The Development of Understanding as an Indirect Memory Strategy

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Ten-through 14-year-old children were presented a complex task designed to elicit a variety of memorization strategies. There was a curvilinear relation of age and memory performance on the task; 12- and 13-year-olds took many more trials to memorize the items than did younger or older children. Subjects reported using strategies ranging from attempts at rote memorization through attempts to avoid memorization altogether by deriving some systematic understanding of the task. Differences in reported strategies were related to age and to differences in memory performance. Results are discussed in terms of a general development of the use of understanding as a deliberate, indirect memory strategy.

Whereas much is known about changes in problem solving and reasoning during adolescence (see Neimark, 1975), there has been little study of the implication of these changes for memorization strategies. Memorization strategies that have been studied with adolescents seem straightforward extensions of concrete operational abilities to classify, seriate, and manipulate images of objects (Neimark, 1976; Rohwer, 1973). However, one could also expect strategy advances brought about by the formal operational child's new found expertise in understanding systems of variables by relating occurrences and nonoccurrences of events to higher order principles, propositions, or systems. The present research is concerned with a type of memory strategy which qualifies as a candidate here; it

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seems to require some formal understanding of the relation of instances to general principles for its deliberate execution. This strategy can be described as one of foregoing attempts at rote memorization in order to "understand" the material, with the expectation that "memory" for particular instances will follow automatically from knowledge of the general principles (or at least follow with much less rote memorization). Intuitively, this strategy is one employed frequently by adults, partly in order to avoid the tedium of memorization more narrowly construed. This approach will be referred to as an indirect, understanding strategy.

In the above description attempts at rote memorization denote strategic activities directed at producing an exact copy of the to-be-remembered stimuli. These would include activities like rehearsal and grouping which produce "episodic memories" (Tulving, 1972) or "memory in the narrow sense" (Piaget & Inhelder, 1973). Information can also be committed to and retrieved from memory not as specifically stored items, but as the result of the ongoing meaningful interpretation and understanding of events; "semantic memory" (Tulving, 1972) or "memory in the wider sense" (Piaget & Inhelder, 1973). These two roughly distinguishable types of memory are interwoven in complex ways. Further, the growing child's understanding of his own activities in relation to these types of memory must be interwoven at some point in development.

While it seems clear that some forms of semantic memorization (processes of understanding which also result in storage of information) must be present from birth, little is known about the development of strategies to enhance these processes (Brown, 1975). The developmental picture for rote memorization activities is more fully studied. Preshool children do not seem to understand the special mnemonic demands of tasks requiring exact rote recall (Appel, Cooper, McCarrel, Sims-Knight, Yussen, & Flavell, 1972). Children younger than 6 or 7 do not employ memory strategies (especially rehearsal, practicing, grouping) that are designed to ensure rote memory. Older children become increasingly proficient at this class of memorization techniques (for reviews see Brown, 1975; Chi, 1976; Kail & Hagen, 1977). We propose a further development. At some point after children understand the demands of rote memory tasks and the usefulness of rote memory strategies, they must realize that tasks requiring exact recall do not necessarily have to be met with rote memory strategies. Accurate knowledge of a presentation can often be generated from some general conceptualization; a person can use semantic understanding processes as a means to rote memory ends.

If this assumed development occurs, then at certain ages it should be possible to demonstrate differences in memory strategies proceeding from direct attempts at rote memorization of specific items (use of rehearsal, for example, to encode discrete items) to efforts at deliberate memorization which are indirect, relying on conceiving some system or structure

from which specific items can be derived. The present investigation was based primarily on this hypothesis. Secondarily, as outlined in the opening paragraph, we hypothesized that use of such an indirect understanding strategy should be temporally related to the attainment of formal operations.

