
6	6	5
7	1	4
8-12	3	12
more than 12	0	4
Total number	144	144

TABLE 8 *Distribution of frequency of "doing nothing" observations in standards I, II and III*

Number of times children observed "doing nothing"	*Number of experimental class children*	*Number of control class children*
0	10	8
1	8	1
2	4	7
3	4	4
4	2	3
5	2	1
6	2	4
7	1	1
8-12	3	5
more than 12	0	2
Total number	36	36

As described in Chapter 6, there were four tests for lower primary children and two tests for upper primary children. In the lower primary classes six children did the Bilo and the Straight Line tests and six children did the Brick Corner and the Missing Piece tests. In the upper primary classes six children did the Bilo test and six children did the Ordering Weights test. On each test, a child might score from 1 to [illegible] points, according to the level of his performance.

Table 9 shows the Phase II upper primary results with the average scores of the children in the experimental and comparison classes, standard by standard. The [illegible] [illegible] here [illegible] very clear. Overall, the children in the experimental classes did better on the Bilo test, and slightly less well on the Ordering Weights test.

*All the F scores in this section were two-way analyses of variance which permitted us to test the significance of grade level differences and that of the interaction of grade level and experimental condition as well as differences associated simply with the experimental condition. In each analysis, the mean differences between grades were significant, as expected. The interaction [illegible] proved more complicated. Some were significant and some were not; among those which were significant, the differences sometimes lay in the expected direction and sometimes in the opposite direction. This means that the interaction terms can scarcely be interpreted with any confidence. We will, then, attribute the fluctuation among interactions to the characteristics of the measures which [illegible] employed, and we will not refer to them further. The fact that the analyses were two-way explains the numbers of degrees of freedom.

TABLE 9 Average test scores for upper primary children

	Standard IV		Standard V		Standard VII	
	E	C	E	C	E	C
[illegible]	3.7[illegible]	[illegible]83	4.[illegible]0	[illegible].33	[illegible]	4.50
[illegible]ng	1.[illegible]	[illegible]7	2.33	[illegible].33	[illegible]	3.5

[illegible] combining the Bilo scores across classes, we obtain [illegible] of [illegible].36 and 3.82 for the experimental and comparison classes respectively. These yield an F (1, 42) = 18 which is significant at the .[illegible] level. For the Weighing Test, the means are [illegible]3 for the experimental classes and [illegible].5 for the comparison classes. These yield an [illegible] = 0.1, which falls far short of significance. In sum, the difference in the Bilo scores -- in favor of the experimental classes -- is significant; the difference in [illegible] weighing scores -- in favor of the comparison classes -- [illegible] negligible.

Table 10 shows the Phase II lower primary results [illegible] by test, with the average results of the children in the experimental classes and the comparison classes grade by grade. The differences are small, but consistently in favor of the experimental classes, with the single exception of the Bilo test at the Standard I level.

TABLE 10 Average test results for lower primary children

	Standard I		Standard II		Standard III	
	E	C	E	C	E	C
Missing Piece	1.58	1.[illegible]	2.72	2.33	3.88	2.83
Brick Corner	2.67	1.00	3.25	3.16	5.50	4.76
Bilo	1.76	1.[illegible]	3.33	2.42	4.33	2.92
Straight Line	3.42	3.3[illegible]	4.38	3.58	5.00	3.08

A result that is significant at the .01 level could happen by chance less than 1 time in 100; it is very likely that it did *not* happen by chance.

A simple analysis of variance was carried out on the data for each test (Table 10); the results are set out in Table 11 together with the means for the combined classes. In each test there were 1 and 96 degrees of freedom and in each the value of F is significant at the .01 level.

TABLE 11 *Single analysis of variance for lower primary tests*

	Experimental (average)	*Comparison (average)*	*F (1,96)*	*Significance*
Missing Piece	[illegible]	2.[illegible]	12.[illegible]	$p < .01$
Brick Corner	[illegible]	2.96	38.[illegible]	$p < .01$
Bilo	3.14	2.42	34.4	$p < .01$
Straight Line	4.26	3.33	57.7[illegible]	$p < .01$

Table 12 shows the results of the two closely-matched schools, including the Standard IV from each school, neither of which was in the experimental program.

Once again the close correspondence between the results of the two Standard IV classes confirmed our belief that the populations of the two schools were indeed closely matched; the total score in the experimental school is 95 and in the comparison 97. This makes the comparisons among the other classes of special interest. Total scores in each standard go in favor of the experimental classes -- 57 to 47 in Standard I; 77 to 71 in Standard II; and 112 to 96 in Standard III.

TABLE 12 *Total phase two test scores of the children in the two closely-matched schools*

	Standard I		*Standard II*		*Standard III*		*Standard IV*	
	E	*C*	*E*	*C*	*E*	*C*	*C(E)*	*C*
Missing Piece	[illegible]	8	14	15	23	22	14	20
Brick Corner	14	8	17	18	33	29	32	30
Bilo	6	[illegible]	20	13	26	20	17	20
Straight Line	24	[illegible]	28	26	30	25	32	27
Total number	57	47	79	71	112	96	95	97

For the sake of a statistical analysis of the comparison between these two schools, we combined each child's scores on the four tests he did, so each child had a possible score of [illegible] points. We then compared the overall results of Standards I, II, and III in the two schools for all the children who did Brick Corner and Missing Piece, and for all the children who did the Bilo and Straight Line. The results are to be found in Table 13. In one set of tests it can be seen that the difference is highly significant. In the other set, the difference falls short of significance.

TABLE 13 *Statistical comparison of the two closely-matched schools*

	Experimental (average)	*Comparison (average)*	*F (1,33)*	*Significance*
Missing Piece and Brick Corner	6.22	5.50	2.22	Not significant
Bilo and Straight Line	7.44	6.06	29.76	$p < .01$

Even without the benefit of statistical analysis, we were so impressed with the 12 children from this Standard III experimental class that we took another sample of 12 children from the same class, just to assure ourselves that the first results had not been some sort of accident. We found that the second group did just as well. We have not included this second set of results, but they did give us confidence that the first set had not been accidental.

When we look at Table 14, which gives the results of Standards III and IV of these two schools, and another school as well, the results of the experimental Standard III stand out still more. They are well above all the Standard IV comparison classes. We even have the suggestion that the original comparison class in Standard III may have been unusually strong.

The extraordinary level of this Standard III experimental class might be due to chance, but there is another way to interpret the result. This was the only experimental class which had been in the program for three years. It seems to us quite likely that the longer period of time might account for the startlingly good results of this class.

TABLE 14 *Test results for standards III and IV*

	Experimental Standard III	*Comparison Standard III*		*Comparison Standard IV*		
		III C1	III C2	IV C(E)	IV C1	IV C2
Missing Piece	23	22	12	14	20	10
Brick Corner	33	29	28	32	30	26
Bilo	26	20	15	17	20	31
Straight Line	30	25	12	32	27	24
Total number	112	96	67	95	97	91

8

Discussion

The results in both these phases suggest that the African Primary Science Program seems really to have affected the children involved in important ways. The diversity and complexity of the work done in Phase I by children who had been in this program reflect the fact that the children felt at home with new and familiar materials, were able to generate ideas of what to do with materials, had the self-confidence to try out their ideas, and the ability and persistence to pursue their ideas in considerable depth. The measures show that these characteristics were significantly more developed in the children in the experimental classes than in the children in the comparison classes.

I would like to draw attention particularly to the following phenomenon. Usually there are one or two children in each school class whom one might call "losers." They seem to feel inadequate when they compare themselves with other children, gradually lose more and more confidence in themselves, and take less and less part in the school activities. Children like this were evident in almost every one of the comparison classes. They were evident by the fact that they spent most of the time watching other children, or they flitted from one thing to another without really trying to do something serious on their own, or they did only those things which they saw other children doing. In the fifteen experimental classes, there was not one child who gave us that impression.

Two of the measures in particular reflect this difference. One is the number of children with high "doing nothing" scores, as presented in Tables 7 and 8. Another is the fourth column of Table 4, which indicates the number of children who did not go beyond the simple manipulation of materials. Neither of these counts tells the whole story. Some children, for instance, may have had a "doing nothing" score of 8 or 10, or may never have done anything complex, and yet may have concentrated on some serious piece of work of their own for some of the time. But these two measures taken together give a general indication of this impressive difference in the children of the experimental and comparison groups. A program that can help *each child* feel that he can do something significant on his own seems to us to be very worthwhile indeed.

At the other end of the scale are the children who did extraordinary work. This was a category we had not even thought to include when we started the procedure. We felt we had to create it when we saw the work of two children in the first experimental Standard V class we examined. The work of a few children in each experimental Standard V and VII went beyond anything we had anticipated. No children in the comparison classes did work of this extraordinary level.

This suggests that the program not only brings out the best potentialities of less able children, but also helps the most able children to develop their abilities to the full.

It is worth emphasizing that this part of the evaluation makes sense only because the African Primary Science Program does not assume that children *start* by being self-sufficient. It does not propose that children be left to their own devices, on the assumption that their "natural curiosity" will lead them to encounter all the significant aspects of the world around them, and to raise all the significant questions. On the contrary, their curriculum development effort has been directed toward finding areas and questions that engage children and teachers in productive investigations, and their teacher education effort has been directed toward helping teachers find ways to "uncover" the world for their students. Only because the program seeks to *develop* children's self-sufficiency does it become of interest to compare children as we did in Phase I.

The Phase II results are I think of greater significance than the Phase I results. Since they are based on problems that are, at least in part, derived from Piaget's work, I think they deserve more serious consideration than comparative studies using traditional IQ tests, although I shall not, here, enter into the debate. Suffice it to say that I share the views of many critics of IQ tests who find them far too dependent on verbal and test-taking conventions. (See Duckworth, 1975.)

