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In a test the presence or absence of a "structure" in the individual's cognitive processes of formal operations thinking, 61 fourth, fifth, and sixth grade students were administered three tasks supposedly requiring such a method of thinking. The three tasks were (1) a problem solving task (PS), (2) a chemistry task requiring a certain combination of substances to obtain a correct answer(CH), and (3) a correlation task requiring the matching of certain elements to obtain the correct answer (CO). Each subject was given all three tasks during two sessions with the experimenter. The higher the correlation between the performances of the students on all three tasks, the greater was the possibility of the existence of a formal operations thinking structure. The results indicated the presence of a low but consistent and significant correlation between tasks PS and task CO. Task CH did not correlate with either PS or CO. It is possible that the CH task contained properties that made it inappropriate for use with this age level of subject. (WD)

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Abstract

In an attempt to evaluate intercorrelations among tasks presumed to measure development of formal operations thought, sixty-one fourth, fifth, and sixth graders were given three tasks in two sessions. The tasks were a diagnostic problem-solving task, PS, and two of Inhelder and Piaget's tasks: combinations of colored and colorless chemical bodies, CH, and correlations, CO. A low but consistent and significant correlation was obtained between PS and CO; CH correlated with neither. Results were interpreted as consistent with the view that formal operations tasks -- at least those employed in the present study -- are correlated. The appropriateness of the CH task was questioned.

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Piaget views cognitive development as a hierarchical process concerned with the consolidation of structures at progressively higher levels of abstraction. Although his theoretical position is widely known and has become the focus for an increasing volume of research in recent years there is almost no direct evidence for the existence of "structures". Specifically, although, e.g., Inhelder and Piaget (1958) report the results of a number of studies of tasks asserted to be diagnostic of formal operations thinking --which may or may not have been run on the same Ss-- there is no evidence of the intercorrelations among these tasks which would support the assumption that they do, in fact, reflect a coherent structure. Recently Shantz (1967) and Goldschmid (1967) have reported data which support the assumption of intercorrelation among tasks reflecting logical multiplication and conservation, respectively. There are, as yet, no available data concerning the more abstract, formal operations level of thinking. The present experiment represents an attempt to fill that gap by providing evidence on the intercorrelation among two Piaget formal operations tasks (correlation and the chemistry experiment) and a problem solving task (Neimark and Lewis, 1967) which seems to get at formal operations thinking.

Method

Subjects. Thirty-five sixth graders in the Ethel Roads school in Piscataway, N.J. and 26 fourth, fifth, and sixth graders (N=3, 16, 7 respectively) in the Roosevelt school in South Plainfield, N.J. served as Ss. There were 31 boys and 30 girls whose Otis IQ score ranged from 92-138. Additional information on group composition is summarized in

Table 1. For all but one S in Ethel Roads data on the Stanford Achievement test (administered in May, 1967) were also available.

Insert Table 1 about here

Apparatus. Three tasks were used: a problem solving task which has been described in detail elsewhere (Neimark and Lewis, 1967), a variant of the combinatorial problem used by Inhelder and Piaget (1958) and Wynns (1967), and a variant of Inhelder and Piaget (1958) concept of correlation task. The tasks will hereafter be referred to as the problem-solving, PS, chemistry, CH, and Correlation, CO, tasks respectively. Materials for the PS task consisted of a 9 sq. in. wooden board with 8 movable shutters, which had been pre-loaded with 8 problems, and 8 accompanying answer-sheets. The materials for the CH task were the same as employed by Inhelder and Piaget with the exception that phosphoric acid was substituted for sulphuric acid. Each of the substances was presented in a droppered brown glass bottle labelled with a number and placed in sequence on the table before S. S also had a wooden rack and a supply of test tubes in which to do his mixing. Because hair- and eye-color are so frequently used as examples in elementary science discussions of heredity we decided not to use combinations of these two properties for the CO task, as had Inhelder and Piaget. Rather, we used health or disease (the red-spot disease which was characterized by a sad expression) and presence or absence of disease agent (green germs on a microscope slide and red spots on face). Drawings representing all 4 possible combinations of these two binary variables were prepared on ditto stencil and pasted on 3 x 4 in. pieces of cardboard.

