MEMORY PERFORMANCE AS RELATED TO INDIVIDUAL DIFFERENCES WITH RESPECT TO A UNIFIED FORMAL-OPERATIONAL STRUCTURE

by

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ABSTRACT

The major aims of the study were to identify individual differences with respect to a unified formal-operational structure, independent of age and IQ, and to relate these to predictable differences in memory performance on a variety of tasks.

Fifty-six female grade seven students were administered the vocabulary test of the Wechsler Intelligence Scale for Children and four Piagetian tasks, the chemical combinations, pendulum, balance, and conservation and measurement of volume tasks. In a later session, they were administered eight memory tasks, each designed to be related both to general formal-operational ability and to one or more particular Piagetian schemes or concepts. The latter included the conservation of occupied volume, the understanding of combinations and permutations, and the method of holding variables constant to test the effect of others. Memory of the displays was tested immediately and four weeks later.

The two hypotheses concerning the unified structure of formal-operations were confirmed. First, even when the effects of age and IQ were removed statistically, significant

positive correlations were found between performance on each of the four formal-operational tasks and the average of performance on the other three tasks. Second, a principal components analysis revealed that the first component accounted for a substantial 89 percent of the variance of the assessment tasks.

The principal hypothesis concerning memory performance as related to formal-operational competency was confirmed. Even when the effects of age and IQ were removed, average Piagetian task performance was significantly correlated with overall memory performance in the original ($r = .47$) and retest ($r = .36$) periods. Furthermore, average Piagetian task performance showed positive and, particularly in the original testing period, often significant correlations with performance on the specific memory tasks.

Two subsidiary hypotheses were not confirmed. In general, performance on particular Piagetian tasks thought to be measuring specific formal-operational schemes or concepts was not significantly related to performance on particular memory tasks also thought related to the schemes. Secondly, contrary to expectations based on a hypothesized considerable deterioration in memory performance over time on the part of concrete-operational Ss who did well initially, the magnitude of the relationship between Piagetian task performance and memory performance decreased rather than increased from the original to the retest period.

Possible reasons for the lack of confirmation of these two hypotheses were discussed. Also, the discussion concerned the positive findings as related to the concept of a unified formal-operational structure, possible design weaknesses in studies not finding consistency of performance across formal tasks, the selection of tasks providing optimal measurement of formal-operational ability, and the distinction between the psychometric and Piagetian concepts of intelligence. Finally, the finding of a relatively high percentage of *S*s (42.9) at the formal-operational stage was discussed in terms of the methodology of the present study and the possibility of the universal achievement of formal operations.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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Chapter 1

INTRODUCTION

The major aims of the present study were to identify individual differences with respect to a unified formal-operational structure and to relate these to predictable differences in memory performance on a variety of tasks. In order to introduce the study and explain its purpose, this chapter will provide the following:

1. A review of Piaget's theory of cognitive development with some emphasis on the concrete-operational stage and major emphasis on the formal-operational stage, which is of prime concern in this study.

2. A description of the commonly replicated formal-operational experiments with a discussion of the empirical status of the formal-operational stage.

3. An overview of memory research including the two historical views of memory and Piaget's concept of memory; the latter's relationship both to these historical approaches and to the currently prevailing views in North America will be noted.

4. A review of studies relating cognitive

development to memory.

5. A statement of the purpose of the present study.

PIAGET'S THEORY OF COGNITIVE DEVELOPMENT

Piaget (e.g., Inhelder and Piaget, 1958; Piaget, 1950; Piaget and Inhelder, 1969) has postulated several stages in the child's development to mature adult thinking, the sensory-motor, preoperational, concrete-operational, and formal-operational stages. The latter two, which are of concern in this study, will be discussed below.

Concrete Operations

According to Piaget, the concrete-operational stage, occurring from approximately 7 to 11 years, involves several substructures or groupings. These enable the child to organize and understand data from the world in terms of either classifications or relations. Thus the concrete-operational child develops many new operations which are unavailable to the pre-operational child, only a few of which will be mentioned below.

For example, the concrete-operational child becomes capable of hierarchically classifying stimuli in the environment and understands the relationship between classes and subclasses. Also in this stage, the understanding of the seriation of objects such as sticks differing in size is acquired. Similarly the child understands the classification of objects in terms of more than one dimension to form a multiplicative matrix, such as one based on objects differing both in size and color. In addition the child achieves an understanding of spacial relations, including the idea of vertical and horizontal, the latter evidenced by successful prediction of how a liquid would lie in a tilted container. The child's imagery becomes less static so that he can anticipate the changing positions of objects such as a triangle which is rotated or a falling and turning stick.

This period is marked by the child's development of a number of conservations, that is, understandings that certain properties of objects remain the same despite transformations that may change the physical appearance of the objects. These conservations include those pertaining to substance, weight, length, and number. For example, the child realizes that despite changes in the shape of a ball of clay, its weight and amount of substance remain the same. Similarly, the child knows that the rearrangement of two sticks of identical length or two rows containing the same number of objects does not alter the equivalence of the objects or sets of objects. These conservations seem closely related to the child's new understanding of the reversibility of operations. This occurs through both reciprocity, neutralizing the operation while leaving it intact (as in the application of an equal counterforce), and more particularly negation, actual undoing of the operation.

Despite its many achievements, the thought of the concrete-operational child has certain limitations. Firstly, as the name of the stage implies, the operations are directed toward concrete things and happenings in the present. Furthermore, the various logical groupings of the concrete-operational child are not integrated into one unified system, which would be required for success at certain complex tasks. For example, the concrete-operational child, while possessing the two types of reversible operations, negation, found in the class groupings, and reciprocity, found in the relational groupings, cannot co-ordinate these operations. This lack of co-ordination is seen in the problem involving a seesaw balance, where the equilibrium is disturbed by the addition of extra weight on one side. The child may realize that the removal of the added weight (negation) or the repositioning of weight on one or both sides (reciprocity) may bring the balance once more into equilibrium. He does not know, however, how to co-ordinate these operations in any precise logical or mathematical manner.

Formal Operations

General. The thinking of the formal-operational child overcomes the shortcomings of the concrete-operational stage. A major achievement of the formal-operational period is that an adolescent at this stage considers not only the real but also the possible. What actually happens is a subset of all the possibilities which the child is capable of envisaging. Unlike the concrete-operational child, whose world is the concrete, the formal-operational adolescent operates in the framework of the hypothetico-deductive method. The adolescent in trying to determine the cause of certain phenomena may entertain a number of hypotheses or propositions from which deductions are made; these deductions are tested with resulting confirmation or disconfirmation of the various hypotheses.

Thus the formal-operational child becomes capable of scientific thought. When presented with a difficult problem he is able to isolate the relevant variables; envision all the various combinations or solutions to the task; test out the effects of the various variables, often by holding factors constant and manipulating others; and conclude correctly on the basis of experimental results. These conclusions are facilitated by the integration of the operations of reciprocity and negation into the group structure, which is described below.

Descriptive models. In addition to the general characteristics of formal operations given above, Piaget uses two logical models, the lattice and the group, to describe in detail the period of formal operations. Together these structures provide the logico-mathematical properties considered inherent in adolescent thought.

1. Lattice structure. As mentioned previously, the formal-operational adolescent is capable of isolating the relevant variables and then combining them in an orderly and exhaustive manner. The resulting network of possibilities is called the lattice. For example, one can consider the size of an individual (p=fat and $\bar{p}$=thin) and state of mind (q=happy and $\bar{q}$=sad). Both the concrete-operational and the formal-operational child can come up with the four possible base associations, pq, $p\bar{q}$, $\bar{p}q$ and $\bar{p}\bar{q}$, that is, fat and happy, fat and sad, thin and happy, thin and sad. The concrete-operational child, however, considers the four associations as concrete phenomenal events. The formal-operational adolescent treats them as propositions; they may be potential and not actually perceived occurrences. Furthermore, unlike the concrete-operational child, the adolescent is capable of generating all the possible combinations of these four associations or propositions to form a lattice of sixteen propositional combinations, described in Table 1. The adolescent with this lattice of possibilities can set out to determine which of the sixteen possibilities actually does occur and then can formulate his conclusions.

The table indicates, in the form of eight complementary

Table 1. Lattice of propositions.

Name	Combinations Observed	Name of Complement	Combinations Observed
Complete affirmation	$pq + \bar{p}q + p\bar{q} + \bar{p}\bar{q}$	Negation	
Incompatibility	$p\bar{q} + \bar{p}q + \bar{p}\bar{q}$	Conjunction	pq
Disjunction	$pq + \bar{p}q + p\bar{q}$	Conjunctive negation	$\bar{p}\bar{q}$
Implication	$pq + \bar{p}q + \bar{p}\bar{q}$	Nonimplication	$p\bar{q}$
Reciprocal implication	$pq + p\bar{q} + \bar{p}\bar{q}$	Negation of reciprocal implication	$\bar{p}q$
Equivalence	$pq + \bar{p}\bar{q}$	Reciprocal exclusion	$\bar{p}q + p\bar{q}$
Affirmation of p	$pq + p\bar{q}$	Negation of p	$\bar{p}q + \bar{p}\bar{q}$
Affirmation of q	$pq + \bar{p}q$	Negation of q	$p\bar{q} + \bar{p}\bar{q}$

pairs of propositions, the name of each proposition and the combinations observed if the proposition is confirmed. For example, the child may observe the combinations $p\bar{q}$ (fat and sad) and $\bar{p}q$ (thin and happy), labelled as reciprocal exclusion in line 6, column 3, of the table. The child may never observe pq (fat and happy) and $\bar{\bar{p}}\bar{q}$ (thin and sad) which is the proposition of "equivalence," the complement of reciprocal exclusion (see line 6, column 1, of the table). Thus the child may conclude that obesity and happiness never co-occur; they are negatively correlated or incompatible.