An empirical demonstration of developmental differences in employing an indirect understanding strategy seems complicated by a variety of factors. Deliberate use of an indirect understanding strategy would depend on more than just realizing its usefulness. How well a person is able to devise a higher-order system and able to appraise the respective efforts required in this approach and rote memory approaches would be influential. Further, certain item sets do not lend themselves to higher order solutions and certain task procedures do not facilitate an exploration for general principles. There must also be intricate interrelationships of memory in the narrow and wider senses that would obscure performance in any concrete situation. The deliberate derivation of a conceptual system often requires (at least initially) exact memory of some of the items or task dimensions; on the other hand, seeking to understand a presentation may result in such exposure to the items that they are rote memorized anyway. In short, a host of factors must mediate use of an understanding strategy, and a full elaboration of the present hypothesis requires a comprehensive theory of strategic behavior, executive monitoring of such behavior, and the relation of these to numerous task variables. In advance of such a theory, however, a preliminary exploration of the use of understanding to achieve rote memorization seems desirable.

Finite mathematical structures such as groups with a small number of elements have been successfully taught to children (Bruner, 1966; Dienes & Jeeves, 1965; Sheppard, 1974). From working primarily with adults, Dienes and Jeeves reported that the combinations of elements in small groups can be learned with or without an understanding of the underlying structures and axioms. For the present study a simplified group task embodied in 16 combinations of lights was devised. The child was to learn the combinations, and at the two extremes this could be accomplished by direct memorization or by comprehending something of the group structure of the task. In general, an understanding strategy has the potential advantages of being less tedious, more challenging, and also more efficient in the sense that general principles encompassing all the items may be devised by studying only a subset of them. Thus, on the present task, differences between approaches adopted in order to learn the combinations might be evident on (a) measures of time or trials taken to learn the combinations, (b) measures of subjects' ability to give correct predictions for items not previously tried, and (c) subjects' reports of rules, systems, or mnemonics used to remember the combinations.

METHOD

Subjects

The 236 children tested were drawn from two primary and two corresponding secondary school districts in Canberra, Australia. There were initially 48 children in each of five age groups, but the data from four 12-year-olds were discarded because of inaudible tape recordings. Each group represented a 6-month age range, with 6-month gaps between groups, and each contained approximately equal numbers of boys and girls. The five groups were 10-year-olds (aged 9 years, 11 months to 10,5; M = 24, F = 24), 11-year-olds (aged 10,11 to 11,5; M = 23, F = 25), 12-year-olds (aged 11,11 to 12,5; M = 22, F = 22), 13-year-olds (aged 12,11 to 13,5; M = 24, F = 24), and 14-year-olds (aged 13,11 to 14,5; M = 24, F = 24).

Apparatus and Task

As indicated in the introduction, the choice of task for the present research was constrained in a number of ways. The child needed free access to the task so that he could adopt his own approach and explore for general principles if he wished. Yet the task needed a trial by trial nature to provide a running measure of memory. The task had to be difficult so that rote memorization would be strained yet engaging so that children would persevere in attempting to learn it. Foremost, the task needed to be rich enough to result in the use of a range of strategies. A version of Dienes and Jeeves' (1965) cyclic four group task, modified to make the apparatus and method of presentation suitable for use with children, was devised.