The work of Inhelder, Sinclair, and Bovet (1974) suggests that children move from one operational stage to another by being confronted with conflicts in their own thinking. The "alertness", as I called it in Chapter 1, would entail the same kinds of search for resolution that these authors provoked in their experimental situations. The significance of the Phase II results, then, lies in the fact that they suggest support for my hypothesis that intelligence develops by being used. Furthermore, they suggest that school can play a role in this development -- not by straining to develop certain specific notions, but by enabling children to pursue and explore their own thoughts.

While to my mind there is no question about the significance of these results, it is clear that in this study they remain sketchy. They raise and leave unanswered many questions. To begin with, it would obviously be of interest to compare these children on a far wider range of operational abilities, including, among other things, experiments drawn from *The Growth of Logical Thinking* (Inhelder and Piaget, 1955).

It would also be of interest to look more closely at relations between Phase I and Phase II. The classes with the best results in Phase I were not always those with the best results in Phase II. Are there some kinds of intellectual "alertness" which have more general effects than others? Is there a time relationship between abilities called for in Phase I and abilities called for in Phase II? It would also be important to look at these two kinds of abilities in individual children.

Is there any significance to the fact that the experimental classes did no better than the comparison classes in the seriation of weights? All the results on this problem were, in fact, very low. This might reflect some fault in our technique. On the other hand, further study of this phenomenon from a cross-cultural perspective might prove interesting.

Finally, the results in both phases of this study suggest that costs of teacher education for this program need not go beyond currently available budgets. Four of the experimental class teachers were introduced to the program by other teachers, as described in Chapter 4. These classes were essentially indistinguishable from the other experimental classes. Their results can be identified in the Chapter 7 tables as the two Standard IV experimental classes, and the Standards I and II in the experimental school which was closely matched with a comparison school.

SOVIET SEA CAPTAINS: FURTHER COMMENTS ON THE PHASE I PROCEDURE

It has been objected that the Phase I procedure favors the experimental group on the grounds that they are used to unstructured situations, group cooperation, working with materials. Briefly, my answer is the following. The qualities which this program is seeking to develop are, by their very nature, related to each other in complex ways. Knowing about the material world, wanting to know more about it, having ideas of one's own about what to do with materials, persisting in the face of difficulties, collaborating with other children in one's thoughts and constructions -- it is almost impossible to study these qualities separately, one at a time. But more to the point, that is not how the children will be called upon to use them. Outside the school, nobody is going to break the world down into component pieces.

I once saw a Soviet film which had little to recommend it dramatically, but which struck me as having its pedagogical values straight. It centered on a rivalry between the two best captains of the Soviet fleet. For some reason, which I do not recall, the two were to be put to some comparative test. While not knowing the nature of the test being prepared for them, both were busy readying their crews. Captain number one trained men well in the details of their specific tasks, demanded strict obedience, reserved for himself all matters of judgment. Captain number two, while also training his men well in their tasks, encouraged them to take decisions relating to their own work, tolerated intelligent mistakes. Each crew was loyal to their captain, proud of the running of their ship, eager to be put to the test. When the test was announced, each ship was to engage in a difficult maneuver, but, on the not unlikely supposition that a captain might one day be incapacitated at sea, the captains were to remain behind. Over the protests of Captain number one, the test was carried out, and, needless to say, it was the other which fared better.

Now, one could say that the test situation favored the winning ship, since it corresponded more to the kind of situation they were used to. But that would be slightly ridiculous. The point is that the situations they were used to simply were more appropriate for the development of a seamanly crew.

Similarly, the African Primary Science Program has operated from the guiding principle that the abilities in which it is interested develop best by being used (just as I hypothesized that intelligence develops best by being used). By definition then, the children in the program will have had much more occasion to pursue their own ideas in unstructured situations. If these children are "favored," it is not the evaluation procedure which favors them; it is their experience in the program. And that, of course, is the point.

In sum, it is true that children in the program are more used to working with materials and to working without direction. But that *need* not mean that they do a more productive job of it than children who are put in such a situation for the first time. One of the things the study showed was that, indeed, as children were given the occasion to work intelligently on their own with materials, they did get better at it: a justification of the guiding pedagogical principle.

I have had fond thoughts of developing a similar evaluation procedure for other areas of learning. I would love, for example, to give a class of children who had been studying music a collection of unfamiliar instruments, and watch (listen to!) how they get along on their own. Or I would love to give children who had been studying history some documents, objects, and perhaps some secondary source materials, to see what questions and hypotheses they might develop.

In fact, one other study has been done based on this Phase 1 procedure. Kolen and Golub (1976) sought to evaluate a kindergarten program by observing children from experimental classes and control classes in a standard unstructured situation. The children were given a large variety of materials and no specific task. Kolen and Golub were interested in two factors -- the complexity of the work with the materials, and the kinds of social interaction. Their measures showed that the experimental classes scored higher on both these dimensions. But it is their qualitative descriptions, and their comments on the use of the procedures that contribute to my discussion here:

> The quietest groups who interacted least and the noisy groups bordering on disorder were all comparison groups. None of the experimental groups showed such extremes. In contrast, some of the experimental groups seemed to strike a lovely balance between spontaneous, active investment with the materials and the other children on one hand, and an easy, relaxed modulation of their behavior on the other, without need for adult guidance. The observers noted that these groups seemed to be accustomed to working together and tended to put materials away when they were finished with them...
>
> There were some clear differences with respect to the number and intensity of negative interactions, in general. In one comparison group in which there seemed to be a generally unfriendly feeling between the children, three children were so intent on trying to fight with each other that, at the end of the session, an adult was needed to physically restrain one of them while the rest of the group was returned to the classroom. In another comparison group, some of the children spent a good part of the session banging the instruments and screaming at each other to "Stop it" and "shut up." In a third comparison group, a few of the children led by one child spent the latter part of their session dumping out the contents of the containers onto the floor while the other children in the group watched passively or ignored the goings on. There were no experimental groups in which we observed any kind of group negative interaction nor any sustained negative interaction even on the part of one child...
>
> To summarize...the activities of the children from the experimental program were more complex than those of children from the comparison group. Furthermore, in pursuing their ideas, the children from the experimental groups demonstrated a higher level of interaction with their peers and were more independent of adult guidance.
>
> We view these findings as an encouraging measure of success in meeting goals of the program, [such as] that children develop initiative and independence, that they actively explore their ideas and coordinate different points of view. We are particularly pleased that children benefitted from the program irrespective of their race (black or white) or sex...

...Our use of Duckworth's method reaffirms to us its exciting potential for educational evaluation. Children enjoy it. It is applicable to populations varying widely in age and culture, and is adaptable to explore any number of substantive educational questions. It allows children to be perceived in far greater dimension than do more traditional methods of evaluation and perhaps bridges the gap between naturalistic observation and "objective" testing..." (pp 6-9)

In short, while many variations might be worked on the kinds of recording and scoring that are done, some of which might be a good deal more appropriate than mine, I have no misgivings about whether the Phase I procedure "favors" the experimental classes. The key, to my way of thinking, is that one must evaluate what one is interested in -- in all its complexity. An educator may have broken down some instruction into bits and pieces, but those bits and pieces are not the end in themselves. An adequate evaluation must take into account the purpose behind these bits and pieces, and try to assess how well, in a realistically complex situation, the students are able to do the overall job.

A comment by one of the staff members of the African Primary Science Program puts into perspective most of my feelings about this procedure. Having watched one of the pilot trials, and been pleased with what it revealed about the children in the program, he had a momentary hesitation. "But then, if teachers know this is the way it will be evaluated, they might simply try (as teachers often tend to do) to 'teach to the test'." And then he realized that that would be just fine. There is no deforming, short-cut way to teach to this test. The only way is to put one's efforts into developing children's familiarity with the material world, their interest in it, their self-sufficiency in finding out about it, the creative use of their intelligence, and their tendency to have "wonderful ideas."

Appendix 1

What You Can Look For

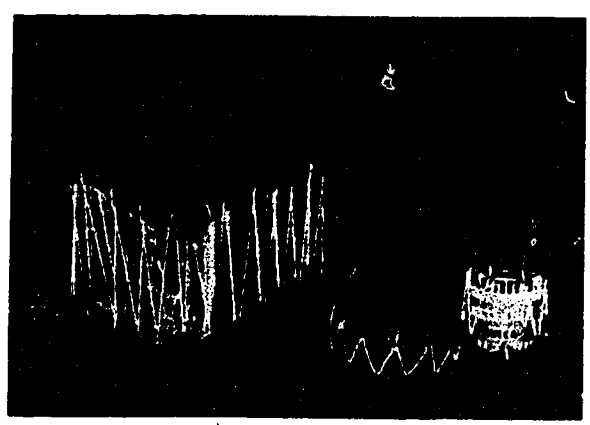
The following paper was written during a workshop for primary school inspectors; it is aimed at familiarizing them with the African Primary Science Program. While they themselves took part in the science investigations, and appreciated many of the merits of the program, their professional concern constantly brought them back to the question which opens this paper.

If there is no list of facts to be attained, how can a teacher or a visitor tell whether children are gaining from their science activities?

These notes are for both teachers and visitors. The first few pages are mainly for visitors. The last two pages are mainly for teachers.

First of all, if the children are engaged in these activities, there will be real things in the room to learn from, and they will look as if they are being cared for and used. Here are some examples:

One class might have 20 or 30 or 40 or 50 tins and containers of various sizes, with plants growing in them. This class might also have some planted outdoors. Or one class might have some hand-made musical instruments hanging from the walls or from the roof. In this class, there would probably also be some materials for making musical instruments -- bamboo, wood, wires, reeds, tins.



A class might have boxes of sand, with insects living in them, being cared for.