2. Group structure. The thinking of the formal-operational child also manifests the properties of the group. This structure helps to capture the essence of how the adolescent manipulates the results of his experiments to come to certain conclusions beyond the data. The group contains four transformations, identity, negation, reciprocal, and correlative;

a. Identity (I). This "null" transformation changes nothing. Thus if the proposition is $p \vee q$ (fat and/or happy), then I $(p \vee q) = p \vee q$. Similarly, the identity transformation of p.q. (fat and happy) is p.q.

b. Negation (N). This transformation negates all aspects of the propositions. All conjunctive (and) statements become disjunctive (and/or) statements, and vice versa, and all assertions become negations, and vice versa. Thus N $(p \vee q)$ is $\bar{p}.\bar{q}$, or to provide an example, the negation of fat and/or happy is thin and sad.

c. Reciprocal (R). This transformation changes assertions and negations but leaves conjunctions and disjunctions unchanged. For example, R $(p.q) = \bar{p}.\bar{q}$, or the reciprocal of fat and happy is thin and sad.

d. Correlative (C). The correlative transformation alters conjunctive and disjunctive propositions, but assertions and negations are unchanged. Thus C $(p.q)$ equals $p \vee q$, or C (fat and happy) is fat and/or happy.

In order to reach conclusions the S uses the various INRC transformations on his data. For example, if the S finds that a long, light rod bends and so does a short, heavy one, he can understand that a long, light rod is the reciprocal of a short, heavy rod. In other words, an increase in weight can be counteracted by a decrease in length and vice versa. Furthermore, through the correlative transformation, he can conclude that the correlative of long is heavy; that is, length and weight have the same effect and are both correlated with bending.

An example of the use of the negative transformation is provided by Inhelder and Piaget (1958, Chapter 8) in the conservation of motion task. Success at this task requires first the discovery that the stopping of a ball on a horizontal plane results from a variety of factors, such as friction and air resistance. The manipulation of this discovery by the negative transformation makes possible the conclusion that the absence of these factors involves the ball not stopping.

These two models, then, the lattice and the group, form the structure of the formal-operational period. As the understanding of the 16 propositions develops, the child becomes aware of their interrelations and learns to transform them through the INRC group; thus the presence of the lattice presupposes the presence of the group and vice versa.

Formal-operational concepts. From this integrated total structure are developed substructures, or formal-operational schemes, which are specialized for certain problems. These include:

1. Combinatorial operations, which are systematic procedures for generating all the possible permutations or combinations of objects.

2. Proportions, which involves the ability to deal with the equality of two ratios, $X/Y = X'/Y'$, as in the understanding of the balance.

3. Multiplicative compensations, closely related to proportions, which involves the understanding, as in the case of volume conservation, that gains in one dimension can be compensated by changes in other dimensions; that is, rectangular buildings of different dimensions can be understood and calculated to have exactly the same volume.

4. Co-ordination of two systems of reference, which, for example, involves the understanding of the position of a person (in terms of an external frame of reference) who is walking on a moving sidewalk in a direction opposite to that of the sidewalk's movement.

5. The concept of mechanical equilibrium, which involves the understanding of opposing forces as in action and reaction.

6. The concept of probability, which involves the understanding of the ratio of the number of confirming cases to the total number of equally likely cases, the latter calculation requiring the knowledge of combinations.

7. Correlation, which involves understanding the degree of relation between variables.

8. Conservation in the abstract, which involves forms of conservation (such as the conservation of motion) that go beyond direct empirical discovery or verification.

EXPERIMENTS RELATING TO FORMAL-OPERATIONAL THOUGHT

The following involves a description of the more commonly replicated formal-operational tasks and a discussion of the empirical status of formal operations.

Commonly Used Formal-Operational Tasks

The majority of the tasks relating to formal-operational thought are the 15 simple physical experiments reported in Inhelder and Piaget (1958). In these the child is required to experimentally manipulate variables in order to reach conclusions concerning the principles involved. To provide an idea of these 15 experiments the 7 most commonly replicated ones will be discussed. In addition, there will be a description of the volume conservation task (see Piaget and Inhelder, 1941; Piaget, Inhelder, and Szeminska, 1960), which has been widely replicated (e.g., Elkind, 1961b, 1962; Towler and Wheatley, 1971). In the case of the first seven tasks, Inhelder independently conducted the studies and Piaget afterward described the logic allegedly used. In the description which follows concerning these tasks and the volume conservation task, the logic (in terms of the formal-operational structures and schemes) supposedly measured by the tasks is that of Piaget. The following tasks, then, are some of the most common formal-operational tasks.

1. Flexibility of rods. In this task the _S_ is required to determine which variables are responsible for the flexibility of rods, the material they are made of, the length, thickness, and/or the form of their cross sections.

2. Pendulum. This task requires the _S_ to determine the effects of a number of variables (including the length of string, the weight of the object fastened to the string, the height of the dropping point, and the force of the push) on

the frequency of oscillation of the pendulum.

Both the flexibility and pendulum problems are closely related to the lattice structure. The successful Ss presumably must consider a wide variety of possibilities and determine which of these occur by holding variables constant and manipulating others to see the effects of the latter.

3. Chemical combinations of colorless liquids. This study involves combining several chemicals to determine which ones reproduce a yellow color. Success is related to the lattice structure and more particularly to the concept of combinations.

The remaining tasks are related to the INRC group and to particular formal-operational concepts.

4. Conservation of motion on a horizontal plane. As mentioned previously (p. 9), this task, involving a formal-operational conservation, requires for success the transformation of experimental findings by negation to reach a new conclusion; that is, the S concludes that as certain factors cause a ball to stop rolling, the absence of these factors implies the ball will not stop.

5. Correlation. In this task the S is required to determine if there is a relationship between two variables, such as hair and eye color, and what is the extent of the relationship.

6. Equilibrium in the balance. In both this and the

following tasks the concept of proportions is required. In this task the $\underline{S}$ is required to determine with a seesaw balance the relationship between the magnitudes of weights hung on each side of the fulcrum and the distances from the fulcrum that these weights are hung.

7. Projection of shadows. Employing rings placed between a light source and a screen, this task involves trying to determine the relationship of the size of the shadows cast both to the diameter of the rings (direct proportion) and to the distance between the rings and the light source (inverse proportion).

8. Volume conservation. This task involves the concepts of both interior volume conservation and the conservation of occupied volume, which are closely related to the INRC group and more particularly to the concept of multiplicative compensations. Interior volume conservation is tested by having the $\underline{S}$s demonstrate their understanding of why an object can contain the same amount of room or space inside even when the shape of the object is changed. The conservation of occupied volume involves realizing that the room occupied by an object (e.g., a model building under water) will not change when the shape, but not the volume, of the object is changed.

Empirical Status of Formal Operations

There would seem to be two major unanswered questions concerning the empirical status of formal-operational thinking. One question concerns whether there exists universality of achievement of formal-operational thinking among people of normal intelligence who are at the age where this competency is supposed to have developed. The other question concerns whether there is a unified formal-operational structure. This would be evidenced by fairly consistent performance across tasks and the presence of one component or factor (produced by principal components or factor analysis) accounting for a considerable amount of variance in the tasks. If, as described by Piaget, formal-operational thinking reflects an organized structure of operations, one might expect to find such consistency with properly designed tasks.

Universality of formal operations. In the original statement of this theory (Inhelder and Piaget, 1958), formal-operational thought was considered to develop through the ages 11 to 15 years with equilibrium achieved by 75 percent of adolescents by the age of 15. However, a considerable body of research has not supported this contention, with the percentage of formal-operational Ss rarely in excess of 55 to 60 percent even in the case of college students. For example, consideration of the conservation of volume, generally characterized as a formal-operational competency that emerges early, reveals considerable lack of universality. Approximately 25 percent of grade six students (Elkind, 1961a; Uzgiris, 1964), 47 percent of junior and senior high school students (Elkind, 1961b), and 60 percent of college students (Elkind, 1962; Towler and Wheatley, 1971) achieved success on measures of this concept. Such results have led Piaget (1972) to restate his position concerning this issue and tentatively conclude:

> ...all normal subjects attain the stage of formal operations or structuring if not between 11 - 12 to 14 - 15 years, in any case between 15 and 20 years. However, they reach this stage in different areas according to their aptitudes and their professional specializations (advanced studies or different types of apprenticeship for the various trades): the way in which these formal structures are used, however, is not necessarily the same in all cases (pp. 9 - 10).

<u>Unified structure of formal operations</u>. Surprisingly few studies have assessed the performance of <u>S</u>s in a wide number of formal-operational tasks, and thus the presence of a unified formal-operational structure is not clear. The majority of the limited number of studies that have investigated the question of consistency of performance among these tasks have been interpreted, however, to support a consistency position.

One of the most ambitious studies (Lovell, 1961) employed 5 combinations of 10 of the experiments used by Inhelder and Piaget (1958). These combinations were given to different groups of <u>S</u>s between 8 and 18 years of age

(192 Ss in all). The values of Kendall's coefficient of concordance W, used as an indicator of the relationship between tasks, were significant. They varied from .89 to .52, depending upon the age and the ability range of the students who took the particular combination of tasks. For example, comparison of the performance of 50 comprehensive students (secondary students offered a variety of vocational and academic courses) on the chemical combinations, pendulum, balance, and shadows tasks produced a W of .73. This is equivalent to an average Spearman rank-order correlation coefficient ($\bar{p}$) of approximately .64.

In another study, Jackson (1965) employed two groups of children, average or subnormal in intelligence, who ranged in age from 5 to 15 years. The performance of these Ss on each of six formal-operational tasks was assigned to one of six substages. Over 70 percent of the Ss in each group had all their responses included within two or fewer substages. When the data from both groups were combined, Jackson found that overall performance on all the Piagetian tasks showed rank correlations of .61 and .86 with, respectively, age and intelligence, as measured by Raven's Matrices scores.

Similarly, Tomlinson-Keasey (1970), using as Ss sixth-grade girls, college students, and mature women (mean age, 54 years), found significantly positive correlations between the pendulum, balance, and flexibility of rods tasks. These ranged from r = .21 (pendulum-flexibility of rods) to r = .45 (pendulum-balance). In another study, Lee (1971) reported a positive correlation of .85 between the balance and the shadows tasks, with Ss selected from kindergarten through 12th grade.