The child saw two smaller panels of lights and switches, connected to a larger display of four colored lights (as shown in Fig. 1). The two smaller (35 × 18 cm) panels, and the one larger (45 × 38 cm panel) each had, in a left to right row, a yellow (Y), green (G), blue (B), and red (R) light. The two smaller panels had one switch below each of the four lights. If a single light was switched on in only one of the smaller panels then the same light lit up on the small panel and on the larger panel. If a combination of one light in each of the smaller panels was on then each light lit up in the small panels but a specified resultant light came on in the large panel. Table 1 shows the resultant large panel light for every combination of lights from the two smaller panels. This arrangement of combinations defines a cyclic four group (see Dienes & Jeeves, 1965, for further discussion). If the large panel's lights are considered a circle (with Y following R) then each combination of one light in either small panel with all the lights in the other small panel yields a unique but complete turn around the circle. In
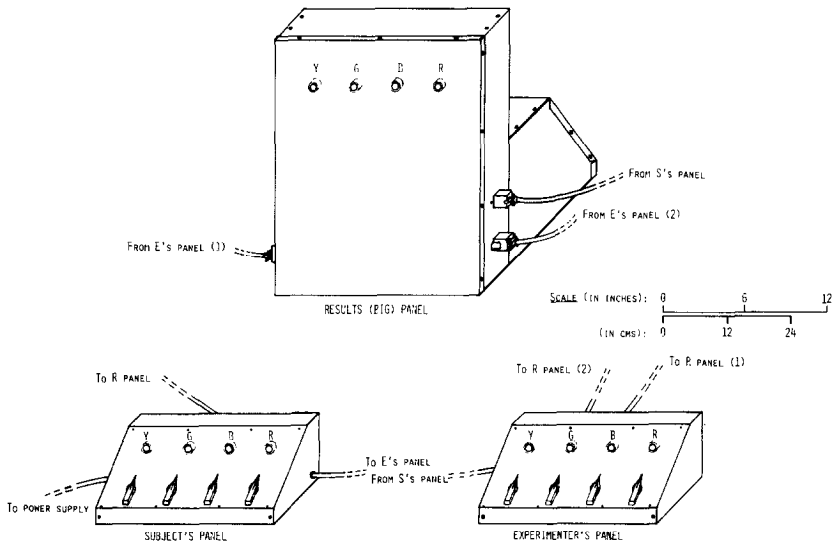
FIG. 1. Apparatus for experimental task.

addition, all of the group properties hold: closure, an identity element, and the commutative, inverse, and associative laws.[1]

The group structure of the task means that there are a number of higher order conceptions that can be used to achieve an understanding of the combinations of lights. It was this property of the task and not its group structure per se that interested us for present purposes. The following two systems (as well as others) capture all the combinations:

Cyclic. The four lights are seen as lying on a circle in clockwise order Y,G,B,R. The lights represent the following moves: Y — no move; G — a move of one position clockwise; B — a move of two positions clockwise; R — a move of three positions clockwise. (Equivalent counter-clockwise moves may be substituted for the clockwise moves).

Numerical. The lights are seen as a group of integers, Y = 0, G = 1, B = 2, R = 3. The numbers combine under addition, and any number

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[1] Specifically, given a set of elements (Y,G,B,R) and a set of combinations defined in Table 1, then: (1) Closure: Any combination of two elements always results in an element in the original set (e.g., G + B = R). (2) Identity element: There is an element, Y, which when combined with any second element results in that second element (e.g., Y + R = R). (3) Commutative Law: For every combination of any two elements, A + B, then A + B = B + A (e.g., G + B = R, and B + G = R). (4) Inverse Law: For each element there is an element which when combined with the first results in the identity element (e.g., G + R = Y, B + B = Y, etc.). (5) Associative Law: For any three elements (A,B,C), A + (B + C) = (A + B) + C (e.g., G + B = R, then R + R = B, so (G+ B) + R = B; also B + R = G, then G + G = B, so G + (B + R) = B).

TABLE 1

Panel 2
(Experimenter's)

		Y	G	B	R
Panel 1 (Child's)	Y	Y (1)	G (2)	B (3)	R (4)
	G	G (5)	B (6)	R (7)	Y (8)
	B	B (9)	R (10)	Y (11)	G (12)
	R	R (13)	Y (14)	G (15)	B (16)

greater than 3 is equal to the remainder after its division by 4. (Many other numerical systems are possible).

In addition to the above conceptualizations which predict every combination, rules could be discovered that would predict some combinations, given knowledge of some other(s). Two obvious ones depend on group axioms; first the commutative law (for a given combination, e.g., B + R, the same outcome results if the lights are reversed in the smaller panels, R + B) and secondly the identity element (the Element Y leaves any element it is combined with unchanged, e.g. Y + B = B).

Procedures

In general, the child's task was to be able to state from memory which combinations caused which resultant lights to come on. The child was free to learn the task by trying whichever combinations he chose, each tryout of a combination defining a trial. In addition, to probe his learning of the task, the child was systematically tested on his recall of all the combinations at periodic intervals. Learning and testing proceeded until criterion performance was obtained.

