EXPERIMENTAL PROCEDURES OF CHILDREN

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It has been pointed out by Bruner and his associates (2) that there are individual and situational differences in choice patterns in concept-formation problems. In the psychology of learning the classical approach has been for the experimenter to organize the sequence of alternatives presented; often, these alternatives are designed to make each choice maximally informative. Little is known about training subjects so that they will themselves adopt optimal methods of questioning and control for particular purposes. The following study is concerned with the conditions under which children use various techniques of control and patterns of choice. It is frankly exploratory and largely descriptive; the next step would be to experiment with appropriate conditions of training.

If a phenomenon has a number of causes or correlates, one way to study exploratory patterns would be to ask subjects to find all the causes. In this study, because the children were young and might interpret this task variously, it was decided to set a goal that would indirectly require a discovery of correlates. The subjects were asked to reproduce the phenomenon with-

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out being permitted to use identical conditions twice. It would be expected that they would try to maximize success by choosing conditions most similar to the model or first instance of the phenomenon. In these circumstances, impressionistic methods in which some variables are ignored lead eventually to erroneous predictions. It may be expected, then, that the subjects will turn increasingly toward analytic solutions, in which they learn to discriminate the relevant conditions and the direction of their effects. The points of interest in these observations are the sequence of choices, the control of variables, and the use of information obtained on each trial.

On the face of it, successive experimentation by subjects looks like an efficient learning method. Each time a choice and a verbal prediction are made, they are reinforced. But if the experimenter, rather than the subject, selected instances, he would try to train discriminations between variables. The usual technique of discrimination training would require the manipulation of one variable at a time.

When the subject himself selects instances, and most particularly when, as in normal experience, maximal success rather than clarity of information is sought, such highly controlled selection may not occur. The theoretically optimum method for acquiring sure information also increases the short-term risk of failure. Controlling a variable believed to be effective increases the likelihood that no contrast will be found under two conditions being explored. One takes this risk for the long-run value of the new, unambiguous information thus obtained, but it is unlikely that people would act this way in the absence of a marked discrepancy of pay-off in favor of later certainty. The use of controls, then, may be regarded as likely to occur only under specialized conditions when acquiring new and sure information is more important than immediate success.

If, in most natural circumstances, conditions are not successively controlled, how are predictions made? One possibility is that the learner, like a giant calculator, correlates over all instances and predicts according to the maximum probability of success.

Such a method would be successful if circumstances were unbiased, so that they have occurred independently in their various combinations. Since natural conditions do not usually form a factorial design, causal variables may be masked by correlated factors.

Furthermore, not all factors are equally present psychologically. While this filtering process is not well understood (1), it is known that there are limits to the sensory intake of the organism as well as to its storage and processing capacity. Therefore, the pattern of reinforcements over past choices may not alone predict choices whenever a complex array of factors is available. It will be necessary to assess attention in some fashion, the easiest method, although a conservative one, being the use of verbal reports.

We may expect that an attentional shift, leading to a change in predictions, is most likely to occur after failure. In explanations for failure, hitherto unnoticed factors may be mentioned. Changes in predictions, then,
SUSAN M. ERVIN

should be most frequent after new factors have been mentioned in explanations for failures.

Explanations and predictions are verbal. One major source of interference for children in the analytic solution of physical problems arises in their lack of experience in discriminating traits verbally. Confusion of traits might arise from three sources. One is the correlation of traits in experience. For instance, big things are usually heavier and stronger. The second is confusion arising from the use of a term for a relative quality; e.g., a short rod might be called thick because it is thicker relative to its length than a long rod. A third difficulty arises when a descriptive term can refer to a number of attributes and therefore may discourage their discrimination, e.g., "heavy" (of material differences or density, thickness, total weight), "skinny" (length, thickness).

In investigations with kindergarten and first grade children, it was found that a substantial proportion of the children refused to accept verbally the independence of such traits as "big," "strong," "heavy." They would say "If something is big, it can't be weak." This suggests that the differentiation of these traits may proceed slowly, relying on instances which violate the usual correlation. The children who said that they were independent offered striking exceptions, e.g., a sick big dog who was weak (3). In view of the lack of controlled presentation of instances in actual experience, most children at first learn to apply these terms roughly to the same domain of traits. Therefore, there should be more verbal confusions in the younger children in the sample.

Method

Subjects

Twenty second and third graders were selected for this study, which was a control training for another experiment. Eight were boys and 12 were girls. They ranged in age from 8 years to 8 years, 9 months. The mean Kuhlmann-Anderson IQ was 116; the standard deviation was 9, the range being from 101 to 139.