Procedure. Each S was run in two sessions separated by several days to a week. On the first session S was instructed in the procedure for the PS task and did four or five practice problems followed by the eight problems of the experimental series. For each of these problems two time measures were recorded: time from start of problem to opening of the first shutter, Time I; and time to completion of the problem, Time II. At the end of the session S was asked to describe his procedure for solving the problems.

For the PS task S was given an answer sheet with eight numbered patterns of eight binary elements (black or white circles) and a problem board in which one of the patterns was concealed by a movable shutter over each element. His task was to identify the concealed pattern by uncovering as few of its elements as possible. Elements differed with respect to their potential informational outcome: half of them (safe moves) would yield one bit of information (i.e., eliminate half of the patterns which were potential solutions) whereas the other half would, at best, eliminate only one pattern from further consideration. The most efficient strategy for this task was, thus, to select three one-bit elements to uncover. Such a strategy will be called an "ideal strategy".

At the start of the second session E had two test tubes, each containing a colorless liquid (water in one and a combination of phosphoric acid and peroxide in the other). She showed that by adding a drop of G (potassium iodide) to each test tube an amber-colored liquid was produced in only one of the test tubes. S was then told "I want you to make the yellow color for me; you may use any of these droppers to do so". He was told that he could use as many test-tubes as he needed and that he could also use the pad and pencil beside him to keep track of combinations if he so desired (very few Ss did so). After S had performed this task (or, in a few instances, given up and refused to go on), he was given a shuffled deck of twelve cards and told: "You are a doctor. You have been seeing a lot of ladies in your office; some of them are sick and some of them are well. You have taken a microscope slide for each one and some of the slides have green germs while others do not. I want you to look through these cards and decide whether or not green germs cause the spot disease". The deck contained 4 cards showing a healthy face and no germs, 4 showing a sick face with germs, 2 with a healthy face and germs, and 2 with a sick face and no germs. After announcing his decision S was asked "do you mean green germs always (never) cause sickness or is this more like the weather report, where the announcer says, for example, there is a 60% chance of showers?". The S was then asked to select from his deck those cards which would prove conclusively that green germs cause sickness. After doing so he was given the deck again and asked to select from it all the cards which would prove conclusively that green germs have nothing to do with sickness.

Results

Criteria for scoring. We initially planned to use the scoring system of Wynns (1967) for the CH task but had to modify it slightly. Scoring was as follows: 0-, does not use G each time until reminded and then produces purely random combinations; 0, purely random combinations of one, or more, chemicals with G; 0+, random combinations (as above) but with occasional evidence of primitive order (e.g., G + 1 + 2 + 3 + 4); 1, primarily random combinations but with evidence of keeping track of past trials (by taking notes or absence of duplications); 2, systematic pairing of each single ingredient with G but no plan beyond this; 3, systematic pairing of each single ingredient with G followed by systematic testing of pairs of ingredients; 4, procedure as in 3 but going on to test for uniqueness of the combination.

For the CD task three aspects of performance were rated: sorting through the data, and response to each of the two subsequent questions. Scoring for sorting through the deck initially was as follows: 0, no systematic procedure so that S cannot even tell where he began (e.g. putting the top card on the bottom and proceeding in this fashion); 0+, no sorting but looking at each only once; 1, sorting into two piles (either healthy vs. sick or germs vs. no germs, or some combination of these vs. all others); 2, sorting into 4 piles in a row; 3, sorting into 4 piles arranged in a 2 x 2 contingency array. The deck produced in answer to the request to remove the cards which "don't fit" and to produce a deck which shows that germs and disease are related was scored as follows: 0, for the 4 cards illustrating sickness and germs combined; 1, for the four showing sickness and germs plus the four showing health and no germs; 0-, for all else. Similarly, the deck produced in response to the request to assemble instances showing that germs and disease are unrelated was scored: 0, for either of the two discrepant instances (germs and health or sickness and no germs); 1, for both of the discrepant pairs; 2, for a deck containing two instances of each of the four possible combinations. Total score was the sum of the three ranks.

