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The traveler, the Peace Corps volunteer (both outward bound and returning), the suburbanite in the ghetto and the black man in the white man's world-all suffer from something called "culture shock." Each of us lives mostly within a world filled with the familiar: landmarks, symbols, a language that seems "right." Whether we were born to our situation or acquired it, there are one or more cultures in which we feel at home, within which we accept events, structure our perceptions, and surround ourselves with the familiar, The rest of the world is alien and to some extent threatening: when we venture outside our culture we must face foreign words and thoughts, we must rescreen our perceptions, we must cope with a new situation,

The world of science is a culture in itself. Those of us who were trained in it feel at home with a particular set of ideas, understand a certain manner of speaking and share a set of values about methods for approaching the world around us. We are scientists. We believe in our culture so much that we want to expose children to it; we want them to understand the world of science.

Mostly we expose our children to science through techniques and gadgets which have the quality of exporting our culture and asking children to cope with it. This is very much like traveling around the world on T.W.A. flights, staying in Hilton Hotels and meeting the natives in American bars, The inhabitants of the countries have to deal with us in terms of American customs, and we see them only as they do or don't succeed in this enterprise. From the results of this effort, we cannot evaluate or even understand their culture.

When we take science to children, we usually do so by introducing our kind of activity, modified to suit the children only in the sense that the Hilton Hotel will be built of local materials and won't need central heating in the tropics. The language we use is a little simpler, the materials we introduce are safer, and the apparatus is cheaper, but we give to the children books and materials that have the form and, to a great extent, the content of academic science. Then we measure their response. Do they become stimulated to do science, i.e., do they do experiments that we recognize, do they enter the science fair with a nifty display, do they ask our kinds of questions, and do they come up with our kinds of explanations? We never find out what they would do if we approached them on their terms and encouraged them to pursue their own concerns.

Exporting the Adult World of Science

If we do open our eyes, look out of the alley windows of those imposing hotels, or talk to children about what they are interested in and able to discuss, we find that theirs is indeed an alien culture-one that is strikingly different from that of the science departments of the university and the industrial laboratory. The child's world is alien when viewed from the perspective of the science culture. But we have to remember what "alien" means: it is foreign to us but not to its locale. What the children express when they explore the world, the activities they pursue and the interests they show are native to their state. They just happen to be different, in some sense, from the discipline of science as we recognize it.

Just how are children different in their approach to the world? What does in fact happen when a scientist goes into a classroom prepared to do science with children?

One way to describe this is in terms of particular experiences with one set of children. Last winter, for example, some of us from Elementary Science Study visited a fifth grade classroom with the beginnings of a unit called "rolling Objects." The basic equipment consisted of an inclined plane and a number of cylinders, spheres, and other objects that could be rolled down the slope. The children were asked to compare the ways the different objects moved down the inclined plane-a fairly standard physics experiment, on the whole, and one for which we might be able to predict the results. But in the children's hands the experiment turned out quite differently from what we had expected. The result was, I think, quite revealing of what concerned and interested these children. What they did demonstrates what they saw and how they interpret the world.

The first thing that kids did in this class, when presented with an inclined plane and a number of objects that could roll down it, was to race these objects against each other.

"Which is the winner?"
"Mine is the fastest."

The competition element was intense. It was reflected between children; but more than that, it permeated each child's view of his own work. If one thinks about a child's life-the activities, the pressures, and the rewards-it turns out to be natural to describe things in terms of races. That is the way the world is. Given such a world view, it is natural for the child to place this particular activity within his common framework and describe his results in terms of that framework.

After watching the children persist in these races, no matter what other questions we tried to ask and no matter in what direction we tried to lead them, we began to realize some of the implications of this mode of thought. One of the consequences of thinking of natural events as "races" is that you tend to ignore the ties. Ties are not important; they don't tell you which is faster. And indeed we had many children tell us that A was faster than B, because they had raced the two 10 times and A won twice, B once, and there were seven ties.

Is this bad science? It certainly isn't what is generally considered a proper way of looking at and interpreting events. But the observations are good (at least there is no reason to question them), and the conclusion follows nicely: if you are going to describe the set of experiments in terms of a race, then A did win-just as Detroit won the pennant, not by winning all the games, but by winning more than any other team.

Yet we recognize that this kind of description is alien to us as scientists. What is missing? What kind of argumentation is not there? The answer is that these children do not have a statistical view of data and scientific observation. Instead they have a particulate view. Each observation has its independent existence, each observation could decide the contest. The whole set of concepts required in order to design an experiment based on the idea that the results of science have a probability, rather than a certainty, the whole notion that null readings or "ties" are valuable ways of obtaining data-these are extremely sophisticated concepts, and children simply do not have them.

The point is not just that notions about probability and the way our adult science culture interprets data are alien to the children, but that these views have to compete with a world view that is already firmly set. The world makes sense in terms of races, in terms of competition. You can summarize and explain your results (and, therefore, remember them and use them to predict) by finding out which one is faster (and not counting the ties). So to change the focus, to shift the attention to the ties and consider the other events as experimental oddities require that the child change his mental set. That, as we know, is hard for anyone to do.