More specifically, each child, tested individually, was told "This is a game with lights; I want you to find out the rules of the game as we play it." One panel was labelled the child's panel, the other the experimenter's panel. The child was shown that lights switched on in the small panels made the lights go on in the big panel. Then the child was told "The game is to find out the rules which tell you which light goes on in the big panel when one in your panel and one in mine are put together like this" (experimenter demonstrates). The child was shown that he was free to try out whichever combinations he wished, then told "When you can tell which light is going to come on in the big panel for all the combinations in the small panels the game will be finished." In trying the lights the child

was required to predict the outcome of any combination in advance of seeing it. This gave a trial by trial index of his progress on the task.

Each child was encouraged to try the combinations as many or as few times and in whatever order he deemed best. This freedom meant the child would not necessarily try all the combinations; therefore the running records do not provide a complete picture of a child's knowledge. To have a comprehensive measure of knowledge of the task each child was tested periodically on all the combinations. Rather than test a child's predictions in a random order (possibly confusing those children with a systematic approach to the task) predictions were tested in order 1–16 in Table 1. This meant that the periodic testing could structure the task for the child. Thus it was important (a) to conduct the tests late in learning (so as not to interfere with early self devised strategies), and (b) to test each child when he had learned a given number of combinations (so no child's learning would be enhanced or constrained merely by a late or early test). Our goal was to first test each child at that point where he had learned about 10 of the pairs. Pilot results suggested that a child first be tested at whichever of the following events occurred first: (1) the child said he knew all the combinations (usually happening only late in learning), (2) he had worked on the task for 25 min, or (3) it was clear from the running records that the child probably knew eight combinations (the chief index being repeated successes on some combinations). Second and third tests, if needed, were provided (1) when the child said he was ready or (2) after 15 min of learning attempts, whichever occurred first. No child required more than three tests.

Each child continued in the learning task until he could correctly predict 12 or more of the 16 combinations on a systematic test. Pilot testing suggested this learning criterion since working to a criterion of 16 correct meant some children became uninterested. The children were told to learn all the combinations but the task was terminated at the first test on which they knew a minimum of 12 of the 16. A child's prediction on each learning or test trial was recorded, and the time spent on each phase of learning and testing was recorded.

After the test on which the child reached criterion, responses to the following questions were tape recorded:

(a) "How did you remember what lights would go on in the big panel? Did you have any special ideas or rules which helped you to remember?" Follow up questions probed answers to this question.

(b) "Suppose you have a G light on in your panel (put it on) and you want G to stay in the big panel, what would you ask me for? (Y) How did you know to ask me for that one?"

(c) "Suppose you have a G light on in your panel and you want to get R in the big panel, what would you ask me for? (B) How did you know to ask me for that one?"

TABLE 2
MEAN NUMBER OF CORRECTLY PREDICTED COMBINATIONS ON THE VARIOUS TESTS

	Age				
	10	11	12	13	14
Test 1:	10.58	11.71	11.16	10.48	11.71
	(48)*	(48)	(44)	(48)	(48)
Test 2:	13.86	13.22	12.81	12.87	13.91
	(35)	(22)	(27)	(30)	(22)
Criterion:	14.00	13.44	13.43	13.56	13.96
	(48)	(48)	(44)	(48)	(48)

* Numbers in parentheses refer to number of subjects in each group.

(d) "Suppose you have a R light on in your panel and you want to get B in the big panel, what would you ask me for? (R) How did you know to ask me for that one?"

(e) "Suppose you have a B light on in your panel and you want to get R in the big panel, what would you ask me for? (G) How did you know to ask me for that one?"[2]

RESULTS

Memory performance. The logic of our procedures required that the systematic tests be given to the children when they had learned approximately the same number of items. Table 2 shows the mean number of items correct on the systematic tests of the 16 combinations. Test 1 includes each child when given his first test; Test 2 includes each when given his second test, for those children given a second test; criterion includes each child on the test on which he reached criterion. An Age (5) × Sex(2) × School(2) analysis of variance on the data for Test 1 indicated only a main effect of Age [$F(4,216) = 3.50, p < .01$]. Similar analyses indicated only a main effect of School on scores at Test 2 [$F(1,216) = 5.84, p < .05$]; and an Age × School interaction on scores at criterion [$F(4,216) = 4.03, p < .01$].