For the PS task a number of quantitative scores were available. Four measures deal with S's information-gathering strategy over the 8 experimental problems: safe first moves refers to the number of initial shutter choices out of 8 on which S obtained 1 bit of information (4 reflects chance; 8 is maximum and less than 4 reflects "gambling"); no. of ideal refers to the number of problems solved by a series of three shutter openings each of which yielded one bit of information; and no. of 0 moves refers to the number of shutter openings which yielded no information. The fourth measure is the sum of the strategy scores for each of the eight problems (a strategy score is obtained by summing the expected informational outcomes for each move and dividing by the number of moves); the maximum possible score is 8. In addition there were two time scores and a qualitative rating, verbal level, of S's description of his strategy. Verbal level was scored: 0, no plan or an irrelevant one; 1, at that point at which two possible answers remained, comparing the two patterns and selecting that shutter with respect to which they differed; 2, a plan for the last move plus one subsequent one; 3, selecting on each move in such a way as to halve the alternative possible solutions.

Insert Table 2 about here

Response measures and their intercorrelations. Table 2 summarizes group means and variances for girls and boys separately and for the total group. No attempt was made to test for significance of sex differences since this experiment was not designed to provide such comparison. Table 3 summarizes intercorrelations among measures for the entire group: levels of significance for correlations for each sex separately are indicated above the diagonal with boys at the upper right and girls at the lower left of each cell. Although the table is complicated its import is simple. Correlations among PS measures of performance are highly intercorrelated--as one would expect--and these relations hold for both boys and girls. Of the PS time measures Time I, or presolution thinking time, is highly correlated with performance: Ss who think first do better. The correlations for Time II, solution time, are more irregular but they tend to suggest that Ss who take a long time solving (and who, presumably, do their thinking in a context of doing rather than prior to action) do more poorly; however, these relations are also confounded with number of moves: Ss who make more moves take longer and do more poorly. The information of major interest is the correlation of the two Piaget tasks, CH and CO, with PS. In general there is a low but consistent correlation of performance on CO and PS although this seems to hold for boys to a greater extent than for girls. In the case of CH, it does not correlate with either PS or CO for either the boys or the girls. The only thing with which CH is correlated is IQ and MA. Thus, it would appear either that there is no evidence for a structure of formal operations, or that the CH task is a poor measure of formal operations thinking. At present we incline to the latter view.

Insert Table 3 about here

Intercorrelations among performance and scholastic achievement tests. Intercorrelations among measures of performance and scores on the Stanford Achievement tests for the Ss of Ethel Road school are summarized in Table 4.

Insert Table 4 about here

In general, neither of the Piaget tasks is correlated with achievement whereas some of the PS measures tend to be so correlated (especially verbal level and, to a lesser extent, Time I). The achievement scores with which PS performance are most highly correlated are Arithmetic Concepts and Reading Comprehension. Interpretation of Table 4 is complicated by the finding of a different pattern of correlations for the boys (N=15) than for the girls (N=10). For the girls Reading Comprehension correlates with a number of PS measures whereas for the boys Arithmetic Comprehension does so. However, because of the small size of the two groups and because of the existence of a number of large differences between them with respect to performance, achievement, and individual difference measures, it is pointless to pursue comparisons.