Apparatus

The apparatus was suggested by Inhelder and Piaget's study of the separation of factors in flexibility (4). A set of rods was prepared, consisting of wood, brass, aluminum, and steel rods. Half of each type were 15 inches long, and half were 24 inches long. In turn, half of these were 3/8 inch in diameter, and half were 1/4 inch in diameter. The rods had washers on one end, and the other end could be inserted in a holder consisting of a block of wood elevated on legs, with holes bored in the block for the two sizes of rods. A hinged section could be hooked down to hold the rods rigidly in place when they were inserted. The holes in which the rods are inserted were seven inches from the base. Large stoppers from standard toilet plumbing equipment were stuffed with lead wool, yielding two different weights,
CHILD DEVELOPMENT

which looked alike. These could be hung by strings from the washer end of the rods. There were two heavy and two light weights.

Procedure

When the child entered the experimental room, he was shown the display of rods, and the materials were discussed and the various differences, to make sure that the child could describe all the attributes. Then:

A. Now I'm going to take the long thin wooden rod and put it in here, and the short thick steel rod and put it in here and lock them in. Then I'm going to take a light weight and put it on the long thin wooden rod and the heavy weight and put it on the short thick steel rod. Let's see what happens. (Wooden rod goes down.) Why do you think that happened? (Probing to find attributes.) Now I'm going to take these off. We won't be able to use these rods again. Now I want you to pick any two rods there you see and use any two weights you want. Pick one to go down and one to stay up. Which one will stay down? Why? Which will stay up? Why? (Test) What happened? Why do you suppose that happened? (This is repeated through four pairs.)

B. 1. I've got a rod and a weight that touches bottom. Could you tell me anything about it? What else would you need to know about before you could tell for sure?

2. Suppose we had only heavy weights and long rods, which rod would you pick to touch bottom and which to stay up?

3. Suppose we had only light weights and long rods?

4. Suppose we had only light weights and short rods?

5. What kind of a wooden rod would stay up and what kind of a brass rod would touch bottom?

6. If we had a long, thin, wooden rod with a light weight on it and a short thick brass rod with a heavy weight on it, what would happen? Why?

7. If we made the wooden rod shorter and thicker and the brass rod longer and thinner, what would happen?

Results

A content analysis was made of each child's choices, predictions, explanations of failure, and responses to hypothetical questions. The data will be described and discussed below in terms of special problems: the effects of verbal habits on performance, use of the information available in the display pair, information acquisition in successive trials, controls, and shifts in the definition of the task. Finally, an over-all assessment will be offered of the relative success of the children in discriminating the effective factors in flexibility.

Labeling Effects

Six second-graders and three third-graders had some kind of confusion of attributes in their speech. Two of the children referred to length as "thickness" and throughout the experiment failed to control length. During the subsequent questioning, they talked about the effects of "thickness."
SUSAN M. ERVIN

These children displayed no knowledge of the effects of length and failed to include length as a variable in verbal discussion. The children did not actually talk about “thickness” and make choices differentiating length; once having converted length information into terms of thickness, they continued to make choices referring to the actual attribute of thickness in the rods.

The most common confusion was the use of “heavy” and “light” to describe differences of material, differences in thickness, and the differences between the weights used, interchangeably. Several children believed that the principle explaining the phenomenon involved some relation between the heaviness of the rod and the heaviness of the weight. Some of the greatest difficulties in making predictions and the clearest failures to discriminate variables resulted from the use of these complex hypotheses. Such children usually identified heaviness both with the heavy materials and the thick rods, and in several cases they failed to control material because they talked about heaviness and controlled only thickness. The most extreme example of terminological overgeneralizing occurred in a third grade girl:

Sara (8;1): (The steel rod stays up in the display pair.) This is heavier than the wood stick. The stick is heavy and so is that (the weight) and that holds that up. . . .

1. (A heavy weight stayed up on a thick long brass rod and a light one went down on a wood rod.) This one is falling down because it's on the light stick and this stick is holding this one up because the stick is heavy and this is heavy too. . . .

2. [Why are you picking those rods? (thick short wood, thin short wood.)] To see if the heavy one goes down and the light one stays up. [Why are you putting the heavy weight on that (thin) stick?] To see if the heavy one stays up on a light stick. [And the light weight on that (thick) stick?] To see if it falls down. [Why did this happen?] The stick is light and the heavy part is pulling the light part down. [Why does this (thick) one stay up?] The heavy part is holding the light part up.