If children received the systematic tests when they had correctly learned the same number of combinations, then the measures of memory performance become how many trials and/or how much time it took the child to reach this level of performance. However, as the above analyses indicate, we were only partially successful in testing every child at the same point in learning. Thus, succeeding analyses on the time and trials measures were conducted using a covariance analysis, with number correct on the relevant test the covariate. We will present only the Test 1 and

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[2] Details of the questioning procedures can be obtained from the first author.

TABLE 3
DATA FOR TRIALS AND TIME MEASURES

	10	11	12	13	14
Trials					
Mean number of trials to Test-1	26.52	25.83	42.41	34.10	19.81
	(12.04)*	(14.24)	(24.80)	(26.08)	(6.03)
Means adjusted for number correct on Test 1	27.49	24.97	42.36	35.04	18.82
Mean number of trials to criterion	68.54	58.69	81.14	75.04	49.04
	(19.91)	(24.47)	(27.70)	(29.99)	(13.92)
Means adjusted for number correct on criterion	67.65	59.37	81.84	75.79	48.63
Time					
Mean number of min to Test-1	9.97	9.35	12.80	11.05	6.88
Mean number of min to criterion	22.02	19.09	22.60	22.13	14.28

* Numbers in parentheses indicate standard deviations.

criterion data since on these measures there is data for every child and since the Test 2 results are parallel. For Test 1 the performance measures were number of trials until the first test and time until the first test; for criterion the measures were total number of trials spent in learning (including those on previous tests since these provide valuable learning information) and total time spent in learning (including time spent on previous tests). Table 3 presents the data for Test 1 and criterion. In each case the measures of time and trials are highly correlated ($r = .82$ for Test 1; $r = .77$ for criterion). We will report analyses only on the trials data; analyses on the time measures yield essentially the same results. An Age (5) × Sex (2) × School (2) covariance analysis on the number of trials for Test 1 indicated an Age × School interaction [$F(4,215) = 3.73, p < .01$] and a main effect of Age [$F(4,215) = 11.51, p < .001$]. An identical analysis on number of trials to criterion indicated an Age × School interaction [$F(4,215) = 3.81, p < .01$] and a main effect of Age [$F(4,215) = 14.89, p < .001$]. The Age × School interactions are accounted for by the fact that 13-year-olds in one school were much better than those in the other school.

As can be seen by the data in Table 3 the Age effect is curvilinear in form. A test for curvilinear trend on the trials to Test 1 accounted for a significant portion of the Age effect [$F(3,215) = 15.16, p < .001$] with a

nonsignificant linear residual [$F(1,215) = .62$]. A test for curvilinear trend on the trials to criterion accounted for a major portion of the Age effect [$F(3,215) = 18.32, p < .001$] but in this case there was also a significant linear residual [$F(1,215) = 4.19, p < .05$]. As can be seen in Table 3, variances also differed at the different ages: (for trials to Test 1 F max $=$ 18.71, $p < .01$; for trials to criterion Fmax $= 4.64, p < .01$).

Strategy reports. Based on the questioning at the end of learning it was possible to identify four general strategies which subjects reported using to learn the combinations. These four levels essentially represent mnemonic devices which subjects had arrived at by the end of learning.

A. Rote memorization: Subjects responded "I practiced till I knew them, I said them to myself," etc. in response to part (a) of the questioning, and responded "because I remembered them" as explanations in parts (b)–(e) of the questioning.

B. Grouping sets of combinations to facilitate rote memorization: The most common groupings reported were: (i) yellow with other colors by a statement such as "Y + G = G, Y + B = B, Y + R = R; they're the easy ones;" (ii) the double ones (Y + Y, G + G, B + B, R + R) by a statement such as "two of the doubles make yellow and two make blue;" (iii) the six combinations of R,B, and G by a statement such as "any two of RBG together make the other one except R + G which makes Y" (Note: the exception was often overlooked; or (iv) idiosyncratic groupings such as "the light ones and dark ones" or "the ones I like best." Children in this category remembered some combinations purely by rote (Level A above) and others by combining items to facilitate rote recall.