There might be some hand-made scales, with different things to weigh -- bottle tops, stones, used torch batteries, palm nuts, soil.

There might be materials to build with -- cigarette boxes, reeds, clay, wood, tins, sand. There might also be some weights to hang on the constructions, to test their strength.

In classes where the teacher has been teaching this way for one or two years, and has developed some experience and confidence, there may be materials for several different kinds of activity all at once.

Second, during the science periods, the children will be working with these materials -- and not just listening to the teacher talk about them, or watching someone demonstrate with them, or writing down what someone tells them to write down. While they are working, the children will be free to talk to each other, to walk about, to go outdoors, to get materials that they need. Some may be making something; some may be using what they have made; some may be trying to do a specific thing -- like making an ant lion go forward, or filling a tin until it sinks; some may be watching something very closely; some may be trying to 'see what happens if'; some may be setting up experiments; some may be arguing about different things they have found; some may be showing each other what they have done; some may be planning what to do next.

In some classes all the children will be trying to do more or less the same thing; in others, children will be doing many different things. Neither of these approaches is necessarily better than the other. It depends on the teacher, and it depends on the interests of the class. The important thing is whether the children are busy, know what they are trying to do, and have ideas about how to go about it.

If the teacher constantly interrupts and addresses the whole class, to give them further instructions, that is probably because he is requiring the children to do something in *his* way, instead of encouraging them to try ways that they have thought of. Similarly, if the children wait to get the teacher's approval of what they have done, that is probably because they are working for the teacher, and not for themselves. Or if a lot of children spend their time watching what a few children are doing, that is probably because they do not quite know what to do themselves.

Third, during the times when the teacher and children are discussing what they have done, the children will be talking more than the teacher. They will be listening to each other, and responding to each other, and asking each other questions, and giving their opinions.

Now the more children work in this way, the better they get at it. During the very first lesson of this sort, even the very best teacher will probably have difficulty, because the children probably will not have very many ideas of things to do; and they probably will not really believe that the teacher wants them to think of their own things to do; and they probably will not think that they should say when they disagree with something that has been said. At first, therefore, they will probably wait to be told what to do, not make suggestions of their own, not talk to their friends about what they are doing, try to guess what the teacher wants them to say. But as children get used to this way of working, and really believe that the teacher wants them to try things in their way, they will take more and more of the initiative themselves.

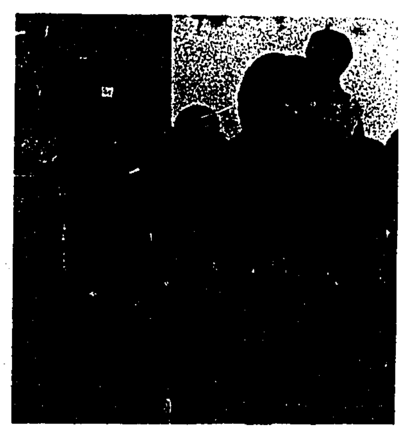
So far, you may have noticed that I have not mentioned talking to the children. That is mainly for two reasons. First, because you can see the most important things just by watching -- children are more likely to reveal what they know by doing rather than by talking. But I confess that there is another reason, too. When I am visiting classes in Africa, I cannot understand what anybody is saying! So I have been forced to develop ways of looking that do not depend on words.

Other visitors, who do know the language, may want to talk to the children. Perhaps when you visit a class, the children will be learning something else -- reading or English, or social studies -- and will not be engaged in science activities. How can you let them show you what they have learned?

Not all children will have done the same thing, or will have paid attention to the same thing, so it is impossible to make up a list of questions and expect all the children to give the same answer to them. Also, some children will have learned things that they cannot *say* very well. They may have learned *how to* do something, for example, and the only way they can express that is by doing it.

Somehow, you want to give the children a chance to show you what it is that they have learned. The best way to do this, of course, is to start from the materials which they have been working with. You can ask some volunteers to tell you about the materials. If they are growing seeds, they may be able to tell you where the seeds came from and where the soil came from, and when they planted them. They may have planted them in some special way, in order to find out what happens (upside down, for instance!). They may have noticed something special as the plant grew, or they may wonder what is going to happen as it continues to grow.

If they have been studying time, and how to measure it, they may be able to show you some time-measures they have made, and how to use them, and why they made them that way, and what difficulties they encountered, and who thought of a way to solve the difficulty. (We hope that children think of ways around the difficulties -- and not only the teacher!)



Some
very much c
learn most
As time goe
things they
it gets muc
the childre
be able to
unusual --
yourself.

You c
aspects of
happened th
that he did
to interest
decrease.
people in tl
potter or a
other teach
what he is
actions fron

So muc
Even the tea
times feels
times he may
benefiting,
dividual chi
is benefitin

I find
ferent kinds
more progres
look not onl
how much int
how much he

will surely be too shy to show you
ey have been doing. You can probably
those children who *want* to show you.
you visit more classes, see more
n doing, and talk to more children,
to know what to ask, in order to get
you what they know. You will also
when some children have done something
you never would have thought of doing

nd out from the teacher some other
You can ask the teacher what has
found exciting, and what has happened
t., You can ask him what he has done
ren, when their interest started to
k him if he has ever asked other
ty for some ideas -- people like a
or a builder. You can ask him whether
school have taken an interest in
u can ask him whether he has any re-

visitor. What about the teacher?
is with his class every day, some-
of the value of the work. Or some-
fident that the class as a whole is
ild like to know more about some in-
can he tell whether a certain child

il to remember, first of all, the dif-
ve have. Some children may have made
than in another. The teacher should
a child knows, but for what he does,
shows, how much initiative he takes,
es with the other children.

Here are some questions a teacher can ask himself as he watches a child's work from day to day:

1. Does he make suggestions about things to do and how to do them?
2. Can he show somebody else what he has done so they can understand him?
3. Does he puzzle over a problem and keep trying to find an answer, even when it is difficult?
4. Does he have his own ideas about what to do, so he does not keep asking you for help?
5. Does he give his opinion when he does not agree with something that has been said?
6. Is he willing to change his mind about something, in view of new evidence?
7. Does he compare what he found with what other children have found?
8. Does he make things?
9. Does he have ideas about what to do with new material you present to him?
10. Does he write down or draw some of the things he does, so he does not forget what happened?
11. Does he sometimes know ahead of time what will happen if he does a certain thing?
12. Does he like to think of variations of ways of doing something?
13. Does he ever decide to do something over again, more carefully?
14. Does he feel free to say he doesn't know an answer?
15. Does he co-operate with other children in trying to solve a problem?
16. Does he ever continue this work outside school time?
17. Does he ever bring materials to school, to investigate in the same way?
18. Does he talk about this work at other times of the day?
19. Does he make comparisons between things that at first seem to be very different?
20. Does he start noticing new things?
21. Does he start raising questions about common occurrences?
22. Does he ever repeat one experiment several times, to see if it always turns out the same?
23. Does he ever watch something patiently for a long time?
24. Does he ever say, "That's beautiful"?

I think you will agree that if a child does even five or six of these things, he is benefiting.

Appendix 2

How Do You Know It's Working?

The following letter was written in response to a question from a new staff member:

Dear ---

I've been thinking of your problem of how to find out from teachers how a unit is working.

I think the first stage -- to find whether you have a workable unit, and to make it more workable -- requires a minimum of teachers. Mainly, I should say, it requires yourself. But if you are unable to make things in a classroom go the way you want them to go -- either because you can't talk the local language, or because your talents lie in some field other than actual primary teaching -- then, instead, find someone who *can* make things go in a classroom, and you work with him. The two of you together simply try as hard as you can to make it work. You can save some weeks by doing the same thing at the same time with somebody else, too, perhaps starting a couple of weeks later, and varying what you do in the places that didn't work so well. At any rate, a single run-through is not likely to be sufficient, and you simply keep trying again until you're happy with it. Or until you and all your collaborators have exhausted all your ideas about how to make it work, and you decide it is simply unworkable.

This may appear to be begging the question. The real questions on your mind may be, how do you know whether it's working? And when it isn't working, how do you know *what* about it isn't working? And how do you know what to try to make it work?

As to the first of those, the answer clearly has to be something like my Morogoro paper, "What you can look for." It's working if kids get busy, know what they are doing and why they are doing it, offer ideas about how to do things, do things you hadn't anticipated, etc., etc. And if they have to be prodded all the time and have nothing to say and all do the same thing in the same way, or six kids work and the other 30 watch them, it's not working.

And as to the other two questions -- *what* isn't working and what you can do about it -- therein, of course lies the whole of this profession. The inventive part is simply having keen ideas about other ways to do things, and trying them out to see if they make any difference. (One of the simplest things to try differently, of course, is the age of the kids.)

In essence, then, at this stage, you have (a) to recognize when something is working and when it isn't; and (b) to have some other ideas to try when it isn't. And clearly, all of this lies right on your own shoulders. You're the guy who decides whether the classroom looks right, and you're the guy who tries to cook up something else if it doesn't.

Now the next stage is: You know the stuff worked. You've seen it work with some class of kids. So you try to write it up to see if you can make other teachers make it work.

You probably need a few more teachers here. You certainly want about 10 if you don't know anything about them. If you've been in that locality long enough to know some of the teachers, you can probably just choose four or five who know you, and who you already know can do a reasonable job on other units. Then you try to see if they can do just as reasonable a job on this one.

If you're dealing with a group of teachers who are new to you, then you sort of have a double job: finding out which of those teachers are most informative for you, and at the same time finding out from them what you want to know about this write-up.