Two studies by Arlin (1974, 1977) found positive correlations between the formal-operational tasks used. The first study involved female college seniors of approximately the same age, randomly selected from all the female students enrolled in their first class in educational psychology. The correlations found between the pendulum, shadows, and chemical combinations tasks were small but significant, ranging from r = .22 (pendulum-shadows) to r = .39 (pendulum-chemical combinations). The second study, which employed male and female students selected randomly from a similar class, found a significant correlation of .58 between the chemical combinations and pendulum tasks.

A number of studies have submitted the performance of Ss to factor analysis and the majority have found that the formal-operational tasks investigated loaded heavily on one factor. Lovell (1971) reports a study by Hughes (1965), involving 40 pupils of average and below average ability tested yearly from 11+ years to 14+ years. Kendall's coefficient of concordance relating performance on the balance, pendulum, chemical combinations, and flexibility of rods tasks varied from W = .39 on the first testing to W = .57 on the fourth. The logical thinking scores on these tasks obtained on the fourth testing were also positively correlated with scores on other tasks, such as tests of nonverbal intelligence and numerical analogies. All the tests showed substantial loadings, ranging from .57 (pendulum) to .81 (chemical combinations) on the first principal component yielded by a principal components analysis. Similarly, Lovell and Butterworth (1966) found that performance on a number of tasks involving proportions, including the shadows and balance tasks, correlated highly, .79 or more, with the first principal component.

Another study by Lovell and Shields (1967) involved 30 children 8 to 11 years old who had verbal IQs on WISC of 140 or higher. Included in the battery of tests were the balance, chemical combinations, and pendulum tasks; they showed significant loadings, respectively .37, .61, and .72, on the first axis resulting from a principal components analysis. When the principal axes were rotated by the varimax method, the loadings of these tasks on one factor were all increased to respectively .83, .72, and .60.

Similarly Bart (1971), using 90 Ss of ages 13, 16, and 19 years, found evidence for a unifactor underlying formal-operational thought. Intercorrelations between the shadows, balance, and pendulum tasks ranged from .52 to .78 with the effect of verbal intelligence, measured by the Experimental Omnibus Vocabulary Test, statistically removed through partial correlation techniques. These Piagetian tasks and the vocabulary test were seen as unifactor, correlating from .44 (vocabulary) to .89 (balance) with a factor resulting from an unrestricted maximum likelihood factor analysis.

Contrary to the majority of the researchers employing factor analysis, however, Ross (1973) reported no evidence of a unified formal-operational structure. He employed a sample of 65 undergraduates of approximately the same age. Among the tests used were the American College Test, a measure of general intelligence, and the balance, pendulum, correlation and density tasks, the latter task testing the understanding of why objects sink or float. All the correlations among the formal tasks were insignificant except for the correlation between the density and the balance problems, $r = .42$. The American College Test correlated significantly with only the balance ($r = .53$) and density ($r = .38$) tasks. Three factors, as found by a Varimax rotation of the principal components, were required to account for the majority of variance in the Piagetian tasks.

A number of other studies not employing factor analysis similarly have found no significantly consistent performance across all the tasks employed. Neimark (1970), with Ss from grades four, five, and six, found no significant correlations between the chemical combinations task and a slightly modified version of the correlation task; the latter task was found to be of greater difficulty. In addition, Neimark (1975a) reported that Kuhn, Langer, Kohlberg, and Haan (1972), using the pendulum, chemical combinations, and correlation tasks, found much more intra-individual variation than did Jackson (1965) and also clear evidence of differential task difficulty (in the order listed).

In another study, Neimark (1975b) examined at intervals during periods up to as long as nearly four years the performance of Ss initially chosen from grades three to six. Included in the study were tasks measuring the abilities to combine and permute and a variant of the correlation task. The permutation task involved having the S provide all the permutations of four digits. The combination task required the S to make all possible pairs of coloured squares, each square being one of six different colours. Significant correlations generally were found between the various measures of performance on the permutation and combination tasks. However, the majority of the correlations between these latter tasks and measures of correlation performance were not significant. This was due in part to the lack of consistent improvement with age of performance on the correlation task measures.

Finally, a study by Schwebel (1975), employing two groups of university students, one of 30 males, the other of 30 females, found generally no significant correlations between the flexibility of rods, balance, and inclined plane tasks. The correlations generally were in the low .30's, and only the correlation in the men's group between the inclined plane and flexibility of rods tasks was significant, $r = .37$, $p < .05$.

While the majority of the preceding studies, with the few exceptions noted (Kuhn et al., 1972; Neimark, 1970, 1975b; Ross, 1973; Schwebel, 1975), provide evidence for significantly consistent performance across the tasks employed, they are open to serious criticism. As none of these studies finding consistency controlled for differences among Ss in both age and IQ, the obtained positive correlations among tasks may have resulted, at least in part, from this lack of control. Clearly age is related to formal-operational thinking and intelligence also would seem to be (Bart, 1971; Hughes, 1965; Jackson, 1965).

In only six of the studies showing consistent performance across the tasks was some attempt made to control for either age or IQ. In none of these studies were both of these factors controlled. In the case of the IQ variable, employing Ss of different ages, Bart (1971) partialed out the effects of verbal intelligence, while Jackson (1965) and Lovell and Shields (1967) employed groups of Ss having IQs within a fairly narrow range. With regard to age, two studies (Arlin, 1974; Hughes, 1965) have definitely controlled for this variable; moreover, another study (Arlin, 1977) has employed Ss that might be expected not to vary greatly in age. Hughes employed Ss of the same age in a longitudinal study while Arlin (1974) found her sample was fairly homogeneous in terms of age. Although the ages in the study of Arlin (1977) were not reported, it is unlikely that Ss drawn from the same university class would vary widely in age.

In none of the preceding three studies in which there was at least some control for age were the effects of IQ removed. In the case of the study of Hughes the Ss clearly varied greatly in IQ as they were selected to be average or below average in ability. The variation in IQ among the university students employed by Arlin (1974, 1977) would not be expected to be as great as that among junior or senior high school students, but still might be considerable.

In conclusion then, the preceding studies which showed consistency of performance across tasks provide no evidence for the concept of a unified structure of formal operations, independent of age and IQ. In fact, of these studies, only three controlled, at least to some extent, for the former variable, and another three had some control for the latter. None controlled for both.

It is important to consider, furthermore, that several studies cited (Neimark, 1970, 1975b; Ross, 1973; Schwebel, 1975) did not find that the majority of relationships among tasks were significantly positive. These findings may be interpreted as running counter to the concept of a unified formal-operational structure. However, the validity of this interpretation may be questioned. In the case of the study of Schwebel, this lack of significantly consistent performance across tasks probably was due to the relatively small number of Ss in each group. In the case of the other studies, this lack of consistency may have resulted from one or more design weaknesses. These included the selection of Ss too young to be expected to be at the formal-operational stage; considerable variation in difficulty among the Piagetian tasks employed; the selection of tasks that were poor measures of formal-operational thought; and the use of procedures that deviated considerably from those of Inhelder and Piaget (1958).

For example, in the case of the study of Neimark (1970), the Ss selected were very young, their grade levels ranging from four to six. It would be expected that formal-operational thinking would not be achieved by many, if any, of these Ss. Furthermore, the correlation task employed was found to be more difficult than the other Piagetian task used (chemical combinations) and, in fact, may be a poor measure of cognitive level for any age group. In the later, longitudinal study Neimark (1975b) found no consistent age trends in performance on this task. Finally, Neimark's (1970) procedure for scoring the chemical combinations task can be criticized as deviating too far from that of Inhelder and Piaget. Credit was given primarily for how systematic the S's method of generating the combinations was. The S's knowledge cncerning the various chemicals, including which one was neutral and which inhibited the yellow colour, seems not to have been taken into account. Inhelder and Piaget considered both of these factors, that is, method and solution, when describing the levels of performance. Similarly, Ross (1973) gave credit only for the method in the chemical combinations task.

HISTORICAL OVERVIEW OF MEMORY RESEARCH

There have been basically two approaches to the study and understanding of memory. The first is the static approach, which was determined largely by the work of Ebbinghaus (1885) and influenced greatly verbal learning research in North America. The second, the dynamic approach, was determined to a great extent by the Gestalt theorists and Freudians and neo-Freudians.

Static Concept of Memory

The study of human learning and memory achieved scientific status with the work of Ebbinghaus (1885) on the learning and memory of nonsense syllables. His work, combined with the prevailing theoretical orientation of North American psychologists, namely behaviourism, resulted in a clearly defined approach to memory, which was dominant until the mid-1950's.

Underlying this approach were certain assumptions. For example, judging by the type of research carried on in this period, it would seem that the learner was assumed to be, or at least was treated like, a "tabula rasa" upon which experience was written. Learning and memory were treated in a quantitative manner with the acquisition of verbal stimulus-response units seen as a function of their reinforced contiguous occurrence. Differences among people, normals and subnormals, adults and children, were considered in quantitative terms; that is, the differences that existed were interpreted, not in terms of qualitative differences in functioning, but in terms of quantitative differences in memory capacity. The basic laws of learning and memory for humans were considered to be identical to those of lower animals. It was thought that more complex processes, of which only humans were capable, could at a later date be examined and in a sense could be derived in an additive manner from the understanding of these laws common to animals, children, and adults.

Learning and memory were considered as synonymous processes independent of others, such as perception, emotion, thinking, and reasoning. Except for motivation, understood in terms of need reduction through reinforcement, organismic variables were neglected. This neglect both resulted from and influenced the choice of learning materials and method of presentation. For example, the presentation of simple items such as nonsense syllables in paired-associate or serial lists resulted in learning material with minimal inherent order. Thus the role of the individual's past experience, reasoning, interest, and so forth was reduced. (See Mandler, 1967.)

Dynamic Concept of Memory

Historically, the dynamic approach concerning learning and memory was basic to two major theories, the Gestalt theory and the psychoanalytic theory.