C. Discovery of a higher order principle for some subset(s) of the combinations: The principles reported were (i) use of the identity element, by a statement like "yellow with anything (including itself) leaves it the same"; and (ii) use of the commutative principle, by a statement like "it's always the same back to front." Subjects in this category typically discovered and used one of these rules; a few discovered both. The remaining combinations were remembered by rote (as in A above) or by grouping (as in B).

D. Discovery of a higher order system that captured all the combinations: All the subjects in this classification reported structuring the combinations into the rows and/or columns of the matrix in Table 2. Thus, at the least, the subject saw that there was a pattern to the results when each light was combined consecutively with all other lights. In addition, almost all subjects stated some generalizations about the nature of the pattern. These generalizations were almost exclusively of two types. (i) Discovery of cyclic operations: The simplest expression of this conceptualization was "The answer goes around the panel; with Y it starts at Y, with G it starts at G," and so on. More complex versions were expressed in terms of cyclic moves: Y moves any light 0, G moves it 1 to the right, B moves it

TABLE 4

NUMBERS OF SUBJECTS REPORTING THE VARIOUS STRATEGIES AT THE DIFFERENT AGES

	10	11	12	13	14
A	9	5	13	9	3
B	27	21	15	18	5
C	9	13	13	5	11
D	3	9	3	10	29

2, R moves it 3. (ii) Use of number operations: For example, addition with Y = 0, G = 1, B = 2, R = 3, as explained before.

It was possible to classify all subjects into one of these categories.[3] The first author rated all the transcripts. The second author rated a random sample of 24 subjects' transcripts (10% of the total sample). Rater reliability (agreements divided by disagreements plus agreements) was .88. All disagreements were rated in adjacent categories; (e.g., B by one rater, C by the other).

Table 4 shows the distribution of these strategies over age [$\chi^2(12)$ = 66.86, $p < .001$]. This table can be best understood by the following three partitions. First, there is a significant relationship of strategy type to age if subjects using Strategy A are compared to those using all other strategies [$\chi^2(4) = 10.78, p < .05$]. This effect seems due to the fact that 12-year-olds use proportionately more A strategies than children at other ages [$\chi^2(1)$ for A vs other strategies and 12-year-olds vs other ages = 5.54, $p < .02$]. Second, if subjects using Strategy B are compared to those using C or D, there is a significant relationship of strategy type to age [$\chi^2(4) = 30.57, p < .001$]. This effect is due to the fact that 14-year-olds use proportionately more C and D strategies than children at the other ages [$\chi^2(1)$ for B vs C and D strategies combined and 14-year-olds vs other ages = 23.43, $p < .001$]. And third, if subjects using C strategies are compared to those using D strategies, there is again a significant strategy type to age relationship [$\chi^2(4) = 23.25, p < .001$]. This effect is due to the fact that 13- and 14-year-olds use more D strategies than the other ages [$\chi^2(1)$ for 13- and 14-year-olds combined vs the other ages and for D vs C strategies = 19.47, $p < .001$].

[3] The most difficult distinction to make was between a grouping together of combinations involving the yellow light, which was merely a mnemonic device (Strategy B); and one which indicated that the general identity role of yellow was understood (C). We used as a distinguishing feature the fact that children who were grouping together combinations of Y + G, Y + B, Y + R as "easy to remember," failed to add Y + Y to the list. The Y + Y combination was most likely to be said to belong to the "double ones," which were a different matter. On the other hand, children who were judged as seeing these combinations in terms of the identity role of Y ("The yellow light makes no difference to the light it goes with") applied this rule "even when it goes with itself," and seemed to see this as a necessary part of the system.