Let's first of all think about the simpler situation, where you have four or five teachers who can be expected to do a reasonably good job, if the write-up is reasonably good. I think you find out most from them by visiting them and watching how the classes go. You probably want to have specific questions in your mind as you watch. That is, you want to have thought about your write-up and to have anticipated trouble spots. For instance, you may have suggested one approach to answering a certain problem: when this comes up in class, you will be interested in seeing whether the teacher imposes this suggestion as the only way to do it, or whether he doesn't use it at all, or whether he in turn suggests it to the kids and some do it that way and others do it another way, etc. Or, on the contrary, you may have raised some question and intentionally not suggested any way to anwer it; you'll want to see if [this means] the teacher leaves the question out, or if he brings it up and nobody has any ideas about it. Or you may have quoted the way some kids in a trial class verbalized something, and you'll want to see whether the teacher writes this on the board as something for his kids to learn by heart. Or you may have proposed quite a tight lesson-by-lesson plan, and you want to see whether this means that kids are kept from doing things that really interest them, or whether on the contrary this means that they always have something solid and interesting to do. You'll also want to see in general whether the write-up works in such a way that kids do -- and teachers accept and are pleased with -- things that were never mentioned in the guide.

If a teacher does new things in these classes and you like them, then of course you make note and think about how to try to make them happen even more often. If he does new things and you don't like them, you can try to figure out whether your guide was ambiguous, or whether the teacher simply decided to try it another way. This you can probably find out by asking, and if it was intentional, you can try to find out why he thought it would be better that way, and then try to decide whether it's worth specifically warning teachers away from this.

Besides your visits, it is probably also worthwhile polling the teachers on a number of questions -- in writing, if your friendship with them is such that they are willing to do this, or in talking with them (best of all, probably, is to get it in writing, and then talk to them about it -- perhaps at a meeting where they all come):

What was the best thing that happened during the teaching of this unit?
What part (lesson? problem?) of the unit would you *not* want to teach again?
What aspect of the written guide was most useful?
What part of this unit did the kids on the whole seem to enjoy most?
Which visit of yours to them, while they were teaching the unit, did they find most helpful?
What materials did you need that you didn't have?

I think you should probably *not* ask in writing for the "why's" to these questions, but try to get that when you talk to them.

If these teachers have taught other units, then there are other kinds of questions you can ask them, too. You can take some standard that you know something about -- *Batteries and Bulbs*, or *Measuring Time*, or something -- and ask for comparisons against this yardstick:

Which of these was easiest to teach?
Which of them did the children enjoy most?
How long did you spend teaching each of them?
For which was the written guide *least* helpful?
Which took the most preparation outside class time?
In which of them did the children carry on their investigations outside school hours?

The questions will depend on the units being compared. You may want to use several different ones as yardsticks.

If the teachers have each answered these questions independently, then if you can get them together as a group their agreements and disagreements can be the basis of discussion that may get at more detail.

On the basis of all this, you sift out what were the good working parts, and keep them, and perhaps try to make other parts more like them. You identify the parts that aren't working yet, and mark them for rewriting. You find in what way extra help was useful (like your visits, or some extra material) and try to see whether ... can build that extra help into the rewrite.

And then you try again -- another writ ... other teachers.

By this time, you have an even better ... the possible trouble spots, and you can probabl... ...ize on your visits.

Now back to the case where you don't k... ...our teachers, so you've started with about 10 of them. ...'s probably a good idea to have a workshop with them on the unit before they start -- a few afternoons perhaps. First, because otherwise it's too much to ask of them to start off teaching a rough unit when they are also pretty new at this kind of teaching. Second, because it will give you a start at assessing them, and knowing ahead of time which ones are likely to be best when they start; then you can choose which ones to concentrate on in your visits. This will have to be confirmed of course in your visiting, but it's a helpful beginning. Then in the visiting I should say you should more or less forget about the ones who seem to miss the whole point, and find out all you can from the ones who seem to be getting somewhere. And proceed as before. In the final questionnaires and discussions, it is no doubt worth it to get the reactions from all of them -- even the bad ones.

A write-up will never be perfect, of course; but, again, you've just got to decide at some point that you've done all you can to help reasonably good teachers do a reasonably good job.

The more you do of this, the more you can start to telescope it. Like, in one area, you can get to know two or three teachers who are such that you know how their classroom will look if a write-up is working, and whom you can count on to tell you what they think. You can cut down your number of trial classes once you have teachers you know like this.

Also, you get to know general things about writing, so you can cut out a number of false starts. For example, you find that some formats never work, while two or three other kinds do, for various kinds of units, and so you can proceed to work variations on these.

Likewise, way back at the beginning, in the early development of the unit, you also get to a point where you make fewer false starts, which starts to save you time and effort at that stage, too.

Greetings,
Eleanor

Nairobi, March 1969

Appendix 3

Some Useful Hints for Writing

The following memorandum was prepared during one of the periodic writing conferences, at which staff members from all the participating countries came together.

Writing units seems to be something that you can learn about and get better at. It seems a pity that what some people learn, through writing four or five of them, can't somehow be of help to other people. I've been reading units that seem to handle well some of the problems I know I have come up against. I am going to make an attempt to see whether some rules of thumb can be made explicit.

1. Make the introduction as brief as possible. A few paragraphs should be the maximum -- except perhaps for some extraordinary instances of which I can think of no examples at the moment. The briefest effective introduction I have come across is the one to *Making Things Look Bigger*. All it is is a sentence on the title page -- "A book about how to make a magnifier that will help you see things so small that you never saw them before."

2. The gist of each new activity as it is introduced should be indicated either in its title (What are the important parts of a bulb and a battery?) or in an introductory sentence ("In this lesson children will be mixing paints, to see if they can match the colours you have made").

3. Use examples and photos for the purpose of making acceptable children's behaviour that seem out of the ordinary. Don't use an example as a prototype of the way things ought to happen, because then it is likely to be simply copied, and other things considered unacceptable.

4. Don't raise a problem to be solved by the children if there is only one possible solution, and nobody can make any headway until someone finds that solution. If there are many obvious ways to solve the problem -- then OK, and anything the kids do goes,

and the different ways lead somewhere, and can be compared. But if really what you want kids to do is see what happens to a pin hole when a water drop is added to it, then don't suggest the problem of "What could we do to the pinhole....?" but rather "Now put a drop of water on the pinhole and see what happens. Compare different sizes of water drops."

Or another instance of this, with apologies to the authors. They really intended this question for another purpose. The question is "Could a small nail be used to make a tin into a clock?" I'd say one kid out of 50 might get somewhere from that question. A teacher might be able to pinpoint one kid who could, and ask *him* that question, as he's working. But operationally, a class as a whole will end up doing the same things, with less frustration and less "Guess what's in the teacher's mind" if the teacher just says "Use the nail to make a hole in the tin and try to use that as a clock." You'll still get big holes, little holes, top, bottom, and side holes -- lots of differences and things to think about.

5. Don't put what the teacher is to say in quotations -- unless there's something very special about the wording. Helpful, suggestive questions that the teacher might not think of -- OK -- together in a group that shows him these are suggestions. But it's silly to put in quotation marks very ordinary things that he would say just as well or better in any number of other ways. Here's an example from *Time* that seems to me to handle the situation well. Instead of writing, "Say to your class, 'We are going to have a contest. Each time I light a candle, a member from each team'.... etc." They have written, "Explain to your class that they are going to have a contest...." (further explanation of the contest to teacher)....Then, "When your class understands the rules, have each team select its first player."

6. There are a number of words and phrases which I think should be avoided. Mainly, there is the group that carry with them a halo of science. They seem to be taken for Good Things, per se, without a further thought. And they seem to suggest something very special, different from what any old person might think of doing, having to be done in a stereotyped way or else it doesn't count.

"Keeping records," for instance, suggests to me ruled notebook pages, and fixed formats for writing stilted information. Some alternate non-jargon phrase seems to me to open up more possibilities:

"Writing down things they don't want to forget;" "drawing what they did so someone else can do the same thing."

"Method." "Ask the children to describe the methods they have been using to help them guess" could be replaced with "Ask the children to describe what they have been doing to help them guess."

"Observation" -- could be "watching closely," "looking very carefully."

"Scientists" -- can usually be replaced by "some people," or "some people who have studied this very closely."

Everyone is careful about not using specialized terms that most people don't understand (adhesion, carbon dioxide, spectrum). But I think that specialized terms which everyone *does* understand -- in too limited a way -- should be avoided, too.

"Erosion," for instance, suggests a macro-scaled, unmanageable conservation problem, and as a result is rather off-putting. Some phrase like "Soil gets moved from one place to another" conveys more.

7. Background information. In most units, I think teachers can be told that the best preparation is to do the activities as they read about them in the guide. In some, the teacher may really feel too lost without some small piece of information. For instance, in fermentation, it seems to me defensible (though others disagree on this) to tell the teacher that yeast is always necessary, and that when no one has added yeast, and things ferment, some yeast was in there from somewhere else. Even if people (teachers, kids) know that ahead of time, it makes no difference to their activities of timing bubbles, comparing rates, etc. It seems to me there's a difference between this and overwhelming teachers with information on specific gravity and the inverse square law.

8. Sometimes there are occasions when you want the children to compare results, and argue about disagreements. Yet if you suggest a class discussion, you can almost be sure it will be 30 deadly minutes. Often you can, instead, suggest to the teacher that as he moves about, watching and listening, he can point out to one child that he disagrees with another, and ask them to see why they disagree. Discussions among a few kids who care are much more worthwhile than ones among many who don't care.

9. Some people have told me that some of the best things that happen in some units happen in almost

every class without ever being written in the unit. In an early written version they described these things, and then found that the teacher, therefore, went out of his way to *make* them happen, and they turned out not exciting, and nobody cared about them. But if they left them out of the writing, most classes did them on their own, with a real feeling of excitement and invention. In writing working papers, it might be a good idea to keep an eye out for such possibilities, and try leaving something out, to see whether classes do it anyway.