Discussion

With respect to the original question of determining intercorrelations among a number of presumed formal operations tasks, although the results do not argue for much of a high interrelation among tasks the conclusion that no such relation exists does not seem warranted. First, if one compares frequency distributions of rankings on CO, CH, and PS verbal level (see Table 5) it is apparent that the three tasks differ in difficulty with PS being easier than CO and CH[2]. Furthermore, since formal operations thinking at its most abstract level is not completely attained until the late teens, one could argue that the age range employed is much too restricted to provide an adequate test. Indeed there is internal evidence that the unselected S sample, even for the younger ages, is not particularly representative of the general population of grades 4, 5, and 6. Finally, one can legitimately question the selection of specific tasks employed: the selection is extremely limited and perhaps these tasks are not the best representations of formal operations thinking.

Insert Table 5 about here

Piaget's treatment of formal operations thought is couched in terms of an elegant system of 16 logical operations and the tasks employed by him and Inhelder are designed to measure specific ones of these operations. We have by no means adequately sampled from among the range of hypothesized operations. Moreover, one would expect that some of the aspects of formal operations thought are developed sooner than others -- as would be implied by the assumption of hierarchical organization with full development being incomplete until well on in the teens. Only more extensive work with a broader age range, a more carefully constituted sample of Ss, and a greater variety of tasks can answer these objections.

Some impressionistic comments on the present assortment of tasks are perhaps in order. More recent work in which the same S does both the combination of colors task (Piaget and Inhelder, 1951; Goodnow, 1962) and the CH task (which is logically equivalent to it) have left us uneasy about the CH task. Children who do the combinations task perfectly well (and successful performance of this task appears to occur in pre-adolescence) do very poorly on the CH task. We have the impression that the properties of the CH task provide an irresistable stimulus to manipulative play and that this incitement to a more primitive level of operation overcomes any analytic problem-solving set which a child might normally bring to the experimental situation. They just have a ball mucking around with test tubes and liquids. Thus, the CH task might not be especially appropriate for use with American children.

It will be noted that the PS task bears no obvious relation to the Inhelder and Piaget tasks. We have used it extensively first because it provides a more objectively administered and scored procedure, and second because it is a more appropriate paradigm of the author's personal approach to formal operations thought. I have assumed that with increasing age and its accompanying broadening of experience with situations in which orderly relationships are observed, the child begins to adopt a "set" to seeking order and to understanding new situations in terms of principles based upon previously-experienced situations. To this end he develops general heuristics, or strategies, for collecting and storing information--i.e., a systematic approach to tasks which transcends the particular stimulus characteristics of a given task. Such an approach is partially reflected in the amount of time spent in surveying the task prior to overt action. It is assumed to be more specifically reflected in e.g., the information-gathering behavior on the PS task, sorting of instances on the CO task, and devising of systematic orderings on the CH and combination of colors tasks. The existence of consistent positive (albeit low) correlations among the PS, CO, and more recently, combination of colors, tasks is compatible with this position. The fact that results for the CH task are inconsistent with the view is not seen to be terribly destructive in view of special properties specific to that task.

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Footnote

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2. Although CO might appear to be comparable to CH, since scores here represent a sum of three rankings the maximum score is 6. Thus, it is obvious that no children in the study have fully attained the concept of correlation.

Table 1

Age and intelligence characteristics of the subject sample

Measure	Boys	Girls	Total
N	31	30	61
C.A. in months, $\bar{X}$	138.87	141.57	140.20
C.A. in months, σ	10.66	10.05	10.45
M.A. in months, $\bar{X}$	154.52	160.03	157.23
M.A. in months, σ	19.69	17.38	18.79
I.Q. (Otis), $\bar{X}$	111.61	112.67	112.13
I.Q. (Otis), σ	10.57	9.76	10.19

Table 2

Summary of mean and standard deviation (in parenthesis) for several response measures