Psychoanalytic view of memory. In the case of the psychoanalytic view, the term dynamic refers to motives and drives and psychic structures which determine behaviour, including learning and memory. In his early theories Freud inferred a "tabula rasa" type of memory in which practically every event that the person experienced was recorded. These memory events either were available in later years or were repressed. The repressed memories, while not conscious, were unaltered. However, Freud later discovered "screen memories," formerly repressed memories which come to consciousness in a distorted version of the original event. He also found that many of his patients' "traumatic" memories were in actuality only fantasies. These findings effected a revision of his former "tabula rasa" position to a more active "reconstruction" view. (See Reiff and Scheerer, 1959.)

A further extension of Freud's concept of memory resulted from the neo-Freudian emphasis on the role of the ego and its development. According to this view (Hartmann, Kris, and Loewenstein, 1946; Kris, 1956) the learner's level of development, including ego development, determines what is experienced and retained. Furthermore, even though an event may not be brought to awareness, subsequent memories may influence and change the original memory so that when it is brought to consciousness it will be in a changed form. In addition, what is remembered is more often a constellation of events rather than any single unchanged and completely intact trace. Thus recollection of a happening often involves reconstruction of this constellation of events; this reconstruction sometimes necessitates the aid of a therapist in the case of a long-forgotten or repressed memory.

Gestalt view of memory. Another main contribution to the dynamic approach to memory came from the Gestalt theorists. In this case, the dynamic aspect refers to certain processes which take place in perception, learning, and memory. The Gestalt modification of the trace theory (Koffka, 1935; Köhler, 1929; Wulf, 1922) postulated that experience is laid down in the brain by some sort of isomorphic process. What is laid down is determined both by the structure of the material, which is more than an aggregate of discrete stimuli, and the organizing activities of the individual. Furthermore, the traces which result are subject to modification by two influences; communication with other traces and stresses inherent in the trace. These influences effect through processes, such as sharpening and levelling, memory traces having maximum simplicity, symmetry, and good form. Thus, for example, working in the Gestalt tradition, Wulf (1922) found that visually perceived forms when reproduced at a later date showed evidence of the processes of sharpening and levelling.

Often considered a support for the Gestalt position is Bartlett's work on memory (Bartlett, 1932). Bartlett concluded that the perception and memory of experiences are rarely literal or precise but are determined by schemas, which are abstractions, simplifications, and articulations of experience. His concept of memory, while in the Gestalt tradition, marked a major deviation in that memory was not considered to be the result of the formation of isomorphic traces; rather it results from the interaction of stimuli and an already structured, active organization of schemas.

Recall becomes an active construction based upon the schema. While certain "dominant detail" of the original stimulus presentation does persist, the major component of the original situation that remains is the attitude--broadly conceived--which was involved in it. Reproduction then can be understood as an attempt to "justify" this attitude by "rationalization," "effort after meaning," and "fit."

<u>Piaget's theory of memory and its relation to other views</u>. The view of memory of Piaget (Piaget and Inhelder, 1968) is in the dynamic tradition and can be considered most closely related to that of Bartlett. Piaget stresses that memory of an event is not a passive recording but is closely bound up with the individual's level of understanding. Piaget makes a distinction between "memory in the wider sense" and "memory in the strict sense." The former involves the conservation of the general schemata in the form of repeatable processes and operations. The latter pertains to the recognition, reconstruction, and recall of situations, events, or objects which have been personally experienced and are localized in the past. Memory in the strict sense is a store of information in figurative form which has been encoded through the transformation of stimulus input by the schemata, or memory in the wider sense. Perception, understanding, and memory of events reflect the nature of these schemata, which change and develop as the child matures and interacts with his environment.

Piaget's concept of memory differs from that of Bartlett mainly in terms of the nature of the schemata. According to Piaget, the schemata proposed by Bartlett are basically mnemonic schemata, which are considerably less general than the structures of Piaget. The precise relationship of these structures to Bartlett's schemas, however, still remains to be determined.

It is interesting to note that the traditional static approach to learning and memory in North America began to lose its dominance in the mid-1950's with the emergence of a more dynamic and developmental approach to learning and memory. This emergence, while probably not due to Piaget's work on memory, presented a favourable environment for his ideas on memory to be explored and extended. This new approach in North America was in part a result of the general dissatisfaction with the trivialty and paucity of findings concerning memory after over half a century of research in the "static" tradition. The new view both resulted from and helped to produce a number of interesting research findings and modifications of experimental paradigms.

Such findings as the discovery of one-trial verbal learning (e.g., Estes, 1960; Rock, 1957) undermined the principles of frequency and contiguity as did evidence for active selection, mediational and organizational strategies on the part of the learner (e.g., Bousfield, 1953; Bugelski, 1962; Underwood, 1963). These strategies obviously were determined by the learner's past experience and were utilized to overcome both long and short term memory limitations. Similarly, such research findings as those concerning the efficacy of imagery to promote learning (e.g. Paivio, 1969), the qualitative differences in memory performance between children and adults (e.g., Bousfield, Esterson, and Whitmarsh, 1958), and the complexity of the supposedly simple paired-associate and serial paradigms (e.g., Battig, 1968; Jensen and Rohwer, 1965), were but a few of the causes and the results of the new Zeitgeist which challenged the traditional views.

Closely related to this new view were changes in methodology. Now in North America, tasks involving such materials as free recall lists, sentences, and paragraphs with testing by recognition and non-rote methods are commonly used, in addition to serial and paired-associate tasks.

STUDIES RELATING MEMORY TO COGNITIVE DEVELOPMENT

This section will provide (a) a general review of studies relating memory to cognitive development and (b) a specific discussion of studies relating memory to development from the concrete-operational to the formal-operational stage.

General: Memory and Cognitive Development

The following will include a discussion of Piaget's work on the relationship between memory and intelligence and the research of others who replicated and extended his work in both similar and different paradigms.

Piaget and Inhelder (1968) provide a number of studies to support their view that "memory in a strict sense" is dependent upon the operational structures available during both initial viewing and recall. Subjects of different ages were presented with a number of displays, each seemingly related to certain cognitive operations. Thus each display possibly required that the S possess the related operations in order to successfully memorize the display.

These displays included the following types:

1. Static presentations, such as an inclined bottle partly filled with water or a row of sticks decreasing in height.

2. Presentations involving transformations, such as the rotation of a triangle through 180 degrees.

3. Presentations of causally related events, such as the transmission of motion (one ball hits a fixed object, which transmits the motion to another ball touching the object).

Piaget and Inhelder reported two major findings. First, memory performance was found to be positively related to the child's assessed operative understanding or to the child's age, with operative level inferred. Second, in the case of some Ss, there was improvement in memory performance from the first test period to the second, even though the Ss were shown the memory displays only once. These improvements were considered to result from cognitive development during the test-retest interval, the operations thus developed presumably serving to improve the memory image through correction and reconstruction.

A small number of researchers working with memory tasks similar to those of Inhelder and Piaget attempted to replicate or extend their findings. One study (Altemeyer, Fulton, and Berney, 1969), employing kindergarten children, found that in approximately 40 percent of cases the memory drawings of a seriated array of sticks improved over a six month period. In another study, Furth, Ross, and Youniss (1974) found that memory drawings of such pictures as a tilted glass of liquid and a falling and turning stick depended upon age, and hence (they concluded) operative level. Certain improvements in memory over time also were interpreted by the authors as resulting from cognitive development.

Similar results were found by Liben (1974), who with fifth grade students found a small but significant relationship between assessed understanding of horizontality and memory drawings of a picture of a tipped bottle with water one week ($r = .39$) and six months ($r = .29$) after viewing. She concluded, however, that the small number of improvements in memory performance could be interpreted best as being due to chance.

In a study involving anticipatory imagery (Anooshian and Carlson, 1973), Ss in each of a number of trials viewed one of nine nonsense syllables and were asked to recognize from a sheet containing all the nine nonsense syllables the one they had just seen. Each of the nine nonsense syllables was presented in four ways, either in the position shown on the recognition sheet or rotated 180 degrees or 90 degrees to the left or to the right. The test of recognition took place immediately or after 10 seconds. The immediate memory performance correlated neither with IQ scores (Lorge-Thorndike Intelligence Test, Form A, levels 1 and 2) or operational understanding, as measured by conservation tasks (continuous quantity and length). Recognition scores after 10 seconds correlated significantly with both IQ and conservation performance. When IQ was held as a covariate, however, there was no significant relationship between recognition and conservation performance.

Other studies, while interpreting the results in terms of operational understanding, employed tasks such as paired-associate, free recall, or sentence recognition; these tasks are fairly dissimilar to those of Piaget and Inhelder and are more closely related to North American research paradigms. Wolf and Levin (1972), using a paired-associate task and instructions to form an interacting mental image of the objects in each pair, found that memory performance was superior in third grade children as opposed to kindergarten children. These results were interpreted by the authors as being due to the older children's ability to generate and use dynamic mental images without additional support provided, for example, by actual manipulation of the objects to form interacting pairs. The ability to produce dynamic mental imagery was presumed to be a concrete-operational skill, which the younger children had not yet achieved.

A number of studies employing some form of free or modified recall procedure have related increasing organization and recall of the items to increasing operational understanding. In a task involving free recall of an array of pictures followed by sequential location recall, Furth and Milgram (1973) reported evidence supporting an increase, from ages 4 to 12, in the ability to classify items into categories to facilitate recall. This increase was interpreted as due principally to the greater operative understanding of the older Ss. Similarly, Tomlinson-Keasey, Crawford, and Miser (1975), who classified kindergarten and first-grade children on the basis of class inclusion skills as classifiers and nonclassifiers, found (despite no significant difference in age between the two groups) that the classifiers both recalled significantly more items and showed significantly more clustering in recall than did nonclassifiers.

Another study (Haynes and Kulhavy, 1976) examined free recall performance of children in elementary and junior high school, who were at one of three developmental levels defined by their ability to conserve weight, mass, and volume. In the first of two experiments reported, a significant relationship was found between developmental level and both recall and clustering. The second experiment examined the use of paradigmatic, syntagmatic, category-inclusive, and unrelated words as cues. It was found that Ss who conserved volume were more inclined to select, and hence perhaps use, superordinate information as an encoding device than were less cognitively mature children.