Nairobi, April 1969

Appendix 4

A Child's Eye View

The following paper was written during a meeting of the African Primary Science Program evaluation group, during which a good deal of time was devoted to task analysis of various of the program's teachers' guides. The paper reflects my concern with the emphasis on "concepts" that characterized many of the analyses.

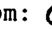
Given my specialty, if there's anything I'm supposed to know it's what a concept is. But I don't. For the past 10 years, I have dealt with that fact by never using the word. This week, however, I have quietly accepted to use it. And, in so doing, I find I have developed some meaning to attach to it. The meaning is something like, "A thought I have learned and that I believe."

I can elaborate on this a little more. Besides being learned, I would attribute to them the following characteristics (if you wish, for "belief" read "concept;" I still can't quite use the word in writing):

a. An opposing belief is conceivable, and would give rise to different actions, in a situation where the belief is pertinent.
b. You may have learned it by being told, or you may have concluded it yourself from evidence you have been told about, or you may have developed the belief from your own personal evidence.
c. It can be confirmed or infirmed in the face of evidence; some people need different amounts of evidence to confirm or infirm a belief.
d. A verbal enunciation of the belief may not really mean that the belief is held:
   i) You may enunciate it because you think it's expected of you.
   ii) You may think you believe it but really don't -- it conflicts with some other belief that really determines how you act.

I have taken four examples of beliefs, and I shall try to show that each one has the above characteristics. If you don't want to be bothered reading the examples, please do read the pages that follow them, where I try to explain why I have entered upon this discussion.

(1) *The more curved the lens you look through, the more it will magnify.*

a. Situation -- you want to magnify as big as possible, and you have two lenses to choose from:  and  If you hold that a greater curve magnifies more, you will choose differently than if you hold that a thicker lens magnifies more.

b. You might have been told this, or you might have found it out.

c. Confirming and disconfirming evidence is easy to think of. I won't bother here. But I'd like to show how the same evidence could lead to one person believing one thing when everyone else believes something else.

If you believe curvature is the factor, then looking through these four lenses could be seen as confirming it. Someone else, who believes thickness is the factor, could take this evidence to confirm his belief.

If this was the only evidence anyone had thought of offering, you might be the only one who believed that thickness was irrelevant.

di) You may have been taught to say that more curved lenses magnify more, having been shown the evidence from the above four lenses. But you may have noticed that the thickness also changes, and you may say to yourself, or to a confidante: "I'll say it's the curvature, because they want me to, but I really believe it's the thickness."

dii) Given the above evidence, you may say and think you believe it's the curvature, without ever noticing that you were basing your choice on the thickness, and that the thickness wasn't necessarily correlated with curvature. Confronted with the choice under 1a, you would choose the thick one. Even to yourself or to a confidante you would say the curvature was the factor.

(2) *It's fun to visit game parks.*

a. Whether or not you believe this may affect how often you go visiting game parks; or may affect how you vote on a conservation referendum. Note that you might very well not believe it.

b. You may believe this because you have been to lots of game parks and have liked it; or because you have read and heard about what is in game parks and it sounded like fun; or because lots of people have told you it is fun.

c. Confirming evidence could be meeting lots more people who say it is fun; or learning the additional fact that you can sometimes even see lions stalking their prey; or going yourself and noting that you have fun.

Infirming evidence could be meeting people who say it isn't fun; or learning the additional fact that you can be bothered by tsetse flies or that the animals are sleepy almost all day long; or going and finding yourself bored and/or uncomfortable.

Note once again that the ostensibly same evidence can lead to different beliefs. Though we went in the same minibus, I may have noticed that the others were all humorless bigots, and you didn't. Though we both saw the same sedentary animals, I may have noticed interesting grouping patterns which you didn't notice. Though we both talked to the same informant, I may trust his judgment and you may not.

di) Everybody says game parks are fun, so you feel you'd better say so too, even though you had a lousy time. To a confidante, you would confess it.

dii) You so expected it to be fun that you aren't aware that you really were bored and uncomfortable. You keep saying -- and believing -- that it was fun; but you never manage to find the time to go back and visit again.

(3) *I can make a pedulum swing at any tempo I want to.*

a. Situation -- you are offered a bet on whether you can do it or not. Your belief affects whether you accept the bet; or: You are a pianist alone in a recording studio, wanting to record a march at a given tempo for a sound track. A metronome would make too much noise. The sweep second hand on the wall clock is tough to follow. A pendulum occurs to you. Your belief on this matter affects whether you try it, or settle for one of the other timers.

b. You might have been told you can do it, and have confidence on that basis; or you might already have done it; or you might have seen someone else do it, and decided that you could do it.

c. You might try and fail. You might try and succeed. Neither of these pieces of evidence is *necessarily* confirming or infirming. In the first case, you might say, "I could do it if I had a heavier weight". In the second, you might say, "I was only able to do it this time because the set-up was perfect" (or "by accident", or some such).

di) You can say you can do it, so other people will believe it, without really thinking that you can.

dii) You can really believe that you can, but if the occasion arose, you would find that you couldn't.

(4) *My cousin is the best source there is of information about frogs.*

a. You want to know lots about frogs. Your belief in this matter will affect whether you go to ask your cousin.

b. Your brother tells you that your cousin is the best source of information about frogs; or your cousin has already told you lots about frogs.

c. Your cousin tells you this one's a female, and later you find that it lays eggs. Your sister tells you she knows more than your cousin. Your teacher shows you a book with things in it your cousin didn't know. You catch more frogs when you go with your cousin than with anyone else.

I won't bother to go into how these pieces of evidence can be used to confirm or infirm (or not so used) because it's easy to work out.

di) You say this because everyone else does, but really you believe you know as much as he does.

dii) You think you believe this, but you decide to go frog watching without him, because you *really* believe you'll learn more if he's not there. (You believe *really* that frogs can tell you more about frogs than your cousin can.)

My chief purpose is to propose that the "I can," "It's fun," and "people can help" beliefs are not different in kind from "the way things are" beliefs; that they have to be learned (you have to *learn* that it's fun to look at the microscopic world); that they can be taught and evaluated in the same variety of ways; that they can be held in varying degrees, and confirmed and infirmed with varying degrees of validity, and that beliefs of many different sorts can interfere with others we think we are concentrating on.

I want to think of two points especially:

First, included in the stated aims of many programs, including this one, are "it's fun" and "I can" beliefs (referred to usually as "interest" and "confidence"). These can be enumerated with the same degree of specificity as the "the way things are" beliefs ("knowledge"). You can, for instance, have lots of confidence in your ability to find interesting properties of new substances, and very little in your ability to find how to make predictions about a new mechanical system. You might love watching pond water life, and not at all like following the motions of Saturn.

Then if we really are sincere about aiming to develop the "I can" and "it's fun" beliefs, we must look for them in the units as carefully as we do the "they way things are" beliefs, develop them as carefully, and test them as carefully. The "people can help" beliefs (discriminating use of other sources) are less often stated, but are in fact stated in the goals of this particular program, and should be treated similarly.

Still on this same first point, I'd like to indicate that these beliefs can get in the way of each other, which increases the urgency of being aware of all of them. An excellent case in point is *Making Things Look Bigger*, where learning more about the physics of magnifiers may mean learning less about what fun it is to use them. In this case, we must make a choice -- how much of each are we willing to sacrifice to the other? In evaluating the success, we have decided that a class in which every kid took the magnifier home at night and ran back for it if he forgot it, but nobody knew that the apparent bigness was a function of distance, would score, say 95 out of 100, whereas the inverse case (all know the rule, but nobody looks unless they are told to) would score 5.

I've not looked as closely at the other units, but I have a feeling that the analysis has been done almost exclusively on "the way things are" beliefs. Now maybe this is an accurate analysis -- maybe the units in fact give no occasion to learn any other kind. In this case, we can point out that the program is not contributing much to its other stated goals, and it needs other units to fill the gap. Or maybe these other beliefs *are* implied in the existing units to a greater or lesser degree, and we should make sure not to overlook them in the analysis and testing.

For instance, in the case of "Growing Seeds," I think we could explicate beliefs like this: "I can learn about seeds by experimenting with them" (let's not bother breaking this down any further right now) and "I can save time learning about seeds by finding out what experiments the others have done." One could make a case for finding that these two are contradictory. Analysis would lead us to search for development of the additional belief, "Some people are more dependable experimenters than others."

The second of my two final points is this: You may notice that many "the way things are" beliefs grow out of "I can" beliefs, "people can help" beliefs grow out of "the way things are" beliefs, et cetera. Look at Example 3 above, for instance. This is related to "pendulums can be made to swing at any given tempo," but it's not the same belief. I think we should watch for cases where "I can" is necessary before "the way things are," or vice versa. Sometimes seeing a model first ("the way things are") is necessary before , u believe "I can." Sometimes doing it first is necessary in order to believe "things are.") An infant's "I can grasp that thing" is necessary for the insight that "that thing is graspable;" a 5-year-old's "I can sort out this part of the world" is the basis for "this part of the world is sortable.") Sometimes they are hard to separate.

I'm sorry, but I've just thought of a third final point. Here it is.

As we did the task analysis, we had difficulty separating instructional strategies from what we wanted to teach. I think we may find it easier with this broader view of what we want to teach. In some units, one of the main things we want to teach is, "I can think of how to find answers to questions." What question the child finds an answer to is not very important. But if he is told the answer, the aim of the lesson is lost. The belief to be taught was not "ant lions catch prey with their pincers" (if indeed they do) but "I can find out how ant lions catch prey." In this case, not telling how ant lions catch prey is not just a cute teaching gimmick. It is an essential.

In another unit, like *Making Thinks Look Bigger*, a major aim is not "I can think of how to make it look still clearer;" the belief aimed at is "I can make things look still clearer." In this case, having children try to guess how to make it look clearer is unessential to the task.