Measure	Boys		Girls		Total	
PS, Strategy	6.71	(1.07)	6.59	(1.29)	6.65	(1.18)
PS, 0 moves	5.03	(6.96)	6.10	(7.83)	5.56	(7.42)
PS, Safe first	5.16	(1.67)	5.53	(1.54)	5.34	(1.62)
PS, Ideal	2.97	(1.89)	3.30	(2.48)	3.13	(2.21)
PS, Time I	98.52	(60.48)	75.00	(50.97)	86.95	(57.22)
PS, Time II	801.77	(141.29)	752.83	(268.94)	777.70	(215.21)
PS, Verbal level	1.90	(1.00)	1.65	(1.14)	1.78	(1.08)
CO	1.61	(0.75)	1.80	(1.08)	1.70	(0.93)
CH	1.28	(1.22)	1.07	(1.21)	1.17	(1.22)

Neimark Table 3

Intercorrelations among response measures (below diagonal) with levels of sig
above the diago

Measure	1	2	3	4	5	6	7
1. PS, Strategy	X	*** ***	** **	** **	** **	* ⌿	**
2. PS, 0 moves	-.98 **	X	* **	** **	** **	*	**
3. PS, Safe first	.62 **	-.52 **	X	** **	** *	⌿	**
4. PS, Ideal	.86 **	-.76 **	.77 **	X	* **	⌿	**
5. PS, Time I	.50 **	-.47 **	.45 **	.42 **	X		**
6. PS, Time II	-.30 *	+.27 *	-.20	-.33 **	.29 *	X	
7. PS, Verbal level	.87 **	-.84 **	.57 **	.75 **	.60 **	-.18	X
8. CO	.28 *	-.26 *	.25 *	.24 ⌿	.22 ⌿	.06	.
9. CH	.08	-.06	.02	.03	.02	-.04	.
10. C.A.	.10	-.12	.01	.08	.11	-.31 *	.
11. M.A.	.22	-.19	.16	.22	.24 ⌿	-.28 *	.
12. I.Q.	.22	-.19	.19	.24 ⌿	.25 *	-.15	.

⌿ = Significance at .10 level * = Significance at .05 level ** =

Table 3

diagonal) with levels of significance for boys (upper right) and girls (lower left)
above the diagonal.

4	5	6	7	8	9	10	11	12
** **	** **	* /	** **	*				
** **	** **	*	** **	/				
** **	** *	/	** **	*				*
X	* **	/	** **	*				/
** .42	X		** **	/		/	*	**
** -.33	* .29	X				/	*	/
** .75	** .60	-.18	X	* /		*	/ /	
/ .24	/ .22	.06	** .33	X				
.03	.02	-.04	.07	.08	X		*	/
.08	.11	* -.31	* .25	.15	.12	X	** **	
.22	/ .24	* -.28	* .30	.08	* .31	** .59	X	** **
/ .24	* .25	-.15	/ .24	.04	* .29	.07	** .81	X

nce at .05 level ** = Significance at .01 level

Table 4

Intercorrelations among subject and performance variables and Stanford Achievement Test Scores

	Vocabulary	Reading Comprehension	Arithmetic Comprehension	Arithmetic Concepts
PS, Strategy	.29	.44*	.34†	.38*
PS, O moves	-.26	-.42*	-.30†	-.36*
PS, 1st move	.27	.20	.27	.20
PS, Ideal	.22	.33†	.39*	.25
PS, Time I	.33†	.37*	.33†	.47**
PS, Time II	.14	.03	-.10	.01
PS, Verbal level	.36*	.51**	.40*	.50**
CO	.21	.15	.11	.13
CH	.20	.27	.07	.26
CA	.15	.09	.03	.05
MA	.65**	.64**	.38*	.62**
IQ	.74**	.74**	.43*	.68**
$\bar{X}$	7.87	8.07	6.97	7.44
σ	1.61	1.95	1.51	1.84

Table 5

Frequency distributions of scores on CH, CO, and PS verbal level

Task	Rank 0	1	2	3 or more
PS	13	6	27	15
CO	3	26	21	11
CH	28	8	12	13