3. (Puts heavy weight on steel, light on aluminum.) Because this is light and so is this. I put the heavy part on the heavy part. I want to see if the light one stays up and the heavy one falls down. [Why did they both stay up?] Because the heavy one is on the heavy part and the light part is on the light part.

4. [Why those weights?] I'm putting the light part on the light part, and the heavy part on the heavy part. I want to see if the heavy part stays up and the light part goes down. [Why will the light part go down?] Because the light part is on the light part? [Why did both stay up?] Because the light part is on the light part and the heavy part is on the heavy part. [What do you mean?] The heavy part is smaller and fatter and it's holding this part up. It's longer and it's holding the light part up. [I have a rod that is touching bottom. What can you tell me about the rod and the weight?] Did you put a light part in there and a heavy part on it? The light stick is holding the light part down.

This child persistently switched back and forth in her description between calling the rod or the weight the “light part” and between referring
to material differences or thickness differences. In the verbal questioning, she did not mention thickness differences as a means of varying flexibility, even when offered an instance when material was controlled. This case was the most extreme example of interference with a verbal analytical treatment of variables that arises when terminology is overgeneralized.

Effects of the Display Pair

The children entered the experimental situation having had previous experience with flexibility and weight. The first formal display was the same for all the children: the long, thin, wooden rod with a light weight went down, and the short, thick, steel rod with a heavy weight stayed up. The weights were deliberately misleading. The children were asked what happened and why. Their responses give some indication of the saliency of the materials, their vocabulary, and their previous training with respect to the flexibility. The material difference one would expect to be most evident because there were four material variants in the display and only two variants on the other dimensions. All of the children offered material as an explanation of the difference, and 12 offered the weights even though, in fact and in their earlier experience, the difference between the weights could not account for the difference in flexibility. A clue to one source of their concern with weight is given by the fact that the third graders all confined themselves to descriptions involving weight and material; they had at that time been exposed to a unit on weight in their regular classroom work. Throughout the experiment there was greater preoccupation with weight in the third graders.

To some extent these explanations were merely enumerative of differences; offering the weights as an explanation is for some children merely descriptive. When asked to explain why one rod bent more than the other, the children may have listed differences without regard to their priority in probable causation. The reduction in the number of children who actually used the contrasts they named as a cause, when the task was to choose a contrasting pair, indicates that the explanations were not based on the same grounds as the later predictions. Of the 20 offering material difference as an explanation, 12 offered material difference as a basis of prediction. Of the 12 children who mentioned the difference between the two weights, five offered the same difference in a prediction. Of four mentioning thickness, three offered it in a prediction, and of three mentioning length, only one offered it in a prediction. Thus, there were differences in the attention to different attributes from the start, judging from verbal reports.

One difference was deliberately designed to contradict previous experience. The heavy weight stayed up and the light went down. Three children who misperceived the weight difference in the display pair, and corrected themselves or were corrected by the experimenter, all proceeded to use weight contrasts in the first pair, with the light weight expected to go down. This prediction regarding weight was intimately associated with the display
pair; if a child did not predict that a light weight will go down on the first pair, he never did. The misleading evidence was disruptive to five of the children. They vacillated in their predictions regarding the role of weight or repeated unsuccessful predictions about weight.

The use of a higher order statement regarding the relations between the rod and the weight occurred with six children at some point. The statement that light weights go on light rods and heavy weights on heavy rods is a natural inference from the display pair; three third graders and one second grader made this comment. For several third graders the persistence in pursuing this relation of congruence—or alternating it with testing a contrast relation—resulted in repeated failures and inability to sort out the independent effects of the weights and the characteristics of the rods.

The Successive Use of Information

It would normally be expected that successful predictions would be followed by repetition when possible, within the limited number of trials available in this study. Out of 19 instances of successful predictions on the first three trials, 15 repeated the same hypothesis. For three of these only were additional contrasts introduced to test new predictions while retaining the earlier contrast.

It is notable, however, examining the verbal content of hypotheses offered, that something special happened after success. While 95 per cent of the verbal hypotheses offered refer to variables the child had already mentioned, there were three children who broke this pattern and with no apparent basis in previous practice made completely novel hypotheses about certain of the variables they had not mentioned before. Each of these cases occurred after a successful prediction.