Nairobi, February 1968

Appendix 5

A Comparison Study

Setting

In the school year 1964-1965, I taught ESS laboratory science to a 5th-grade class at the Perrin School in Wellesley, Mass. On the whole, I taught three 40-minute classes a week from the end of September to the end of May, missing one week in October, two weeks in April, and about a dozen other scattered classes. The children worked on *Batteries & Bulbs, Pendulums, Pond Water,* and *Balancing.* They also worked a bit on layers of liquids with various densities, and spent a couple of days looking closely at hand lenses. A few children played with some tiling blocks at lunchtime; and the class as a whole visited the ESS offices and laboratories one afternoon. In the middle of the year, I spent about an hour with each child individually as they tried to solve three *Batteries & Bulbs* mystery boxes.

This is a report of one effort I made to assess what the children in this class had gained. There were two 5th grade classes in the Perrin School, and the children had been assigned more or less randomly to one or the other. The I.Q. range in one was 92 to 139; in the other, 92 to 140. The other class spent a few weeks doing the ESS *Small Things* unit, and had no other science.

In addition to this, I presented to each class, as a class, a new problem during the last week of school. The present account is a report of the reactions of these two classes to the new problem.

Procedure

It was an ice cube problem. In each class I did this:

(A) *I asked them what* they knew about melting ice cubes. I asked them how they thought they could make a hole in an ice cube.

(B) *I gave them each* a round flat ice cube along with

2 1/2-inch aluminum blocks and
2 1/2-inch wooden blocks and asked them if they could use these little blocks to make a hole.

As an individual succeeded in making a hole, I asked him if he could find any better way to do it.

When more than half the class had made a hole. I asked everyone to try to make one using only a wooden block.

When most had made a hole, I gave each child 2 more small aluminum blocks and asked them to try to find the *fastest* way to make a hole using 2 aluminum and 1 wooden.

When any child's ice broke into pieces so small that he no longer had a large enough surface to sink a small block, I gave him another. This happened four or five times in each class.

When any child made a hole using 2 aluminum and 1 wood, I asked him if he could find a faster way.

When many ice cubes were no longer usable, I collected the small blocks, had them wipe their desks, and let them keep the remains of their ice.

(C) *I asked the class* in general how they had made holes.

I asked them how they had done it using the 3 specified blocks. I drew these on the board as they told me.

Without comment, I took 2 ice cubes, 4 aluminum blocks, and 2 wooden blocks and placed them on a high table in front of the room.

I asked how they could tell which of the suggested ways was the fastest.

(D) *After some discussion,* I gave them each a piece of paper and asked them to write what they would do next to find out which way worked fastest.

(E) *When they finished* writing, I asked them, mostly out of curiosity, why they thought the aluminum sunk in better than the wood.

Results

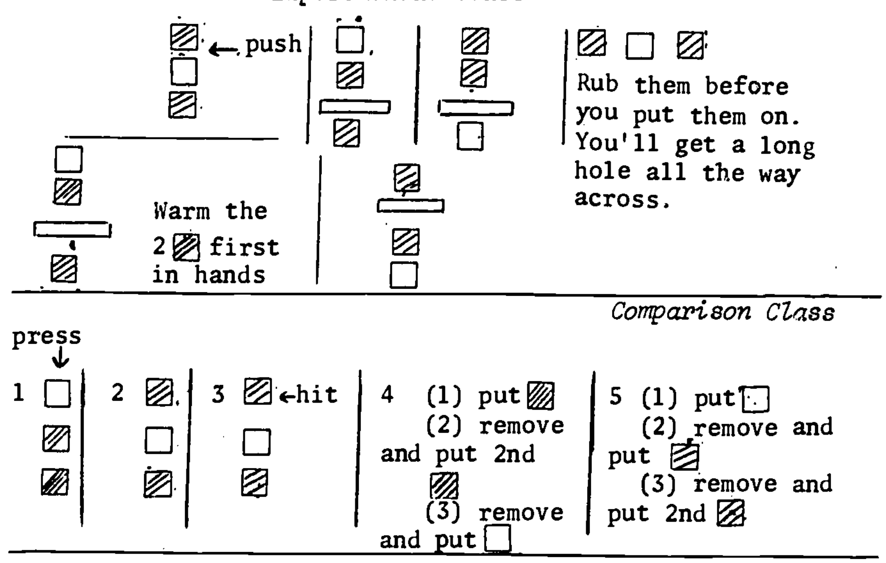
Here is a summary of the two classes:

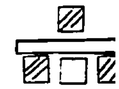
	Experimental Class	*Comparison Class*
(A) What do you know about melting ice cubes?	(1) it gets watery (2) put hot water on it (3) if you have dry ice and melt it, it turns into bicarbonate of water	(1) heat melts them (2) they turn to water (3) after they melt they evaporate (4) they turn from a solid to a liquid (5) they expand when they melt
How could you make a hole in an ice cube?	(1) drip hot water on it (2) put it under a a faucet (3) use a hot nail (4) stick your finger through it real hard	(1) hot nail (2) steady, stream of water (3) put a stick in before you freeze it, let it freeze around the stick, and remove the stick (4) put a penny on it (5) drill a hole

(B) Working with the cubes	(1) rubbed aluminum block on desk to get it hot by friction (2) pushed (3) piled them up (4) rubbed 2 aluminum blocks together to make them hot (5) asked for a match (6) put one on each side of ice cube (7) tried 2 piles at once, to compare them	(1) piled up (2) pushed (3) used a corner of metal block (4) hit one small block with another (5) alternated blocks as they cooled off (6) blew on aluminum
(C) How can you use the little blocks to make a hole?	(1) rub it on the desk and put it on the ice (2) put aluminum on one side and on the other and press them together.	(Didn't answer this question. The first child answered the 2 aluminum, 1 wood question, so we went to that)
How can you use 2 aluminum and 1 wood to make a hole?		

Experimental Class

aluminum
wood
| = ice cubes



6	7 (1) put (2) remove and put (3) remove and put (4) remove and put	8 hit 	9 (1) put (2) remove and put (3) remove and put 1st upside down	10 

Some children suggested a couple which other children pointed out were the same as ones which were already on the board, only upside-down.

	Experimental Class	*Comparison Class*
How can you find out which way is fastest?	(1) Time them - but the ice might be different thicknesses. (2) Half the room do one and half the room do another. (3) If different people do it, people will press different amounts. (4) Make sure they're the same size ice cubes. (5) The same person should push so they push the same amount. (6) Put the same amount of water in the cups before you freeze them to make sure they're the same thickness.	(1) Try Emilio's way. (2) See which kind of block cuts in faster and put it on first (3) Have everyone pick one and tr it and see whic comes out first (4) Have each perso do his idea again.

Further class activity transpired in the comparison class. I agreed that idea (3) was a good one, and there was quite a lot of sentiment in its favor. I pointed out that we couldn't do it right now because I didn't have enough ice cubes, and asked them what we should do now with the two we had. Someone suggested that we try a couple of them on these blocks, but without suggesting that we try two at a time and race. When I asked which ones we should try, about four or five children suggested individual ones, most of which turned out to be the one that they themselves had done earlier. I proceeded then to take a vote, in which three of the ways came out ahead of the others, and were selected by the class as the ones to try. Then I asked exactly what I should do next, to decide among these three. I called on Caroline to answer and she started describing one of the ways to try, namely, the one with the most votes. This involved hitting one block with another. I did as she told me and stood there with two blocks piled up and hitting them with a third while the children watched me. *One* child looked at the clock when I started! After a minute or so of silence I asked them if they were learning anything by my doing this; they all said yes, yes, keep going. A little later I asked them again; most of them said yes, but one child said "you shouldn't hit it you should just push on it, because that works better."

Before this attempt at hole-making was completed, I proceeded to ask them each to write what they would do to find out which way worked best.

In the experimental class, despite my intention to run the two classes similarily, I felt compelled to omit any further discussion of how to find out which way was best. All of the suggestions had been to the point, and further belaboring of the question would have missed entirely the tenor of the class. As a result, I gave them the writing task with no further discussion.

(D) The written results were strikingly different. I have established five categories for grouping these written experimental designs. They are described here from best to worst:

1. Time them, then re-do the experiment with the several that come out best.
2. Time them, with reference to possible experimental error and how to control it.
3. Time them, with no reference to experimental difficulties.
4. No suggestion of timing or racing but several alternative ways were described.
5. One way described as the best way.

Of 25 children in each class, the breakdown is as follows:

	Experimental Class	*Comparison Class*
1	1	0
2	9	1
3	6	8
4	4	4
5	5	12

Examples from each of these categories are appended.

	Experimental Class	*Comparison Class*
(E) Why does aluminum melt in faster?	(1) Aluminum can get friction. (2) Metal holds the heat better. (3) It's harder. (4) You can heat up metal more easily. (5) If you heat up wood until it gets white hot it would work better. (6) If you heat up aluminum it makes a bigger hole than if you don't heat it up.	(1) It's harder. (2) It's metal. (3) It's doesn't get soggy. (4) Metal gets warmer. (5) Aluminum is heavier. (6) Heat can stay in aluminum for a while. (7) Wood gets soggy. (8) Aluminum stores up and melts the ice.

Comparisons

There is no discernible difference between the two classes in their initial comments on melting ice cubes and making holes in them nor in the final reasons why aluminum works better.

The experimental class was certainly livelier while they were working with the ice cubes; that is, more active and sharing what they were doing. Our observations of what the classes were actually doing during this time were not complete. However, two strikingly good ideas were initated and spread in the experimental class which we are certain did not turn up in the comparison class. One was putting blocks on each side of the ice. The other was warming the aluminum blocks by rubbing them; this idea has never come up before in an ice cube class, as far as we know. Individuals in the comparison class did think of two other ways of heating the blocks -- blowing on them, and exchanging them when they were cold. One other idea in the experimental class was to warm them in your hands. We are not sure whether these ideas came up in both classes or not.