One of the most recent of these studies involving some form of free recall is that of Arlin (1977), who employed a group of university students enrolled in the first class of educational psychology. They were required to recall an array of 12 types of objects after being asked to raise questions about this problem-rich array. The quality of these questions was considered to reflect problem-finding ability, which, according to Arlin (1975), when in the superior range is dependent upon formal-operational thinking but constitutes the stage beyond. Accuracy of recall of the items was significantly and moderately related to overall performance on formal-operational tasks assessing combinatorial and propositional thinking. The relationships increased from r = .38 for immediate recall to r = .59 for recall measured after one month. Also, there appeared to be a similar but slightly stronger relationship in both the original and retest periods between recall and the quality of questions asked concerning the array. Arlin concluded that the results imply that recall was related to the organization of the material that had taken place. In this case, the organization would seem closely associated with formal-operational thinking in the Piagetian sense and with problem-finding ability.

The final study to be mentioned (Prawat and Cancelli, 1976) examined the tendency to recognize sentences which were not presented initially but were correct logical inferences of the presented statements. The Ss were first grade children who were classified as conservers and nonconservers. The two groups thus formed were equivalent in age and IQ. A significant interaction was found. Conservers made slightly more errors than nonconservers on true inference sentences, whereas on the other types of sentences conservers made a similar number of errors or fewer errors than did nonconservers.

It must be noted that many of the memory experiments reported by Piaget and Inhelder (1968) in addition to several of the later studies cited (e.g., Furth and Milgram, 1973; Furth et al., 1974; Wolff and Levin, 1972) explored memory performance as a function of age. As many skills not clearly related to operational level develop with age, the interpretation of findings of relationships between age and memory performance in such studies is difficult to make.

In the majority of the studies cited where operational level was measured directly and not inferred from age, either or both of the possible covariates of operational level, age and IQ, were not taken into account. Without age and IQ held constant through S selection or statistics, any finding of a significant relationship between operational level and memory performance is again difficult to interpret. In the cases of the experiments of Piaget and Inhelder where operative understanding was assessed and the study of Haynes and Kulhavy (1976), there was no control for IQ and the ages of the Ss varied considerably. In the study of Arlin (1977) the ages and IQ's of the Ss were not reported, but it might be expected that the majority of the university students in the sample would be approximately the same age. Whether they differed much in IQ is not known. Two studies (Liben, 1974; Tomlinson-Keasey et al., 1975) clearly took into account age but not IQ. Liben used Ss from the same grade, while Tomlinson-Keasey found that the two groups, classifiers and nonclassifiers, formed from kindergarten and grade one children, did not differ in age.

In only two studies where operative level was assessed were both age and IQ taken into account. In the study of Anooshian and Carlson (1973) the effects of age and IQ were removed statistically. On the other hand, Prawat and Cancelli (1976) used Ss from the same grade and found that the conservers did not differ from the nonconservers in age or IQ.

Memory and Development
from Concrete to Formal Operations

Of particular relevance to the study reported here is that the majority of the studies discussed in the preceding section employed pre-teen Ss and interpreted results in terms of changes from preoperational to concrete-operational thinking. Very few studies investigated memory as related to the development in thinking from the concrete-operational to formal-operational stages.

In several of their memory tasks Piaget and Inhelder (1968) employed groups of Ss in which a few Ss were older than 11 years and thus possibly could be at the formal-operational level. However, successful performance in the majority of these tasks would seem to be related principally to achievement of concrete-operational thinking. Such tasks included remembrance of double classifications, remembrance of double serial correspondences, reconstruction of a geometrical configuration with partly regular and partly contingent elements, and remembrance of the movement of a three-sectioned lever fastened to a board by a central bolt.

Only one of the memory tasks of Piaget and Inhelder (1968) seems to be related to formal-operational thought. Employing Ss from 4 to 12 years, this task investigated the memory of the nine arrangements of three objects taken two at a time. It was found that correct memory drawings were made only by the older Ss. One of five 9-year-olds, two of six 10-year-olds, and four of seven 11-to 12-year-olds achieved correct memory performance. Piaget and Inhelder concluded that these successful Ss were in the formal-operational stage, and thus memory performance was related to formal-operational achievement.

A pilot study by this E indicated, however, that this conclusion may be unwarranted. Despite differences in operational level, as assessed by the chemical combinations, pendulum, and balance tasks, 18 of 19 grade seven girls made correct memory drawings of the nine arrangements.

Another study which investigated memory change as a function of development from the concrete-operational to the formal-operational stage is that of Arlin (1977). In this study, recall was found to be correlated with measures of formal-operational thought and problem-finding ability. However, Arlin (1975) concluded that formal-operational thinking is necessary but not sufficient for the development of the problem-finding stage. Therefore the relationship between recall and formal-operational thinking may not be direct in this particular case. As overall performance on the formal-operational tasks covaries with the measure of problem-finding ability ($r = .43$), the relationship found between formal-operational performance and memory performance possibly would be mediated to a great extent by problem-finding ability. The questions asked by the Ss concerning the array (the quality of which defined problem-finding ability) would serve as strategies to organize it; thus increased quality of the questions would result in more effective organizational strategies and hence better memory performance.

Furthermore, while the results of this study are of considerable interest, the task used is a very specialized case of free recall. The Ss were instructed to ask questions, which presumably could be used to organize storage and recall, the quality of these questions being known to be related to formal-operational thought. Furthermore, as mentioned previously, there was no clear control for age and IQ in this study.

In conclusion, then, it would seem that there has been very little work investigating whether there are changes in memory performance wrought by the achievement of formal-operational thinking. Neither within the Piagetian tradition nor with tasks more closely related to North American research paradigms has this question been investigated with a variety of memory stimuli seemingly related to the various important aspects of the lattice and INRC group. In fact the two studies cited which have investigated this question, the arrangement study of Piaget and Inhelder and the modified free recall study of Arlin, have been questioned concerning weaknesses in methodology, generality, and/or interpretation.

PURPOSE OF THIS STUDY

The two major aims of this study were to identify individual differences with respect to a unified formal-operational structure and to relate them to predictable differences in memory performance on a variety of tasks designed in the Piagetian tradition of memory research.

With regard to the first aim, two hypotheses were investigated. The first hypothesis was that each of a representative sample of formal-operational tasks would show significant positive correlations with the averaged performance of all the Piagetian tasks (excluding the task being correlated with the average). These significant correlations would be maintained even when the effects of age and a measure of IQ were removed. The second hypothesis was that one component, as indicated by a principal components analysis, would account for a considerable amount of variance in the formal-operational tasks.

With regard to the second aim, the principal hypothesis investigated was that both overall performance on a wide variety of memory tasks and performance on each of these tasks would be related significantly to overall differences in cognitive maturity, as measured by average performance on all the Piagetian tasks. It also was hypothesized that performance on each Piagetian task thought to be measuring a specific formal-operational scheme or concept would be significantly related to performance on a particular memory task or tasks thought to be related to the specific scheme. For example, it was expected that performance on the volume conservation task would be significantly related to performance on the memory task presumed to be related to the understanding of volume. All the preceding relations were expected to remain significant even when the effects of age and a measure of IQ were removed.

The final hypothesis pertaining to the second aim was that the magnitude of the correlations between Piagetian task performance and both overall memory performance and performance on specific memory tasks would be greater one month after presentation of the displays as compared to immediately following. Certain concrete-operational Ss may have memory (organizational) strategies sufficient to permit successful memory performance over the short term, but not over the long term. Successful long term memory performance was considered to require strategies involving a complete understanding of the task, presumably a function of formal-operational thought in this study.

Chapter 2

METHOD

In order to explain the method of this study, this chapter will provide the following:

1. a brief introduction to the general rationale of the method, followed by a more detailed description concerning the selection of Ss, the design, and the general procedure for testing and scoring.

2. a description of the assessment tasks, including the four Piagetian tasks and the vocabulary test of the Wechsler Intelligence Scale for Children, and the scoring criteria for these tasks.

3. a description of the memory tasks and their scoring criteria.

METHOD: GENERAL

In the case of the first aim of the study, to identify individual differences with respect to a unified formal-operational structure, each S was assessed through the chemical combinations, pendulum, balance, and volume conservation tasks. These assessment tasks were so chosen that together they were thought to measure all the important aspects of formal-operational thinking; thus they presumably could provide a solid estimate of operational level.

The first two tasks are considered more closely related to the lattice properties of formal-operational thought where the S must verify hypotheses by the systematic manipulation of variables. The particular schemes thought to be tested by these tasks were the combinatorial operations, in the case of the chemical combinations task, and the ability to hold variables constant to investigate the effects of others, in the case of the pendulum task. The latter two tasks are considered more closely related to the INRC group, with the balance task presumably requiring the concept of proportions and the volume task, the concept of multiplicative compensations.

With regard to the method of the present study, care was taken to avoid problems which could reduce the consistency of performance across the formal-operational tasks chosen. The Ss were selected from grade seven, because it was thought that this grade would be a time of transition to formal-operational thinking; thus a wide range of responses, including responses at the formal-operational level, might be expected. In addition, the tasks were presented in such a manner that they would elicit among the Ss a wide range of responses. Thus all the Ss would not find a task too difficult or too easy but would vary in their performance level. An example of this attempt to produce assessment tasks of equivalent difficulty which also elicit a wide range of performance among the Ss was the selection of the apparatus for the balance task. Inhelder and Piaget (1958, Chapter 11) provided a number of different models of the balance apparatus, differing, for example, in such features as the number of hooks on each side from which weights could be suspended. The type of apparatus selected for the study was the model which pilot work indicated would produce the desired range of responses. Finally, whenever possible, the method followed, particularly in the case of scoring, closely resembled that of Inhelder and Piaget in the essentials.

In the case of the second aim (to relate formal-operational competency to memory performance), each memory task was designed to relate closely to the various aspects of the lattice and/or INRC structures. Thus when considered together, the memory tasks would seem to be related to all the major aspects of formal-operational thought.

In order to make clear statements concerning whether the two aims were achieved in the present study, an attempt was made to control the two possible confounding variables, age and IQ. All the Ss were from the same grade in school, and any differences in age that remained were controlled by statistical procedures. A measure of IQ, the vocabulary test of the Wechsler Intelligence Scale for Children (Wechsler, 1949), was used, and any differences among Ss in this variable were taken into account.