In the case of failure in prediction, a child could revert to familiar contrasts which have previously succeeded in his own trials or on the model pair. In 60 per cent of the cases the children did not do this; they repeated, with minor modifications, the prediction just offered.

The intervention of a forced explanation is likely to bring the child to observe factors in the situation that differ from the model he has been using. In this design, since all the children were asked to give explanations, there was no way of contrasting those who did with those who did not. Of 50 instances of explanations offered after failures, almost half involved comments about uncontrolled variables. The rest were divided evenly. Some children mentioned new information, usually about the materials whose relative strength they had not known; some reversed their hypotheses and in effect said they had been wrong. The remaining times they compared a current condition with an earlier one—for instance, this wood rod stays up because it's thick and the other one was thin. In effect, the last behavior could indicate observation of a new variable.

Thus, there are two criteria in explanations inferring attention to variables not used in making a prediction. One is noticing uncontrolled
variables, the other is comparison with earlier trials. Almost half of these cases involved variables that had been mentioned before on earlier trials but had been subsequently left uncontrolled. A fifth had been mentioned in describing the display pair, but the rest involved the observation of variables never mentioned before. The four crucial variables were mentioned with equal frequency in explanations, in spite of the marked discrepancies in describing the display pair. Thus, thickness and length, ignored at first, came to be noticed in explanations for predictive failures.

Once an explanation was offered, was the variable used systematically? The fact that almost half of the uncontrolled variables involved familiar aspects used earlier in explanations indicates one vicissitude—the children shifted their attention. But, if we examine only the new hypotheses in prediction that occurred immediately following a failure, it appears that half followed noting unfamiliar variables or new contrasts with old instances. Thus, while a child might notice an uncontrolled variable and then not use it or control it, it also happened that he used these cases in setting up novel hypotheses. Also, though he might appear to forget in that he failed to control a variable he just mentioned a minute earlier, the verbal interrogatory later revealed that he had not in fact forgotten at all. These observations, even when they were not repeated, were a source of information that might be drawn on immediately in the following hypothesis or control, might be ignored immediately but used in a later prediction, or might not be referred to again until the interrogatory.

The Use of Controls

One of the most striking ways in which a child’s approach to this procedure differs from a trained adult is that there is considerably less use of controls both on known and unknown factors. If the effect of a factor is known, it is damaging to let it vary in the wrong direction. If its effect is unknown, risk is minimized by holding the variable constant. If one examines the instances where there is no positive indication that the child was using a factor—that is, he used it neither in prediction or explanation—one finds that thickness was controlled only a little better than chance and length even less. In addition, we have seen that, even after a child has used a variable in an explanation, he may fail to vary it favorably or control it in a substantial proportion of cases. Over half the children made such errors, some several times.

Control could arise simply by chance—the child selected two rods and he happened to choose rods alike on a particular characteristic. Active control was rarely discussed by the children, except for a few instances of deliberate testing of hypotheses by second graders:

Peter (7;11): (A wood and a steel short thin rod. Heavy weights on both.) [Why did you use heavy weights?] On the wood, because the wooden one on the first pair went down. On the steel, because I want to find out which can hold it.
SUSAN M. ERVIN

(Again, two heavy weights on a short thin aluminum and long thick steel.) Because I want to see if they go down. The steel one will stay up.

Tom (7;0): (Heavy weights on a thin short steel and a thick long steel.) I want to see which one can hold it best. I think the thin one will touch bottom.

John (7;2): (Heavy weights on a long thin brass and short thin aluminum.) I'm going to find a short stick. Both are skinny, and this one is once and three-fourths longer than that one. The long one is going to go down.

Harvey (7;11): (Heavy weights on short thin aluminum and short thin steel.) I think aluminum bends easy, but I'm not sure. I'm trying to find out if the heavy weight would bend steel.

The chief competitor with the use of controls was a belief that, if a variable is effective, it should stand up in spite of the other variables at work. Another approach was control across pairs, violating the rules of the procedure.

Jean (8;9): (Two heavy on long thin aluminum and long thin brass.) I want to see if both go down or both stay up if they have two heavy ones on them.

(Two light ones on short thin steel and short thick wood.) I want to see what will happen if both are light. They both should go down because on the two heavy ones they both go down. [Why is that?] The two heavy ones were the same and they went down so maybe the two light ones are the same and they'll go down.

The method of testing by contrast is striking.