The ideas of ways to compare the suggestions were clearly better in the experimental class, both in class discussion and in the written proposals.

Discussion

There are, of course, lots of other things that might have contributed to the differences, besides the experience which one class has with ESS science materials:

(1) The experimental class knew me better, and I knew them better, which may have made communication between us better, and also made them feel more free.

(2) I clearly had hopes for the outcome, which may have influenced my handling of the two classes.
(3) I did this first in the comparison class, and so I may have felt surer of what I was doing by the time I did it in the experimental class.
(4) Perhaps just by accident, one or two children in the experimental class made suggestions which were then picked up by a large number.
(5) The extra discussion in the comparison class may have had the effect of focussing the children on guessing which way would be best, rather than how to find out.

There is always the question of whether the children write as much as they are thinking. Obviously, they do not. For instance, the child in the experimental class who suggested pouring the same amount of water in order to have the same sized ice cubes, did not mention in writing that the ice cubes should be the same size (although eight other children did.) Another child (also in the experimental class) put on paper only six drawings, of different ways to try, with no written word; but he told me that what he planned to do was to time them. (In categorizing his proposal, of course, I took account only of what he had put down on paper.)

Both these examples are from the experimental class, but it could be that many children in the comparison class had many more notions in their heads than they felt they were being asked to write down. I worry to think that in the comparison class I did not manage to make it clear that what I wanted was *a way to find out* which way was fastest, *not a prediction* about which would be fastest and why. However, for one thing, the two observers (both ESS staff members) did not feel I had been less clear in one class than in the other. For another thing, the class discussions already had indicated a big difference between the two classes, before writing came into the situation at all.

Despite the far-from-controlled aspect of this comparison study, it is a heartening beginning to find a detectable difference in favor of the experimental class.

The following are examples of children's written experimental designs:

Category I

First Example (Experimental Class)

"The thing you should do is to take the second one and do it and time it. Then time all the rest and take the one or ones that are the next highest and test it again." Further down the page he wrote, "The one I want is," and drew the way he thought would work best.

Category II

First Example (Comparison Class)

"1) You pick up your ice cube and put three metal squares under it, then you take a wooden square put it on the top and press. Try the other two and time them (they may work faster for you and not for someone else).

"2) Just take a metal square and press until it is halfway through then let it sit and press it again." (This one was not one of the three chosen fastest.)

Second Example (Experimental Class)

This boy drew two ways that he would try with a one-pound weight drawn sitting on top of each of the ways. The ways were labelled "test one," "test two." Beside them he wrote, "I think these are the best." Beside one of them he wrote the word "fastest." Underneath all this, he wrote, "The reason for the one-pound weight is: the ice is the same thickness. If you want it to be fair, the one-pound weight would have the same pushing power. I would try all of them so it would be fair."

Third Example (Experimental Class)

This boy also drew two different ways that he would try it, and then he wrote, "Time it and make sure the ice cube is the same thickness by taking cups and putting the same amount of water in the cups. Get a stop-watch and record the exact time it took that person to get through the ice. (BE SURE TO HAVE THE SAME PERSON DO THE EXPERIMENT!!)"

Fourth Example (Experimental Class)

Put the water in the same size container. Then have the person do different ones. Use the same blocks and let the person rest in between or he (her) will get tired."

Category III

First Example (Comparison Class)

"Time each one and the one that goes through the fastest in the less time is the fastest." Then he drew the way he thought it would work plus a drawing of a watch.

Second Example (Experimental Class)

"1) Rock two aluminum cubes on the desk until they are hot. 2) Put one aluminum cube on one side and one on the other and a wooden cube on top of an aluminum one. 3) Press hard until a hole is formed. To test it, time it with the other ideas."

Category IV

First Example (Comparison Class)

This boy drew one of the ways he thought would work, then he wrote, "On doing so, I would change my ways of testing."

Second Example (Experimental Class)

This boy drew two different ways. Beside one he put, "best one." Beside the other he put, "two best one," then he wrote, "two cubes," and, "have someone push end down."

Category V

First Example (Comparison Class)

"I would press down on the ice cube with the metal on the ice cube first, then another metal, and then a wooden one." Under this he drew a picture.

Second Example (Experimental Class)

"Miss Duckworth, I think the best way to make an ice cube have a hole in it is to have a wooden block on top of the ice cube with an aluminum one under the wooden one and under the ice cube have another aluminum block, and press."

Newton, Mass., July 1965

Appendix 6

Philip Morrison's Physics Examination

It was a course in physical science teaching methods for a mixed group of graduate and undergraduate students who were majors in the curriculum of that sort, in the state school at Cornell. I read a surprising piece in the *American Journal of Physics* which showed how a uniform block the shape of a brick floats either symmetrically or canted depending on the ratios of its two dimensions of cross section and on the density ratio of material of block to flotation medium. I therefore put out a fair variety of blocks of wood, wax, plastic, etc., and a couple of biggish containers of two or three flotation media (water and salted water--maybe oil too--somewhat tampered with to make the color and taste funnier than expected), plus rulers, calipers, graph paper, balance, weights, magnifiers and so on. Then I wrote a big question mark on the board. It was the set time for a three-hour term final; the course had been a diverse set of experiences with apparatus, lectures, PSSC kits, etc. There were six or eight students, a good mix, older and younger, men and women, novices and old holds. Three or four got the same idea I had had -- they saw that the blocks floated in differing and strange ways. One even worked out the theory in a rough way, and had the main idea! A couple got somewhere, but were not so sharp as to see what is a pretty striking feature. Try it.

References

Abelson, W.D., Zigler, E., and DeBlasi, C.L. Effects of a Four-Year Follow Through Program on Economically Disadvantaged Children. *Journal of Educational Psychology, 66*, 756-771, 1974.

African Primary Science Program. *Activities for Lower Primary: An Introduction.* Newton, Mass., 1968a. *Activities for Lower Primary: Water.* Newton, Mass., 1968b. *Ask the Ant Lion.* Newton, Mass., 1969a. *Common Substances.* Newton, Mass., 1969b.

Almy, M. *Logical Thinking in Second Grade.* New York: Teachers College Press, 1970.

Atkin, J.M. Behavioral Objectives in Curriculum Design: a Cautionary Note. *The Science Teacher,* 35, (5), 1968.

Bearison, D.J. Induced Versus Spontaneous Attainment of Concrete Operations and Their Relationship to School Achievement. *Journal of Educational Psychology, 67,* (4), 576-580, 1975.

Bleier, M., Groveman, H., Kuntz, N., and Mueller, E. A Comparison of Yielding to Influence in Open and Traditional Classrooms. *Childhood Education,* 49, (1), 45-50, 1972.

Bredderman, T. Elementary School Science Experience and The Ability to Combine and Control Variables. *Science Education,* 58, (4), 457-469, 1974.

Bruner, J. *The Process of Education.* New York: Vintage Books, 1960.

Bussis, A., and Chittenden, E.A. *Analysis of an Approach to Open Education.* Princeton, N.J., Educational Testing Services, 1970.

________________ and Amarel, M. Methodology in Educational Evaluation and Research. Unpublished mimeograph, Princeton, N.J., Educational Testing Services, 1973.

Butcher, H.J. Divergent Thinking and Creativity. In W.D. Wall and V.P. Varma (eds.) *Advances in Educational Psychology,* Vol. I, London, University of London Press, 1972.

Carini, P. The Prospect School: Taking Account of Progress, *Childhood Education, 49,* 1973.

__________. Observation and Description: *An Alternative Methodology for the Investigation of Human Phenomena.* North Dakota Study Group on Evaluation, 1975.

Chaytor, D.E.B. The Unit Approach to Primary Science: a Guide for College Tutors and Primary Science Teachers. Mimeographed paper, Education Development Center, Newton, Mass., 1971.

Chin, R. Thoughts and Activities in Evaluation Research Planning for African Science Program. In E.A. Yoloye, (ed.) *Evaluation for Innovation,* Education Development Center, Newton, Mass., 1971.

Dillon, S.V., and Franks, D.D. Open Learning Environment: Self-Identity and Coping Ability. *The Educational Forum, 39,* (2), 155-161, 1975.

Duckworth, E. Floating Color Tubes. In *Highlights,* Elementary Science Study, Newton, Mass., 1964.

__________. Mimeographed memorandum, African Primary Science Program, Akosombo, 1967.

__________. The Virtues of Not Knowing. *Elementary Principal,* 1975, *54,* 64-66.

Dyasi, H.M. The Science Education Program in Africa. In J. Ponsioen (ed.) *Educational Innovations in Africa: Policies and Administration,* The Hague: Institute of Social Studies, 1972.

__________. Integrated Science Education in African Primary Schools. *Prospects,* 4, (1), 63-71, 1974.

Elementary Science Study. *Gases and Airs.* St. Louis: McGraw-Hill, 1967a.

__________. *Small Things.* St. Louis: McGraw-Hill, 1967b.

__________. *Batteries and Bulbs.* St. Louis: McGraw-Hill, 1968a.

__________. *Microgardening.* St. Louis: McGraw-Hill, 1968b.

__________. *Balancing and Weighing*. St. Louis: McGraw-Hill, 1969a.

__________. *Daytime Astronomy*. St. Louis: McGraw-Hill, 1969b.

__________. *The Elementary Science Study: A History*. Education Development Center, Newton, Mass., 1973.

__________. *The ESS Reader*. Education Development Center, Newton, Mass., 1970.

Educational Services Incorporated. *African Science Program*. Mimeographed paper, Newton, Mass., 1965.