Another area in which children's approaches are very different from what we might expect is simply the particular individual experiments that children decide to do. An inclined plane and a series of cylinders and spheres suggest to a physicist that he compare the time it takes for various objects to roll down and measure the effect of such variables as mass, shape, and center of gravity. Children do spontaneously study these things, although they use different words to describe what they are

doing. But they also get interested in a number of other variables. If you in the role of parent or teacher try to push a particular result that you believe can be obtained-say the independence in the rate of rolling on the mass (for identical distribution of mass)-you run into two problems. First, the results are not likely to be very clear unless you take a great deal of trouble with the apparatus, and, second, even if the results come out as you expect, they do not seem to convince the children very much. How can that be? How can they see a result come out as it "should be" and not be impressed by it?

The answer is, of course, that you can only be impressed by a result if it confirms or denies the thesis that you held to begin with. If you were indifferent to the thesis, or just didn't know it, you are hard to impress.

The Various Criteria of Validity

What most children do seem to know is that physical events, such as the time it takes a cylinder to roll down an inclined plane, are affected by a numb~r of variables. They may even know roughly what it means to study one variable at a time, or at least to limit the number of variables which one examines. What they don't know is how to do this kind of limiting, and especially they don't know which variables to concentrate on. What affects the rate? Is it temperature, mass, altitude, shape, time of day, the teacher's mood, the observer's tie in the way, or Johnny's jiggling of the board? There is a bewildering array of factors which could enter in.

In the scientist's laboratory work, the problem of deciding what factors are relevant is solved in two different ways. First, we build apparatus which tests only a very small number of variables at a time. We enclose things in boxes, thermostat them, and probe with electrical circuits which essentially screen out many of the variables that we are not interested in. Secondly, and more important, we have a pretty good idea of the order-of-magnitude effect of a number of factors on experiments. Gravitational attraction is simply not significantly affected by temperature, humidity, noise, and a number of other things, over ordinary ranges. We can discount these things in concentrating on the area of interest.

We usually don't have trouble in recognizing a friend of ours if he has just had his hair cut or is wearing somewhat different clothes. We are so familiar with him that these variations can be discounted. But let our guide in a foreign country appear the second day in a different getup and we become confused. Faced with a wide range of new perceptions, we have trouble picking out the relevant ones, trouble organizing what we see to make sense out of it. In a similar way, children have this difficulty. Because they don't know what is important and what isn't, they have a terrible time devising experiments which scientists would consider significant.

The complexity of the situation is brought out even more when we take into account the problem of error that is involved with most of the equipment that we choose for "science" experiments. If we happen to let the cylinders roll "incorrectly" (that is, if we release them at different times accidentally), if we bump the board, or introduce anyone of a number of "extraneous" factors, we automatically discount the experiment and do it over. But the child has no prior knowledge of what is "incorrect" or "extraneous," so he counts a number of experiments that we would reject and may discount others which appear valid to us. He ends up with a pile of data which may make no sense because he does not have the preconceptions that one needs in order to place them in an adult scientific framework.

How does one handle piles of data that make no sense? It is almost impossible to resist the temptation to explain them in terms of some theory or concept that one already has. That is precisely what children do. They take a number of experiments which include the inevitable error, impose

on them the selective perceptions which result because they are not sure of what counts and what doesn't, and end up with data which will support any theory which they happen to hold. And if you ask what theory that is, it turns out to be, by and large, a kind of Aristotelian physics. The basic belief relevant to these experiments is that-as in most things that matter in the child's world-weight makes a difference: heavier things hurt more if you drop them on your toe, they are harder to lift and harder to throw, and they do more damage to whatever they hit. So why shouldn't heavy objects roll down slides faster too?

If that is the conclusion that you expect, you can very easily reach it from the experiments. What about all the times this was not the case-all the times when the heavy and the light thing rolled at the same rate? First of all, the ties don't count. Secondly, many of the experiments that did not support the Aristotelian thesis may have involved the extraneous factors discussed above. Finally, in a great number of cases it is true that, other things being equal, the heavier object does get to the bottom first. Of course, this is good Aristotelian physics, too. Galileo's objects dropped from the Tower of Pisa didn't strike the ground simultaneously; the heavier got there first by a little bit. His argument was much more sophisticated than that.

The children got stuck, just as generations of scientists did, on the fact that the heavier Objects do behave differently from light ones under most ordinary circumstances. The children reinforced th is bel ief when they tried to devise tests to decide which object did, in fact, roll down the board faster. The children thought of ingenious methods for doing this. One group had a child place his fists at the end of the board, close his eyes, and report which hand was struck first by the rolling object. Another group invented a balance with a pencil that tipped in one direction or the other, depending on which side of the balance first felt the impact of the rolling object.

Unfortunately, both these methods can be influenced by the mass of the object used. The hand test is sensitive to the force of impact, and the balance is prejudiced towards the heavier object if both objects strike it at nearly identical times. This is a case in which the children's ingenuity and cleverness happened to reinforce their prejudices and the theory they held. It is extremely difficult for anyone to resist accepting data which fit his theory and, more than that, are gathered with the help of a specially constructed device that happens to "work." We are all familiar with the kind of control experiments we run: if they come out as we expect them to, we seldom repeat them. Only if they come out in a way that appears odd, do we recheck everything carefully.