George (8;4): (Had consistently used heavy weights on the rod he predicted would go down. On the fourth trial put a heavy weight on a short thick brass rod to stay up and a light weight on a long thin steel rod.) [Why did you use the heavy weight?] I don't think it would bend down. [Why is that?] Because the brass rod is strong. [Yes, anything more?] It can hold a lot of weight. [Why did you put the light weight on the steel?] I think it might bend this rod because the rod is skinny. [Why didn't the steel rod bend as you thought it would?] It wasn't heavy enough. [Why did you use the light weight?] I wanted to see if it would bend it.

Betty (8;2): (A light weight on a long thick aluminum, heavy weight on long thick brass to stay up.) [Why did you use the heavy weight on the brass?] It's strong enough to hold it up I think. [Why did you put the light weight on the aluminum?] So it'll go down. It seems kind of light, as though it'll go down. I'm running out of wood.

(Two heavy weights, on a short thick wood to go down and long thin steel to stay up.) I'm picking the wood to put one of the heavy ones on so it'll go down and the steel is probably strong enough to hold it up.

Tom (7;0): (Light weight on a long thin brass, heavy on a long thick brass to stay up.) [Why are you putting the light weight on this one?] To see if it can hold it. This (thin) one will touch because it's not as strong.

(Light weight to go down on long thick wood, heavy to stay up on short thin aluminum.) [Why the weights?] I want to see if the aluminum
CHILD DEVELOPMENT

can hold the heavy weight. The wood will touch because it's not as strong as aluminum.

John (7;2): (A light weight to go down on a long thick steel rod, heavy to stay up on a short thin wood rod.) We want to find out if it's weight or longness or shortness. I think the skinny one will go down. Even if we put two heavy weights on the wood it wouldn't sink. Mostly they will stay but the steel will sink the farthest, the other one just a little.

Stephen (7;8): (A light weight on a short thin wood rod to bend and heavy on a thick long aluminum to stay up.) [Why the heavy weight?] The aluminum has to have more power to bend, more heaviness. [Why?] Aluminum is more strong than wood.

(Two heavy weights on a long thin aluminum and short thick wood.) It isn't very heavy or very long. And the aluminum will bend because it's long but it isn't heavy. I want to see if both will stay up or touch bottom.

"I want to see if . . ." just as often accompanied uncontrolled contrast as controlled contrast.

In sum, the notion of holding constant for purposes of testing did not seem to be the most frequent procedure. Holding extraneous variables constant did not at all appear to be in evidence; this process may require conscious analysis of the possible irrelevant variables. It would be of considerable interest to know what experiences will give rise to the use of controls. This experiment was not designed to explore this problem. It would be valuable to discover what range of comparisons the child considers logically equivalent—that is, whether it makes a difference to him, when he says he is testing a contrast, whether the items are controlled on supposedly extraneous variables or not. Piaget's observations that, when so questioned, children may repeatedly insist on tests favorable to their outcome rather than holding relevant factors constant is not completely borne out here; all three possibilities occur, and the reasons for the variations need to be discovered.

Motivational Shifts

The children were instructed to try to maximize difference—to make one rod bend and the other stay level. Yet, for a number of children the definition of the experiment seemed to change. The generating circumstances reveal to some extent the instigations to research.

Jean (8;9): This child was one who had described the light weight that went down on the display pair as heavy. When corrected, she sought a variety of other explanations, e.g., there is a magnet in it.

She used the light weight to go down twice and continued to offer far-fetched explanations. On the third trial she suddenly completely reconstructed the procedure and presented two rods with two heavy weights "to see if both go down or both stay up if they have the heavy weights." On the fourth she did the same with the light weights.

This child seemed genuinely troubled by the inconsistency with previous experience.

Sara (8;1), the child preoccupied with hypotheses about the relationship between the heaviness of the rod and of the weight, was another child who
SUSAN M. ERVIN

seemed more interested in explanations than in success. After a successful prediction that light rods and light weights would go down, she tested a prediction that light rods and heavy weights would stay up and a heavy rod with a light weight would go down. Her predictions were always framed as "to see if" phrases. Sara described the display pair as a light weight on a light stick and the first test pair was the same. It is not clear why she switched hypotheses. She failed in every subsequent prediction.

George (8;4): After several successful predictions, took a new departure on his fourth test. He presented the clearest example of risk-taking on the heels of success. Weight, thickness, and material strength had been successfully manipulated. After a trial in which he first commented that thickness mattered, he reversed the usual weight and material relations in order to test the role of thickness. He chose a thin steel rod with a light weight to go down and a thick brass rod with a heavy weight to stay up. When asked afterwards why he had chosen these weights and rods, he said, "I wanted to see if it would bend it." Thus, even though his earlier predictions and explanations had indicated that he knew that steel rods bend less than brass rods and heavy weights more than light weights, he made the contrary prediction in this case as a test of the role of thickness.