Relation of strategies and performance. If subjects' reports at least partially reflect their attempts to learn the combinations, strategy reports should account for performance. Age (5) × Strategy(4) analyses of covariance were performed on both trials to Test 1 and trials to criterion, with number correct on Test 1 and number correct on criterion the respective covariates. Because of the significant relation between age and strategy reported above the two factors are decidedly nonorthogonal. Appelbaum and Cramer's (1974) procedures for nonorthogonal analyses were used. On trials to Test 1 the analysis indicated no interaction but a main effect of Age [F, for Age eliminating Strategy $(4,215) = 9.07, p <$ .001] and a marginal main effect for Strategy [F, for Strategy eliminating Age $(3,215) = 2.46, p = .06$]. The means for Age are reported in Table 3; the means for Strategy are: A $= 40.21$, B $= 29.50$, C $= 27.92$, D $= 23.06$. On trials to criterion the analysis indicated a significant Age × Strategy interaction [$F(12,215) = 1.83, p < .05$], in addition to main effects for Age [F, for Age eliminating Strategy $(4,215) = 9.80, p < .001$], and for Strategy [F, for Strategy eliminating Age $(3,215) = 9.16, p < .001$]. The means for Age are in Table 3 and the means for Strategy are: A $= 87.13$, B $= 67.68$, C $= 62.95$, D $= 54.02$. The Age × Strategy interaction indicates that children at the different ages used a strategy with differing degrees of success and that this pattern of success differed from strategy to strategy. According to Newman-Keuls tests ($p < .05$) Strategy D produced uniformly good performance at all ages. When used by the 13-year-olds Strategy C produced significantly poorer performance than when used by the other ages. With Strategy B, 12-year-olds performed worse than the other B-strategy children. Strategy-A produced poorest performance of all the strategies at every age, however, in using this strategy 11-, 12-, and 13-year-olds performed more poorly than 10- and 14-year-olds.

Performance on untried combinations. In learning, each child could try whichever combinations he wished. Thus, on Test 1 it was possible for each child to be tested on (a) combinations he had never tried before in learning, (b) combinations tried in learning but never predicted correctly, and (c) combinations both tried and predicted correctly (at least once) in previous learning. On the average each subject had 4.8 Type A, 3.6 Type b, and 7.6 Type c combinations at Test 1. Subjects just memorizing ought to test poorly on combinations never tried before, since there could be no memory of those combinations. Subjects formulating a higher order system need not have seen the combinations to predict them correctly. To test this hypothesis the percent correct on Test 1 of c combinations minus the percent correct of a combinations was computed for each child. A high positive score on this measure indicates better relative performance on combinations previously predicted correctly than on untried combinations; a lower score indicates better relative performance on untried combinations. Seventeen subjects were eliminated because they had no a

combinations. An Age (5) × Strategy(4) covariance analysis indicated no interaction, no effect of Age, but a significant effect of Strategy [$F(3,198)$ = 3.18, $p < .05$]. The means for strategy were A = 40.79, B = 34.35, C = 25.09, D = 21.73, reflecting increasing relative success on the a combinations going from A to D. (Note: the results are Appelbaum and Cramer's (1974) Pattern 7 of results).

DISCUSSION

The results are best discussed as preliminary not definitive findings; the research was exploratory in conception, task selection, and procedures. A deliberate decision was made to allow subjects the maximum freedom of approach consistent with obtaining evidence of learning to a standard criterion. This was important in that it enabled subjects to display a rich variety of approaches to the problem. It also resulted in a degree of imprecision in procedures, especially as related to the timing of the systematic tests. In this respect our procedures were imprecise but informative; in another respect they were precise but surprisingly uninformative. Systematic trial by trial records were kept of subjects' choices of combinations for learning the task. These records showed that some subjects tested principally items that they already knew the answer to, interspersing these gradually with unlearned combinations. Others tested only those they were not yet sure of. Neither of these characteristics corresponded with developmental patterns of performance on the task or with reports at the end of learning. This was also true of more complex aspects of the learning records such as the tendency to try a number of combinations in succession, all involving one light. Thus, the present analysis of strategies relied on the admittedly indirect self-report measures obtained at the end of learning. Nevertheless, the data offer a developmental picture which seems both promising and reliable.