The Choice Between Exports and "Going Native"

I have tried to describe in the preceding pages the results we had in working with a group of children using a rather simple physical setup and testing what appeared to us to be a relatively direct physical situation. It turned out that the children, when left to themselves, viewed it as a complex situation;

and when they tried to order it, they reinforced the notions that they already possessed instead of using the opportunity to expand and modify their views. How do we, as scientists or parents, handle this common situation? There are a number of points which can be made.

It may appear at first thought that the problems which came up in this class are not really so important. One could argue that much of our difficulty arose simply because the particular experiment chosen was a difficult one and we were trying to do the job with inadequate equipment. But I don't think that more sophisticated gadgetry or a more tightly controlled experimental situation would provide much of an answer. True, the difficulties were particularly noticeable in this situation, but they are there whenever we introduce our science to children.

Every experimental situation with children presents the same problem. Either the experiment is simple, direct, and with nothing that can "go wrong," or else it is open and fallible. But in the former case, it is simply a lecturer's demonstration placed in the hands of the children; it is not an experiment.

We have to make a choice. We can decide to export our science culture to our children or we can decide to "go native," to find out what the children are doing, and to encourage them to develop their interests, their concerns, and their approaches. In either case, our goal should be to do what we can to make them good at what they are doing. By "being good at it," I mean to allow them to have satisfaction in the results of their activity. In the former case they will presumably become good at adult science; they will learn "our thing."

If we decide to do the former, we know what our goals are fairly clearly; the task is easier because we have our own standards for comparison. But this is offset by the fact that there is no reason why any large number of children should be turned on by our activity or should want to be good at what we want them to be good at. In fact, given the relations between adults and children these days, there is ample reason to believe that just because this is an activity that we adults endorse, the kids, at the least, will look at it very critically.

Whichever course we decide to pursue, we should be clear and honest with the children about what we expect of them and what we think of their work. If we really believe that the children should devise and perform their own experiments, then we have to be willing to face the consequences of this decision. The kids are likely to do things that we consider trivial or even misleading, and they are likely to arrive at conclusions that we do not accept. We must either put up with this or else recognize that we propagandize and direct them. We can make them get the results we want, but this will require limiting the materials we give them and "guiding" their experiments so that they will perform the ones that we consider important and that give us *our* answers, too. In this case, we should be honest and make it clear that we are insisting on *our* science, not letting them do *theirs.*

We must recognize how much we usually demand of children; we know that "changing one's set" is extremely difficult, that the history of science is full of examples of people who could not change their minds even when confronted with contrary evidence, and it is difficult to suppose that this should be any easier for children.

Finally, I think it is important that we try to free ourselves from our prejudices and recognize that what children do, even if it reinforces beliefs that we think are wrong or involves experiments that we think are trivial, may be good science.

From Preconception to Insight

I have indicated that asking children to adapt themselves to our scientific culture is easier for us scientists than trying to acculturate ourselves to our children. It should be obvious that from the

children's point of view the opposite is the case. But is it worth it? Should we go to the trouble of learning those aliens' language, taking their awkward customs seriously, and entertaining their puzzling notions?

Yes, I believe it is desirable and indeed necessary that we make this effort. We cannot really claim that we have gone beyond rote learning and uncritical memorization if we simply substitute our set of cause-and-effect relationships and our set of activities which support them for those we learned a generation ago. As long as we decide what a child will get out of a particular experiment and accept that result and not others as a measure of the success of the task, then we have not changed the age-old relationship between parent or teacher and child-the relationship in which one hands down the sacred truth to the other. If we insist that children learn and accept Galileo's laws concerning falling bodies from the results of their experiments with inclined planes and rolling objects, then one of two things will happen: Some children will lose interest in science because they will recognize that we do not really honor their experiences but accept only that part of it which fits our notions. Others will become docile adherents of the science we have taught them.

The best we can hope to accomplish by the more rigid teaching is to train technicians, to prepare students to work within the confines of the theories and beliefs which are current during the years that they are learning.

If we are interested at all in helping children to become creative, to have the breadth of knowledge, the strength of mind and the critical ability to go beyond accepted beliefs, then we must give them the kind of start in life that helps them go beyond present viewpoints and come to new understandings, new insights and new concepts. They must be able to think and act on the basis of their own experience, not on the basis of a world which consists of testing and confirming present ideas. The more we make the scientific work of children a game in which our beliefs are the goals, the harder we make it for them to go beyond present views. The more we respect their science culture and try to understand it, the more likely we are to equip them to look at the world through their own eyes rather than through ours-to interact with it as it is rather than as it "should be."

George E. Hein is associated with the Elementary Science Study program of the Education Development Center in Newton, Mass. He has taught chemistry and worked on research at the University of Michigan, California Institute of Technology, Boston University, and Harvard Medical School; his interest in teaching children began, he says, when he realized "that education problems were just more exciting and relevant to me and to the world today than research on enzyme specificity." The photographs are from Elementary Science Study, E.D.C.