Peter (7;11): Chose two heavy weights on a thin short steel rod and on thin short wood "because I want to find out which one can hold." Later he put a heavy weight on short thin aluminum "to see if it goes down" and another heavy weight on long thick steel "because I want to see if it goes down."

Tom (7;0): Said he chose a light weight for a long thin brass rod "to see if it can hold it" and later a heavy weight on a thin short aluminum rod "to see if the aluminum can hold the heavy weight." On this trial he predicted the aluminum rod would stay up. In the next trial he put heavy weights on a thick long steel rod and a thin short steel rod and said, "I want to see which one can hold it best." His use of "to see" seems more to imply uncertainty than an active series of experiments.

Sandra (7;5): Emphasized material only on her first two trials and used heavy weights. On the third trial she again contrasted material, but used light weights. "I used light weights to see—I'm sure wood goes down with heavy weights." On the fourth trial, for the first time, she contrasted weights, using the heavy weight on the rod to go down and the light on the rod to stay up.

A series of experiments was conducted by two children:

Stephan (7;8): Noticed on his first effort that weight, material, and length were relevant—an aluminum rod had stayed up, and a short wood rod had bent only slightly with a light weight. On the next trial he chose a thin, long aluminum rod to bend and a short, thick wood rod to stay up, both with heavy weights. He said that both would bend because the wood rod "isn't very heavy or very long and the aluminum rod is long but it isn't heavy." He remarked that he wanted to see "if both will stay up or touch bottom." Note that he uses "heavy" both in the sense of material and thickness here—later on, a thick steel rod is called "heavier" than a thin one.

John (7;2): The most clearly experimental approach was used by this child who described all the characteristics of the display pair systematically and remarked that "the shorter it gets the harder it is to pull down." His consistent use of "we" in describing what he was about to do suggests an imitation of someone else's teaching. In the first contrast he said, "Let's find
CHILD DEVELOPMENT

a short stick. Both of these are skinny and this one is 1¼ inches longer than that.” On the second pair he remarked that he wanted to find out whether it was the weight or the thickness or the length that matters. He chose a long thick steel rod to go down and a short thin wood rod with a heavy weight to stay up, remarking that “even if two heavy weights were on the wood it wouldn’t sink.”

The children had been instructed to maximize short-term success. Their use of common predictions for both rods violated the rules, as did their refusal to predict. In some cases these deviations in favor of “to see if . . .” statements seemed systematic and to derive from uncertainty and a wish not to commit themselves; in others, they stemmed more from organized curiosity as indicated by deliberate manipulation of variables in the service of curiosity rather than maximum predictive success.

Verbal Questioning

The verbal questions were a test for verbal training primarily. There were two sets: an open-ended question about the characteristics of a rod that sinks, and the restricted questions with certain variables defined as controlled.

The open-ended question tapped the amount of practice in relevant statements about a variable. This would consist of mentioning a variable in relation to the display pair, in predictions, and in explanations. The nonverbal calculus of rewards based purely on the occurrence of a contrast with positive or negative reinforcement should not be effective unless the variable had occurred in an explanation.

Since virtually all the children began with material as a relevant variable, and none mentioned length, thickness is a good test for this hypothesis. There was no association with the number of contrasts involving thickness predicted, or reinforced, or in the consistency of the reinforcement pattern across all instances seen. But, if one examines the children who offered thickness as an explanation in some terms during the experiment, then, with only three exceptions, they mentioned thickness in the open-ended question. The relationship is significant beyond the .01 level by Χ².

To predict what children will say during questioning, it is therefore more pertinent to know what they have said before than to know what they have seen, or at least looked at.

A second set of questions asked what kind of rod would go down and what would stay up, if certain conditions were restricted. With two exceptions, the children who offered thickness as an explanation for this question had two characteristics; they all had separate terms for thickness—that is, did not merge it with length or material in a term like “heavy”—and either commented about it on the display pair or used it in constructing new comparisons. The same properties hold for children who offered thickness as an explanation when asked “What kind of a wooden rod would stay up and what kind of a brass rod would touch bottom?” All
SUSAN M. ERVIN

who had separate terms for thickness and constructed new comparisons with it mentioned thickness at this point. In addition, two out of three other children who had noticed thickness and used it in explanations, but never in hypotheses, offered it in this question. Two children who had described short rods as thick offered thickness as an explanation at this point.