Subjects

The Ss were 56 female grade seven students for whom E received parental permission to take part in the three sessions of the study. One of these Ss later became unavailable for the last session. Forty-seven of the Ss were from elementary schools where the principles of the balance had not been taught. Three of the remaining Ss were obtained through a community centre and six through acquaintances of the E; these girls were ones who stated that they had no experience with the balance. The average age of the Ss was 13.1 years. While exact details are not known, it would seem that the majority of the Ss came from working class and lower middle-class backgrounds.

Design

Each of the Ss was administered (a) five assessment tasks, including four Piagetian tasks to assess level of understanding and the vocabulary test of the Wechsler Intelligence Scale for Children to estimate IQ, and (b) eight memory tasks.

General Procedure

One E administered the five assessment tasks during the first session, while another E was responsible for the memory tasks in the second and third session. During the second session, occurring usually a day after the first, the eight memory displays were presented and each display was tested. The final session, which took place four weeks after the second, involved only the testing of the memory of the displays with no further presentation of them. In this session the E, for each memory task except Task 1, both reviewed how each display had been introduced in the last session prior to the viewing period and re-explained the testing procedure. In the case of Task 1, the S was questioned in a nonleading manner as to what had taken place in the last session and then memory performance was tested.

In all sessions the S was tested individually, and an attempt was made to ensure that the S was relaxed before testing began. The S was encouraged to speak freely concerning what she was doing and why, and if any doubts existed concerning these points, she was questioned.

The assessment and memory tasks were administered to all Ss in the order they are presented in this chapter.

The tasks were scored by the E who had administered them. In order to evaluate interrater reliability of the scoring of the Piagetian tasks, 10 response protocols were randomly selected in the case of each task. These protocols then were scored by a person not involved in the study. The correlation coefficients between this person's scoring of the protocols and the E's scoring of them were as follows: chemical combinations .86; pendulum .94; volume conservation .99; equilibrium in the balance .96.

ASSESSMENT TASKS

The following provides a description of the assessment tasks, including the four Piagetian tasks and the vocabulary test of the Wechsler Intelligence Scale for Children, and the scoring criteria for these tasks. In the case of the scoring of each Piagetian task, the basic performance measures will be discussed and then the method of integrating these measures to form the substages of concrete-operational and formal-operational performance will be described. Three of the Piagetian tasks, chemical combinations of colorless liquids, pendulum, and equilibrium in the balance, are described in Inhelder and Piaget (1958). The fourth, the conservation and measurement of volume task, is from Piaget, Inhelder, and Szeminska (1960).

Chemical Combinations of Colorless Liquids

In this task the Ss were presented with five small bottles with droppers; each bottle contained a colorless liquid and was labelled 1, 2, 3, 4, or g. The Ss also were presented with a box of test tubes and two test tubes containing clear liquid into which the E had added several drops from the g bottle. In one of the two test tubes to which the E had added liquid from bottle g, a color change took place. Initially, the liquid took on a yellow tone which gradually turned brown. The S was told that these latter two test tubes both contained liquids taken in some way from the bottles. The S's task was to reproduce the color using liquids from the bottles as she wished and using as many of the test tubes as she wished. At any time when the S indicated that she had solved the problem or could not think of anything else, she was asked if there was anything else that she could do. When the S said she was finished and did not wish to continue, even after the preceding questions, she was questioned concerning the way(s) of making the yellow color, the roles of liquids 2 and 4, and what combinations she considered in determining the roles of 2 and 4.

Scoring

Basic Measures. The two basic measures, which related to how systematic the S's method was and to what extent the S determined the solutions to the problem, were as follows:

1. Method measure. The score on this measure was the number of different combinations the S made minus the number

of repetitions which the S did not appear to know were repetitions when asked by the E why she had made the particular combination. If the S worked systematically until she found one combination that made yellow and then went on to test the role of the members of the combination, a procedure that often would produce repetitions, she still was considered to have an excellent score on the method measure.

2. Solution measure. The S's solution score was based on her answers to the E's questions concerning the way(s) of making the yellow color, the roles of liquids 2 and 4, and the combinations she considered in determining the roles of 2 and 4. These measures were scored as follows with a resulting maximum score of seven:

a. One point for each combination found and correctly stated as making the yellow color.

b. One point for stating the correct combinations compared to determine the role of 2 (1 + 2 + 3 + g and 1 + 3 + g); if the preceding comparison was correct, one point for correctly stating the role of 2.

c. One point for stating the correct combinations compared to determine the role of 4 (1 + 3 + g and 1 + 3 + 4 + g and/or 1 + 2 + 3 + g and 1 + 2 + 3 + 4 + g); if the preceding comparison was correct, one point for stating correctly the role of 4.

d. One point for correctly stating the role of 2 as being different from that of 4.

<u>Substages of performance</u>. In order to integrate the method and solution measures to form substages of performance, the scores on these measures were classified as follows:

Classification	Method measure: no. of different combinations minus no. of repetitions	Solution measure: no. of points
poor	$\leq$ 7	$\leq$ 2
average	8 - 11	3 - 4
good	12 - 13	5 - 6
excellent	14 - 15	6 - 7

The five substages of performance (and their point values) formed from considering the classifications obtained on both the method measure and the solution measure are outlined below. The achievement required for each substage is listed to the right.

1. Substage 2 A, 3 points, poor method and poor solution;

2. Substage 2 B, 4 points, average method and poor or low average solution or average solution and poor or low average method;

3. Substage 2 B+, 4.5 points, poor method and good solution or good method and poor solution;

4. Substage 3 A, 5 points, average method and good or excellent solution or good or excellent method and average solution;

5. Substage 3 B, 6 points, good or excellent method and good or excellent solution.

While the majority of performances fell within the preceding substages, the few that did not fit precisely were classified with these substages in mind.

Pendulum

As seen in Figure 1, a simple apparatus was used in the pendulum problem. It consisted of two strings of equal

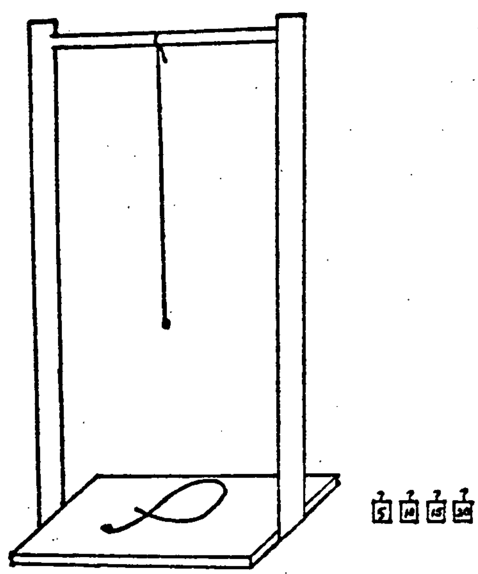

Figure 1. Apparatus for pendulum task.

length, four different weights of equal volume, labelled 5 oz., 10 oz., 15 oz., and 20 oz., and a support on which to tie these string(s) and hang the weights. The pendulum, the weights, and the string(s) were presented to the S. With one string, the S was shown how to tie the string to produce the various lengths. The other string was pointed out as it lay at the base of the support. The _S_ was asked to determine which factor, factors, or their combination(s) determined the frequency of the oscillation, or more simply, the time it takes for the pendulum to make one complete round trip. The possible factors, weight, length of string, and amplitude, were explained to the _S_. While experimenting, the _S_ was asked throughout what she was doing and finding out. If the _S_ failed to test the effect of one or more variables and said she had solved the problem, she was asked if there was anything else that might have an effect. If the _S_ could not remember, she was reminded of the untested variable(s). After finishing experimenting, the _S_ was asked to write down her solutions to the problem. If she failed to mention one or more variables in her solution, she was asked if there was anything more to her solution. If she still did not mention all three variables, the role of the neglected variable(s) was questioned. After the _S_ finished writing down her solution, she was questioned concerning any portions of it which were difficult to understand. Then, if the _S_ had not used both strings simultaneously while experimenting, she was instructed to do so and to test again the effects of the three variables.

Scoring

Basic measures. The two basic measures, which related to the S's method and to her solution, were as follows:

1. Method measure. The method measure was based primarily on the S's testing procedure prior to the writing of her solution. For those Ss who did not use both strings simultaneously during the initial experimentation, the method during the period of experimentation following the writing of the solution was taken into account only when (a) there was some doubt as to whether the S was holding variables constant in her testing of one or more variables in the initial period, sometimes the case, for example, when the S had very few trials, or (b) the classification of the S's performance was unclear.

There was a maximum of one point for each variable, which was given in the following manner:

a. One point for holding constant everything but the variable under consideration. Full credit was given if there was evidence that after some trials of incorrect testing the S seemed to "catch on" and began to test correctly.

b. One point for reversing variables which were not held constant. For example, in the case of the length variable, full credit was given if the S, using two strings of different lengths to test the role of length, put one weight on one string and a different weight on the second, tested what happened, and then repeated the procedure with the weights and strings used before but with each weight placed on the other string.

2. Solution measure. The solution measure was based on the S's written statement concerning the roles of the three variables, weight, length of string, and amplitude, on the frequency of oscillation. There was a maximum of one point for each variable, which was given in the following manner:

a. One point for correctly stating the role of the variable if the effects of the variable had been tested and a similar conclusion reached during the testing period.

b. No point for stating correctly the role of a variable if its effect had not been tested or a different conclusion had been reached during the testing period.

c. One-half credit for incorrectly stating the role of the variable if consistently correct conclusions had been reached during the testing period.

Substages of performance. In order to integrate the method and solution measures to form substages of performance, the scores received on the method and solution measures were classified as excellent if they were three points, good, if two points, average, if one point, and poor, if no points. The five categories of performance (including point values) formed from considering the classification obtained on each measure are outlined below with the achievement required for each category listed to the right:

1. Substage 2 A, three points, poor method and average or poor solution or average or poor method and poor solution;

2. Substage 2 B, four points, average method and average solution or good method and poor solution;

3. Substage 2 B+, 4.5 points, good or excellent method and average solution or average method and good or excellent solution;

4. Substage 3 A, 5 points, good method and good solution;

5. Substage 3 B, 6 points, excellent method and good or excellent solution or good or excellent method and excellent solution.