There were remarkable differences in the amount of time and the number of trials that 10- to 14-year-olds used to achieve memory criterion on the task; and there are reasons to believe that these differences reflect underlying strategy differences. There is the curvilinear relationship of performance to age. It is striking to find older children performing worse than younger ones; such data often signal developmental differences in method of approaching the task. Also variances increased and then decreased with age. This speaks for heterogenous approaches to the task, at the intermediate ages. In addition subjects reported using a variety of strategies for remembering the combinations. With increasing age there were decreasing reports of rote memorization and increasing reports of attempts to remember the combinations indirectly by understanding a system from which they could be derived.

The reported strategies seem to reflect subjects' approaches to learning the task. Given an ideal index of the strategies that were used in learning,

the distribution of strategies over age would completely account for the age differences in performance. The strategy reports could not be such an ideal index. A child may have used a strategy he could not report; a child may have been seeking a higher order strategy but then have had to resort to a more memorization-like one; a child may have reported a strategy discovered late in learning which therefore only partially affected his performance. (The last mentioned possibility may account for the fact that the strategy factor had a significant effect on trials to criterion but only a marginal effect on trials to Test 1). Still, strategy reports were related to performance. On trials to criterion there was a main effect of Strategy indicating   better   performance   as   strategies   became   less   rote memorization-like. There was also a Strategy × Age interaction indicating a poorer performance of especially those 12- and 13-year-olds who used Strategies A,B, and C. However, the strongest evidence of the influence of strategies on learning the task comes from analysis of performance on untried combinations. The potential benefit of an indirect intentional understanding strategy lies in a capacity to infer unseen or unpracticed items by deriving them from an understanding of other items. In the Age × Strategy analysis of performance on unseen items Strategy was the only significant factor; performance consistently increased as strategy reports became less memorization-like and more based on understanding.

The best present interpretation, consistent with these data, seems to be that many of the youngest children use a memorization strategy and use it fairly efficiently, while the oldest children use a strategy of trying to apprehend some system for the items and use it fairly efficiently. Children in the middle, especially the 12- and 13-year-olds, seem dissatisfied with pure memorization yet are either inefficient in using the more sophisticated strategy of the 14-year-olds or never discover enough about the task to employ it effectively, and so resort to memorization after all. As one child put it: "If I worked them all out I wouldn't have to practice them because I'd know them, so it'd be a waste of time; (but) trying to work out B + R was a waste of time because I spent a lot of time on it anyway and learned it."

As hypothesized, employment of a strategy of trying to understand the principles of the task as a means of learning the combinations was an acquisition of early adolescence, roughly coincident with the onset of formal operations. However, this observation requires qualification. In the strategy questioning 73 of the 236 children, including 40% of the 10-year-olds, explicitly mentioned that at first they thought the lights might be like color mixing ("at first I thought Y + R would be orange, I thought it had to be colors they'd make not on the panel but with real paints"). This approach is clearly distinguishable from the 14-year-old's attempt to derive a new system appropriate only to the present task. Color mixing provides a familiar, practiced, previously remembered set of in-

formation which is concretely similar to the present stimuli (both involve combinations of colors). On the other hand, numbers, or moves around a circle, are not perceptually inherent in the stimuli and their use necessitates the tailoring of more general ideas to fit this particular problem. In spite of these differences, an attempt to predict the combinations in terms of color mixing represents an important step toward a strategy of deliberate understanding. These responses indicate that use of an intentional but indirect understanding strategy could profitably be studied with younger children, and that the beginnings of this development are likely to lie in cases of provoked, unmodified, yet deliberate assimilation of new information to old.

A number of recent studies with children and adults (Bransford & Franks, 1972; Brown, 1975; Paris & Carter, 1973) have shown that apprehension of general principles or prototypes leads subjects to remember old previously seen instances and also "remember" or infer new previously unseen but valid instances. These studies have been based on spontaneous, naturally occurring comprehension of prototypes or general representations. In contrast the present study focused on children's deliberate attempts to generate such representations as a means of remembering items. Thus, the basic cognitive phenomenon of interest is similar but we wished to examine subjects' understanding and exploitation of this phenomenon for their own ends. The present results, while requiring extension with other tasks and younger subjects, suggest that some time after the child becomes aware of the efficacy of rote memory strategies he further appreciates that recall of specific items may be achieved by derivation from a general conceptualization.

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