The last two questions repeated the display comparison, verbally, and then hypothesized a change in length and thickness and asked the outcome:

If we had a long, thin, wood rod with a light weight and a short thick brass rod with a heavy weight, what would happen?

Suppose we made the wooden rod shorter and thicker and the brass rod longer and thinner?

There are three possible outcomes, mutually exclusive, if the children are consistent. (a) The child predicts that in both pairs the rod holding the heavier weight will go down. (b) The child predicts that in both pairs the wood rod will go down. (c) The child predicts that the longer or thinner rod will go down.

Material, it will be recalled, was the first thing the children were likely to notice as differentiating the rods. This is a difference they have experienced before as relevant to the breakability and flexibility of toys, so therefore it is probably, to start with, the most obvious variable. Yet only six children cited material as important in making their predictions in this case.

The chief competitor to material as an explanation, for the third graders, was weight. Seven of the children mentioned weight, four exclusively, as the determining factor. Four of the children had been preoccupied with testing hypotheses about weight, in some instances about the relation between heaviness of the rod and of the weight. The three third-grade children who did not mention weight as a determinant included one who had decided it was irrelevant during his trials; George (8:4) who after three successful predictions that the heavy weight and wooden rod would go down became more interested in thickness and made a prediction in which the heavy weight was to stay up, which it did; and Betty (8:2) who ignored weight during all but the first pair and concerned herself entirely with the strength of the rod.

Twelve children used a thickness explanation, some modifying it by some other effect. These were all children without terminological difficulties about the thickness variable, who had used thickness in some form as a hypothesis or commented about it in explanations. The children who failed to use thickness in their hypothetical explanations either had never noticed it or called length thickness or thickness heaviness.

Three variables, then, appear to be relevant to the verbal responses of the children and to their singling out of certain variables as being effective. One is the age or grade of the children. The older, third grade children concentrated on weight more than did the others. Another is the lack of
CHILD DEVELOPMENT

terminology confounding several variables. A third is whether there had been some prior verbal emphasis on the variable in the form either of prediction, explanation, or both. The actual calculus of reinforcement for choices is not related except insofar as prediction failures lead to explanations referring to particular variables.

Successful Acquisition of Information

If the verbal answers and explanations be examined in order to judge whether each child could predict for an isolated variable the direction of its effect, it appears that three second-graders and six third-graders could probably have been successful with all four variables. A child was judged to “understand” a variable if he did at least one of the following: correctly used the variable in response to verbal questioning; used it correctly in hypotheses, not followed by explicit reversal; used it as a facilitative variable following an earlier explanation, without necessarily mentioning it in his hypothesis; or offered it as an explanation for an effect and subsequently either controlled it or used it facilitatively.

More of the third-graders than second-graders succeeded in discriminating the effects of all four variables, and in each grade the boys’ performance was superior to the girls. The three children who only understood two of the variables were girls. There was no difference in Kuhlmann-Anderson IQ between those who succeeded by the above criteria and the others.

It is enlightening to examine the 11 cases of failure to extricate all four variables. Donna (8;9) and Peter (7;11) both confused length and thickness and therefore did not separately note them. Donna systematically chose thick rods to stay up and thin to go down, though her experimental encounters had been with length contrasts. Peter explained a contrast of length as one of thickness and subsequently manipulated thickness and left length uncontrolled. In the questioning he chose a long thin rod to go down and short thick one to stay up, referring to thickness only.

Alice (8;0) did not notice length, or manipulate it, but persistently used “light” and “heavy” to describe contrasts of thickness or length. When asked what kind of wooden rod would stay up and what kind of brass rod would go down, she picked out a thin short brass rod and a thick long wooden rod and said that only the second was heavy and would go down. Sara’s extreme terminological confounding did not prevent her from extricating in her choices all four factors.

Two second-grade children happened to make successful predictions whenever the unnoticed variable was left uncontrolled and thus were never under circumstances of noting the extra factor. In the remaining four cases in the second grade, the children did not offer the uncontrolled variable at issue as an explanation when predictions failed. Instead, they gave some other explanation.

Jean (8;9, IQ 112) was the only child to offer rather far-fetched explanations for failures, such as the angle of the holder. She became so highly
focused on the issue of the rule about the weights that she varied widely in her use of material and thickness and never spoke of them to account for failures.