Elite, A. Some Thoughts on Evaluation. In E.A. Yoloye, *Evaluation for Innovation*, Education Development Center, Newton, Mass., 1971.

Elstgeest, J. Teachers or Instructors? In SEPA, Report of the Teacher Training Materials Workshop, Accra, Ghana, Science Education Program for Africa, 1971.

Engel, B. *A Handbook on Documentation*. Grand Forks, N.D.: North Dakota Study Group on Evaluation, 1975.

Ennever, L. A Case Study of a Project. *Secondary Education*, March 1974, *4* (2), 87-93.

Espejo, M., Good, R., and Westmeyer, P. Evaluation of a Child-Structured Science Curriculum Using the Intellectual Models of Piaget and Guilford. *Journal of Research in Science Teaching, 12*, (2), 147-155, 1975.

Feynman, R. What is Science? The Physics Teacher, *7* (6), 1968, 313-320.

Friot, F.E., quoted in McKinnon and Renner

Gagné, R. *The conditions of learning*. New York: Holt, Rinehart and Winston, Inc., 1965.

Haddon, F.A., and Lytton, H. Teaching Approach and the Development of Divergent Thinking Abilities in Primary Schools. *British Journal of Educational Psychology, 38*, 171-180, 1968.

______________. Primary Education and Divergent Thinking Abilities: Four Years On. *British Journal of Educational Psychology, 41*, 136-147, 1971.

Harlen, W. Formulating Objectives -- Problems and Approaches. *British Journal of Educational Technology*, 3, (3), 223-236, 1972.

Hawkins, D. Introduction. In *Highlights*, Elementary Science Study, Newton, Mass., 1964.

_________. Messing about in Science. *Science and Children*, February 1965.

_________. On Living in Trees. *Colorado Quarterly*, Summer, 1965b.

Hawkins, F. *The Logic of Action*. Boulder, Colo.: Elementary Science Advisory Center, 1969.

Hein, G. Children's Science is Another Culture. *Technology Review*, December 1968.

_______. *An Open Education Perspective on Education*. North Dakota Study Group on Evaluation, 1975.

Henriques-Christofedes, A., and Coll, C. Apprendre à dialoguer avec les objets ou l'enseignement des sciences à l'école primaire. *Cahiers de la Section des Sciences de l'Education*, no. 2, Université de Genève, 1976.

Hudson, L. *Contrary Imaginations*. London: Penguin, 1968.

Inhelder, B. and Piaget, J. *The Growth of Logical Thinking*. New York: Basic Books, 1958.

_________. *The early growth of logic in the child*. New York: W. W. Norton, 1965.

___________, Sinclair, H., and Bovet, M. *Learning and the Development of Cognition*. London: Routledge and Kegan Paul, 1974.

Kamii, C., and Derman, L. The Engelmann Approach in Teaching Logical Thinking: Findings from the Administration of Some Piagetian Tasks. In Green, D.R., Ford, M.P., and Flamer, G.B. (eds.), *Measurement and Piaget*. New York: McGraw-Hill, 1971, 127-146.

__________ and Devries, R. Piaget for Early Education. In Parker, R.K. (ed.), *The Preschool in Action* (second edition). Boston: Allyn and Bacon, 1977.

_________ and Elliott, D. Evaluation of Evaluations. *Educational Leadership*, 28, (8), 827-831, 1971.

Karplus, R., and Thiers, H. *A New Look at Elementary School Science*. Chicago: Rand McNally and Company, 1969.

Kolen, C., and Golub, M. A Piagetian Kindergarten Program and its Evaluation. Paper presented at the Sixth Annual Symposium of the Jean Piaget Society, Philadelphia, 1976.

Kuhn, T. *The Structure of Scientific Revolutions.* Chicago and London: The University of Chicago Press, 1962.

Langstaff, N. *Teaching in an Open Classroom.* Boston: National Association of Independent Schools, 1975.

Linn, M., and Thiers, H. The Effect of Experimental Science on Development of Logical Thinking in Children. *Journal of Research in Science Teaching, 12* (1), 49-62, 1975.

Mayor, J.R., and Livermore, A.H. A Process Approach to Elementary School Science. In Good, R.G. (ed.), *Science and Children.* Wm. C. Brown, Co., Dubuque, Iowa, 1972.

McKinnon, J.W. and Renner, J.W. Are Colleges Concerned with Intellectual Development? *American Journal of Physics* 39, 1047-1052, 1971.

Morrison, P. The curricular triangle and its style. *ESI Quarterly Report,* Summer-Fall 1964a.

__________. Experimenters in the Schoolroom. *ESI Quarterly Report,* Summer-Fall, 1964b.

Neuman, D.B. The Influence of Selected Science Experiences On the Attainment of Concrete Operations by First Grade Children. Paper presented at the Annual Meeting of the National Association of Science Teachers, Pasadena, California. February, 1969.

Patton, M.Q. *Alternative Research Paradigm.* Grand Forks, N.D.: North Dakota Study Group on Evaluation, 1975.

Piaget, J. Cited in E. Duckworth: Piaget rediscovered, *Journal of Research in Science Teaching, 2,* 172-175, 1964.

__________. *Réussir et comprendre.* Paris: Presses Universitaires de France, 1974.

__________. *L'équilibration des structures logiques.* No. XXXIII, Etudes d'Epistémologie. Paris: Presses Universitaires de France, 1975.

__________ and Inhelder, B. *The Child's Construction of Quantities.* New York: Basic Books, 1974.

______. *The Child's Conception of Space*, London: Routledge and Kegan Paul, 1956.

______ and Szeminska. A. *La genèse du nombre chez l'enfant*. Neuchâtel and Paris: Delachaux et Niestlé, 1941.

Progress in Learning Science. Information papers. University of Reading, 1975, 1976.

Ramey, C.T., and Piper, V. Creativity in Open and Traditional Classrooms. *Child Development*, 45, 557-560, 1974.

Rappaport, M., and Rappaport, H. The Other Half of the Expectancy Equation. Pygmalion. *Journal of Educational Psychology*, 67 (4) 531-536, 1975.

Rieben, L. L'examen des fonctions cognitives chez l'enfant: Q.I., opérativité et créativité. Thèse de doctorat, Université de Genève, 1974.

SEPA. Report of the Teacher Training Materials Workshop. Accra, Ghana, Science Education Program for Africa, 1971.

____. *Handbook for Teachers*. Accra, Ghana: Science Education Program for Africa, 1974.

Science -- A Process Approach. Observing 5 -- Observing color changes. New York: Xerox Education Group, 1967.

Science 5/13. *With Objectives in Mind*. London: Macdonald Educational, 1972.

Shapiro, E. Educational Evaluation: Rethinking the Criteria of Competence. *School Review*, November 1973, 523-549.

Stafford, D.G., quoted in McKinnon and Renner.

Thomson, B.S., and Voelker, A.M. Programs for Improving Science Instruction in the Elementary School: Part II, SCIS. In Good, R.G. (ed.), *Science and Children*, Dubuque, Iowa: Wm. C. Brown Company, 1972.

Tobier, A. (ed.) *Evaluation reconsidered*. New York: Workshop Center for Open Education, 1973.

Torrance, E. P. *Torrance Tests of Creative Thinking.* Princeton, N.J.: Personnel Press, 1966.

Wallach, M. Creativity. In Mussen, P.H. (ed.) *Manual of Child Psychology*, New York: Wiley, 1970.

Ward, W.D., and Barcher, P.B. Reading Achievement and Creativity as Related to Open Classroom Experiences. *Journal of Educational Psychology, 67*, (5), 683-691, 1975.

Wastnedge, E.R. (ed.) *Nuffield Junior Science, Teacher's Guides 1 and 2.* London and Glasgow: Collins, 1967.

Wilson, F.S., Stuckey, T., and Langevin, R. Are pupils in the open plan school different? *Journal of Educational Research, 66*, 115-118, 1972.

Wright, R.J. The Affective and Cognitive Consequences of an Open Education Elementary School. *American Educational Research Journal, 12*, (4), 449-464, 1975.

Yoloye, A. E. *Sourcebook for Evaluation.* Newton, Mass.: African Primary Science Program, 1969.

____________. *Evaluation for Innovation.* Education Development Center, Newton, Mass., 1971.

Zacharias, J. Mimeographed file memorandum. Educational Services, Inc., Newton, Mass., 1965.

Also available as part of the North Dakota Study Group on Evaluation series:

Children's Language and Thinking: A Report of Work-in-Progress
by Edith H. E. Churchill and Joseph N. Petner, Jr.

First California Conference on Educational Evaluation and Public Policy, 1976
Edited by Nick Rayder

A View of Power: Four Essays on The National Assessment of Educational Progress by Paul Olson

Developing Hypotheses About Classrooms from Teachers' Practical Constructs
by John Elliott

Children's Interactions in Traditional and Nontraditional Classrooms
by Sylvia Ross, Herbert Zimiles and David Gerstein

Psychological Effects of Open Classroom Teaching on Primary School Children: A Review of the Research by Robert A. Horwitz

Special Education: The Meeting of Differences by Steven D. Harlow

A Handbook on Documentation by Brenda Engel

Informal Evaluation by Brenda Engel

An Open Education Perspective on Evaluation by George E. Hein

Alternative Evaluation Research Paradigm by Michael Quinn Patton

Observation and Description: An Alternative Methodology for the Investigation of Human Phenomena by Patricia F. Carini

The Word and the Thing: Ways of Seeing the Teacher by Ann Cook and Herb Mack

Teacher Curriculum Work Center: A Descriptive Study by Sharon Feiman

Testing and the Testing Industry: A Third View by John Williams

Single copies $2.00 (unless otherwise indicated) plus 50¢ handling charge, from North Dakota Study Group, Box 8039, University of North Dakota, Grand Forks, North Dakota 58202