If the S's performance bordered between two classifications, greater weight was given to method than to correct solution; that is, the classification of Ss whose method was acceptable tended to be moved upward, while the classification was moved downward if the method was not acceptable. Also, in the case of the borderline Ss, if their methods seemed acceptable but there were very few trials to judge properly, the classification tended to be moved downward. If any performances did not fit exactly into these substages, they were assigned with these substages in mind.

Conservation and Measurement of Volume

Five subtasks were involved in this assessment. The procedures for these tasks were as follows:

1. The S was shown a solid wooden model 3 X 3 X 4 centimetres and was asked to reproduce with plastic bricks, each 1 cubic centimetre, an identical building some distance away from the model. The S's construction was halted when the S had shown what she considered to be the number of bricks required for the base and for the height.

2. The S again was shown the wooden model (3 X 3 X 4 centimetres) and was asked to construct from the 1 cubic centimetre plastic bricks a number of buildings having the same volume as the model. However, the buildings were to be constructed on different-sized plots of land which included 2 X 2 centimetres, 2 X 3 centimetres, 3 X 4 centimetres, 1 X 2 centimetres, and 1 X 1 centimetre. Generally, once the S indicated her final idea of how high the building would be, she was not required to continue construction.

3. The E built with the plastic bricks a building 3 X 4 X 3 centimetres and then with the same bricks constructed a building 2 X 2 X 9 centimetres. The S was questioned as to whether the two buildings had the same or different volumes.

4. The S was asked to compare the volumes of six pairs of wooden models. She was asked to determine if the

members of each pair had the same or different volumes and was to explain her conclusion for each pair. The S was provided with six plastic bricks and was advised that she could use them to help her solve the problem. The members of the first two pairs had the same dimensions, but one member of the pair was placed differently so that the height of the two members differed. The members of the other pairs had different dimensions. The dimensions of the six pairs were (a) 1 X 2 X 1 centimetres, 1 X 1 X 2 centimetres, (b) 1 X 3 X 1 centimetres, 1 X 1 X 3 centimetres, (c) 2 X 2 X 3 centimetres, 1 X 1 X 12 centimetres, (d) 2 X 3 X 3 centimetres, 1 X 2 X 9 centimetres, (e) 1 X 2 X 9 centimetres, 4 X 3 X 2 centimetres, and (f) 4 X 3 X 2 centimetres, 12 X 2 X 1 centimetres.

5. The E built with metal blocks, each 1 cubic centimetre, a house, 3 X 3 X 4 centimetres, in a glass dish having a base of 10 inches by 4½ inches and a height of 3 inches. The dish was filled two-thirds full of water. The S was asked to predict whether there would be any change in water level if the bricks were rearranged by cutting the building vertically and separating the two parts or by spreading all the bricks along the bottom of the dish. If the S was successful in these predictions, she was further questioned as to whether there was any way the bricks could be rearranged under the water to affect the water level.

Scoring

Basic measures. Performance on the five subtasks provided five measures of performance.

Substages of performance. The following four substages (including their point values) are based on success in the number of subtasks noted to the right of the substage;

1. Substage 2 A, 3 points, two tasks;
2. Substage 2 B, 4 points, three tasks;
3. Substage 3 A, 5 points, four tasks;
4. Substage 3 B, 6 points, five tasks.

The total point value of the S's classification was modified slightly in two cases. First, .25 was subtracted for each task in which the S was finally successful but had a considerable amount of difficulty. Second, in the case of subtask 4, .25 was subtracted if, in comparing the volumes of the pairs of models, the S, in a majority of trials, did a good deal of placing one model against the other rather than using the bricks to measure.

Equilibrium in the Balance

As seen in Figure 2, this apparatus involved a simple balance with 11 equidistant hooks on each side and a set of weights. These weights included a pair marked 5 oz. and three individual ones marked respectively 10 oz., 15 oz., and 20 oz. The S was required to try to understand the

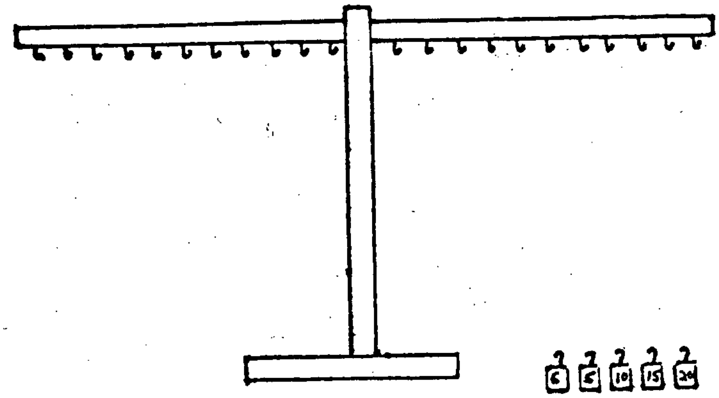

Figure 2. Apparatus for equilibrium in the balance task.

principle of the balance so that in a testing situation she could balance all the six combinations of the four different weights with one member of each combination placed by the E.

The S first was given the 5 oz. and 10 oz. weights and was asked to put the balance in equilibrium with equal weights on each side and then with unequal weights on each side. The S was required to balance the 5 oz. and the 10 oz. weights at at least three different places. The S then was encouraged to experiment with the remaining five combinations of weights. While the S was free to choose the order the combinations were tried, she was encouraged to try each combination of weights at at least two different places. If the S failed to try all combinations, the neglected ones were suggested. Throughout the trials the S was asked why the weights were in balance.

After the learning period, the S was tested by being required to balance pairs of weights with one member of the pair being placed by the E. Each of the six combinations of weights was tested two times with the weights at different places. The S was questioned after each balancing as to why the weights were in equilibrium. Subjects who experienced difficulty in achieving equilibrium were asked on several test trials, once equilibrium was achieved, to reachieve equilibrium by reversing the weights (moving each weight to the correct place on the opposite side of the balance). When the testing of the combinations of weights was completed, the S was asked to state a general principle to cover as many cases as possible.

Scoring

Basic measures. The basic measures of the S's performance during the testing period included assessments of the following abilities outlined briefly below in ascending order of difficulty:

1. the ability to move weights in the appropriate direction when balancing them;

2. the ability to reachieve equilibrium with different weights already in balance by reversing them;

3. the ability to understand the balancing of a few

pairs of weights including (a) at least one pair where the members have a two-to-one ratio and (b) at least one other combination not involving a two-to-one ratio;

4. the ability to balance correctly the six combinations, but with no understanding, in terms of proportion, as to why the weights are in balance;

5. the ability to understand the balancing of all the simpler combinations (5 oz. and 10 oz., 5 oz. and 15 oz., 5 oz. and 20 oz., 10 oz. and 20 oz.) where the ratio of the weights does not involve a mixed number;

6. the ability to provide a general rule to explain the balancing of the simpler combinations;

7. the ability to understand the balancing of the more complex combinations (10 oz. and 15 oz., 15 oz. and 20 oz.) where the ratio of the weights involves a mixed number;

8. the ability to provide a general rule to explain the balancing of all the combinations.

Substages of performance. The following substages (including their point values) are based on the assessed achievement of the abilities listed to the right of the category:

1. Category 2 A, 3 points, none of the above abilities;

2. Category 2 A-2B, 3.5 points, ability 1 or 2;

3. Category 2 B, 4 points, abilities 1 and 2;

4. Category 2 B-3 A, 4.5 points, abilities 1, 2, and 3 or 1, 2 and 4;

5. Category 3 A, 5 points, abilities 1, 2, 3, and 5;

6. Category 3 A+, 5.25 points, abilities 1, 2, 3, 5, and 6;

7. Category 3 B-, 5.75 points, abilities 1, 2, 3, 5, 6, and 7;

8. Category 3 B, 6 points, abilities 1, 2, 3, 5, 6, 7, and 8.

Vocabulary Test: Wechsler Intelligence Scale for Children

The method of administering the vocabulary test, including the procedures for scoring the responses and scaling the total score according to age, were as prescribed in the WISC test manual (Wechsler, 1949). This vocabulary test has been found by its developers to have a correlation of .78 with the full scale of WISC in the case of children 13½ years of age. This is the age having correlations reported which is closest to the average age of the Ss in the present study. The full scale of WISC involves a composite of the results of five verbal tests, including the vocabulary test, and five performance tests.

MEMORY TASKS

The eight memory tasks can be grouped into four categories involving memory displays designed to relate to four aspects of formal-operational understanding: volume conservation, combinations, permutations, and the lattice of propositions.

For each category of memory display, the following provides an introduction to the category, a description of the materials of each task in the category, and the scoring criteria. The method of achieving an overall memory score which includes the performances on all the memory tasks also will be described.

Memory Related to Volume Conservation and Measurement: Task 1

Task 1 is related to the conservation of occupied volume, which, as described previously, involves the understanding that the room or volume occupied by an object remains the same when the shape, but not the volume, of the object is modified. This particular conservation is considered a formal-operational achievement involving the concept of multiplicative operations.

In this task the S watched while two balls of clay of equal shape and volume were placed in identical containers, each having equal amounts of water. The balls were removed from the water, one was reshaped into the form of a sausage, and then they both were placed again in the container. The

S was asked to look at the container so that she could later remember what she saw.

The possibilities investigated in Task 1 were that the S's recall and recognition of the water levels would be related both to general formal-operational understanding and to less general competencies. The latter included the understanding of volume conservation in general and conservation of occupied volume in particular. The possible relationship between volume conservation in general and memory performance probably would be mediated principally by the understanding of the conservation of occupied volume. This conservation would seem the most closely related to the memory task and forms part of the general understanding of volume.

General formal-operational ability would be indicated by average performance on the Piagetian tasks. Understanding of volume conservation in general and conservation of occupied volume in particular would be indicated respectively by overall performance on the volume conservation and measurement task and specific performance on subtask 5. In this subtask the S was required to predict whether the water level would stay the same or would change when the metal bricks of a building constructed under water were rearranged.