Ann (8;9, IQ 101) showed signs of considerable confusion. She first predicted that a steel rod with a light weight would go down and a wood rod with a heavy weight stay up. When the opposite happened, she said she really had expected that and said that something light “will hold on the heavy.” But on the next series she again chose a light weight to go down and persisted thus throughout. She failed to learn from her erroneous weight predictions. She did not take thickness into account either, and she seemed only to notice the “heaviness” of the rod material. She concluded several times that heavy rods and light weights go down, though her verbal responses were inconsistent during the questioning.

At the other extreme was Betty, (8;2, IQ 122) who, through noticing the uncontrolled variables, added later to her observation of material contrasts weight and thickness. She had left length uncontrolled three times and only during the verbal questioning figured out the last variable:

[Now I want you to tell me what kind of a wooden rod would stay up, and what kind of a brass rod would go down.]
Well a thin, short brass one would go down.
[Why?]
Because it was thin and it was short and it didn’t have so much weight to it. And a fat, long wooden one, because it would have a little more weight . . . (inaudible). I was just going to change it to short.
[Why?]
Because I think it would have a little more short than long.
[Why? I don’t understand.]
Because if it was long and kind of fat at the end of the weight there would be more but if it were shorter there would be so much weight at the end and I think it would be a little stronger to hold it up.
[What do you mean if it . . . what would happen if it was long?]
If it was long it would be something like this and at the end it would be the weight and it would be because it’s long and just one at one end and one weight at one end it would be too much for it. It would go down. But if it was a little short fat one like this one then it would stay up. I think because it would be more closer to the other part and it wouldn’t be too heavy. Well it wouldn’t be too heavy the weight.
[What do you mean if it was closer?]
Well actually if it was closer it would be more closer to the end and it would probably be more closer to this where it was sticking in into and then it would just be staying up a little better. I can’t explain it too good either.

In sum, nine of the children succeeded in identifying the direction of influence of all factors in the limited trials available. The failures which were most frequent were those, all in the second graders, due to overlooking uncontrolled variables in offering an explanation. Next in frequency were confusions of terminology which prevented discrimination of several
variables from each other. Repetition of unsuccessful hypotheses and focusing on too narrow a range of possibilities also occurred. Two children were too successful to learn—that is, they happened to choose contrasts which were successful even though they failed to take several variables into account.

**Summary**

Twenty second- and third-grade children were presented with a task in which they could succeed best by discovering the relation of four variables to the flexibility of rods. The following generalizations emerged from a content analysis of the choices, hypotheses, and explanations of the children:

1. A number of children confused several variables verbally. This occurred more often in the younger children and interfered in a few cases with successful solutions.

2. There was a difference in the probability that children would make predictions about the different variables or use them in explanations. The fact that a variable might be the only one left uncontrolled did not necessarily result in its early appearance in an explanation of prediction failures. The intrinsic "salience" of the variable seemed more important than whether or not it was the only variable uncontrolled.

3. The older children made more complex hypotheses, stating relationships between the properties of the rod and of the weight which was placed on the rod, rather than isolated statements about the relevance of each variable alone.

4. New variables most often were mentioned first in explanations of failure, but determined choices as often after success as after failure. Success did increase the probability that the following verbal predictions would mention a new variable for the first time.

5. After noticing that a variable was related to flexibility, the children frequently did not control it or vary it in a direction favorable to their prediction. This was not due to forgetting, since such variables often were mentioned later in response to hypothetical questions.

6. Control of unfamiliar variables or of familiar variables for purposes of experiment was rare.

7. Children who stated they were testing hypotheses sometimes controlled known variables, sometimes varied them favorably, and sometimes deliberately varied them in a direction opposed to the prediction. They described the last technique as if it were a test of the strength of the variable.

8. Some children altered the definition of the task, by refusing to make predictions or by testing hypotheses rather than trying to maximize successful predictions as instructed.

9. When the children were presented with hypothetical questions, the actual contrasts they had seen were not predictive of the variables they men-
tioned as relevant. These could be predicted from the explanations and predictions they had offered—that is, from their previous verbal behavior—and from their use of separate terminology for the different variables. In addition, the third graders systematically emphasized the weights more often.

10. According to a criterion of knowledge regarding each variable, three second graders and six third graders extracted the relationship of all four variables to flexibility. Failures appeared to be due to repeating unsuccessful predictions, focusing on a narrow range of hypotheses, terminological confusion, and failure to note an uncontrolled variable in giving an explanation. The last was most frequent.

References