Method

Materials: Display 1. The materials included two clay balls, each of 50 grams, two amber-colored glasses, approximately five inches in height with a diameter of two and three-quarters inches in height at the top tapering to two inches at the base, a graduated cylinder, and a pair of tongs.

Procedure. The two glasses were placed approximately two feet apart in front of the S. The two balls of clay were shown to the S, and their identical nature in terms of shape, volume, and weight was emphasized. In each glass was put one ball of clay and then 200 millilitres of water, measured carefully and obviously in the graduated cylinder by the E. The S was asked concerning the equality of the water levels, and, when the E was assured that the S considered the levels equal, both balls of clay were removed with tongs from the glasses. One was put back in one glass and the other was reshaped into the form of a sausage and then returned to the other glass. The S was permitted to view the two glasses and their contents for 10 seconds and was advised to remember what she saw.

One hour after viewing, the S was presented with a drawing of the outlines of both glasses and was asked to draw what she had seen. If the S failed to draw the clay and/or water levels, she was prompted by the question "Anything else?" until she did so. Her drawing then was removed, and she was asked to select from three drawings the drawing closest to what she had seen. Each drawing was of two glasses, one containing the sausage and the other, a ball of clay. The drawings were identical except for the water levels of the glasses. In one drawing, the levels were identical. In the second, the water level of the glass with the sausage was slightly lower than the level of the glass with the ball. In the third, the reverse was true; the water level of the glass containing the sausage was slightly higher than that of the glass containing the ball.

After the S made her choice, the drawings were removed and she was shown her previous drawing and asked why she had drawn the levels the way she had. If the S replied that she simply had remembered them that way, she was asked if there were any other reasons.

Scoring. The measures of performance included two basic measures and a third measure which was a composite of the first two. The first involved whether the S drew the water levels as equal or unequal. The second concerned whether the S selected as similar to what she had seen before either the drawing containing glasses with equal water levels or one of the two drawings of glasses having unequal water levels. For each measure, the incorrect response was awarded 0 points, the correct response, one point. The third measure, the composite score, was the sum of the points achieved on the first two measures.

Memory Related to Combinations: Tasks 2 and 3

As mentioned previously, the achievements of the formal-operational stage include, among other developments, the understanding of the lattice of propositions and the attainment of a number of formal-operational concepts. The latter include combinatorial operations, which are of interest here. These operations involve the ability to make in a systematic manner all the combinations and/or permutations of a set of objects.

According to Inhelder and Piaget (1958) the understanding of the organized lattice structure and the combinatorial operations appear together and are closely related. At the point of time where children first show evidence of reasoning in terms of the propositional combinatorial system, they also spontaneously (as indicated by the experiment involving combinations of colorless liquids) begin to make systematic one-by-one, two-by-two, three-by-three, and four-by-four combinations. Inhelder and Piaget conclude:

> The combinatorial operations do not actually belong to the set of propositional operations and do not derive from them; on the contrary, they are the prerequisite condition of their development (and as such they are quite different). (p. 313)

Piaget and Inhelder (1975) provide a detailed description of the stages in the development of the combinatorial operations; these stages correspond to the preoperational, concrete-operational, and formal-operational stages. In the case of combinations they include:

1. Stage one, up to 7 years of age, which involves the empirical discovery of combinations without system and simply by means of groping (e.g., by looking to see what might be missing).

2. Stage two, 7 to 11 years, where some combinations are made by rudimentary systems, while the remainder are determined empirically by groping.

3. Stage three, from 11 or 12 years, which involves the discovery of a system to generate all the combinations.

The displays of the following two tasks involve the presentation of complete sets of combinations. Task 2 tested the reconstruction of the 15 possible combinations of the four base associations, red dog, green dog, red cat, green cat. These associations were formed from the multiplication of two variables (type of animal and color), each having two values (dog and cat or red and green).

While any task involving combinations presumably is related to the understanding of the lattice structure in addition to the understanding of the combinatorial operations, it was thought that this task was particularly closely related to the former. The lattice, as described previously in terms of the example involving the variables of size (fat or thin) and state of mind (happy or sad), consists of all the possible combinations of four base associations. These associations, in this case, fat and happy, fat and sad, thin and happy, thin and sad, are formed from the multiplication of two variables, each having two values. Thus the similarity between the display of Task 2 and the lattice can be seen; both involve all the combinations of the base elements formed by the multiplication of two variables each having two values.

Task 3 tested the children's reconstruction of the 15 possible combinations of four different objects, truck, Cadillac, Volkswagen, and motorcycle. The display of this task, while presumably not as closely related to the lattice structure as that of Task 2, still would be expected to be related to the understanding of the lattice of propositions in addition to the understanding of combinatorial operations.

In conclusion, then, the possibilities investigated were that performance on Tasks 2 and 3 would be related to the understanding of both the lattice and the combinatorial operations. A good indicator of the former general understanding would be the average of all the performances on the Piagetian tasks. The latter specific competency presumably would be related to performance on the chemical combinations task and more specifically to performance on the basic method measure of this task.

Method

<u>Materials</u>. The materials for the two displays were as follows:

1. Display 2, Combinations of Animals. Figure 3 shows the top one half of the display of the 15 combinations of four animals, red dog, green dog, red cat, and green cat. The animals, approximately three-quarters inch in height, had a sticky back surface which adhered to the cardboard sheet measuring 12 inches by 18 inches.

2. Display 3, Combinations of Vehicles. Figure 4 shows the bottom one half of the display of the 15 combinations of four vehicles, truck, Cadillac, Volkswagen, and motorcycle, which were stuck on a cardboard sheet 12 inches by 22 inches. The vehicles varied in length from approximately one inch (truck) to one-half inch (motorcycle).

<u>Procedure</u>. In both Tasks 2 and 3, each <u>S</u> was told that she was to try to remember the total display in both the correct horizontal and vertical order. For each display the <u>S</u> was asked to determine the rule or order involved in the display in order to help her remember it. The <u>S</u> was permitted to view each display for four minutes. After each viewing the <u>S</u> was given a cardboard sheet identical to the one on which the display had been mounted. To the left of the cardboard sheet were placed four piles of cutouts, one pile for each of

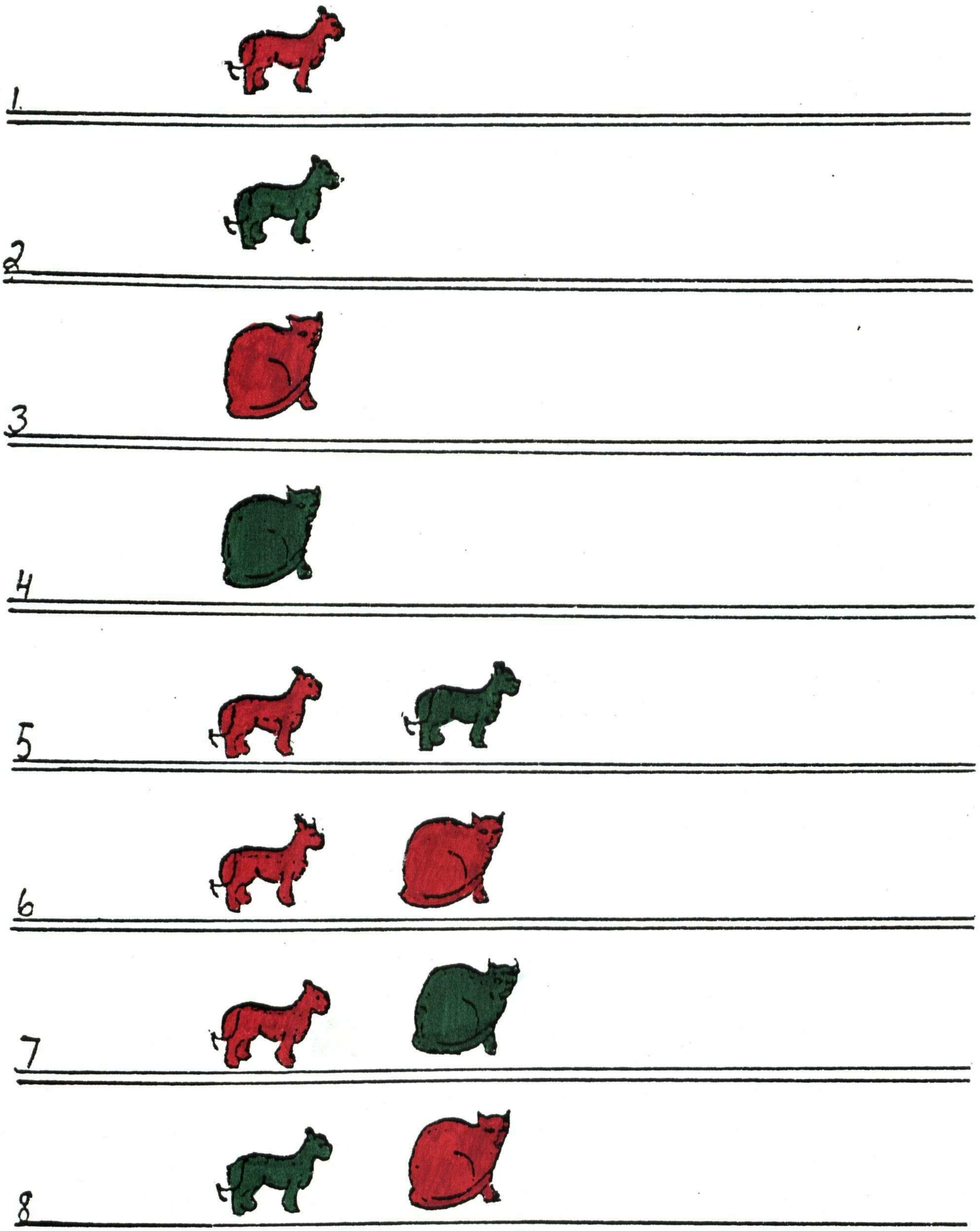

Figure 3. The top one half of the display of the 15 combinations of four animals, red dog, green dog, red cat, and green cat.

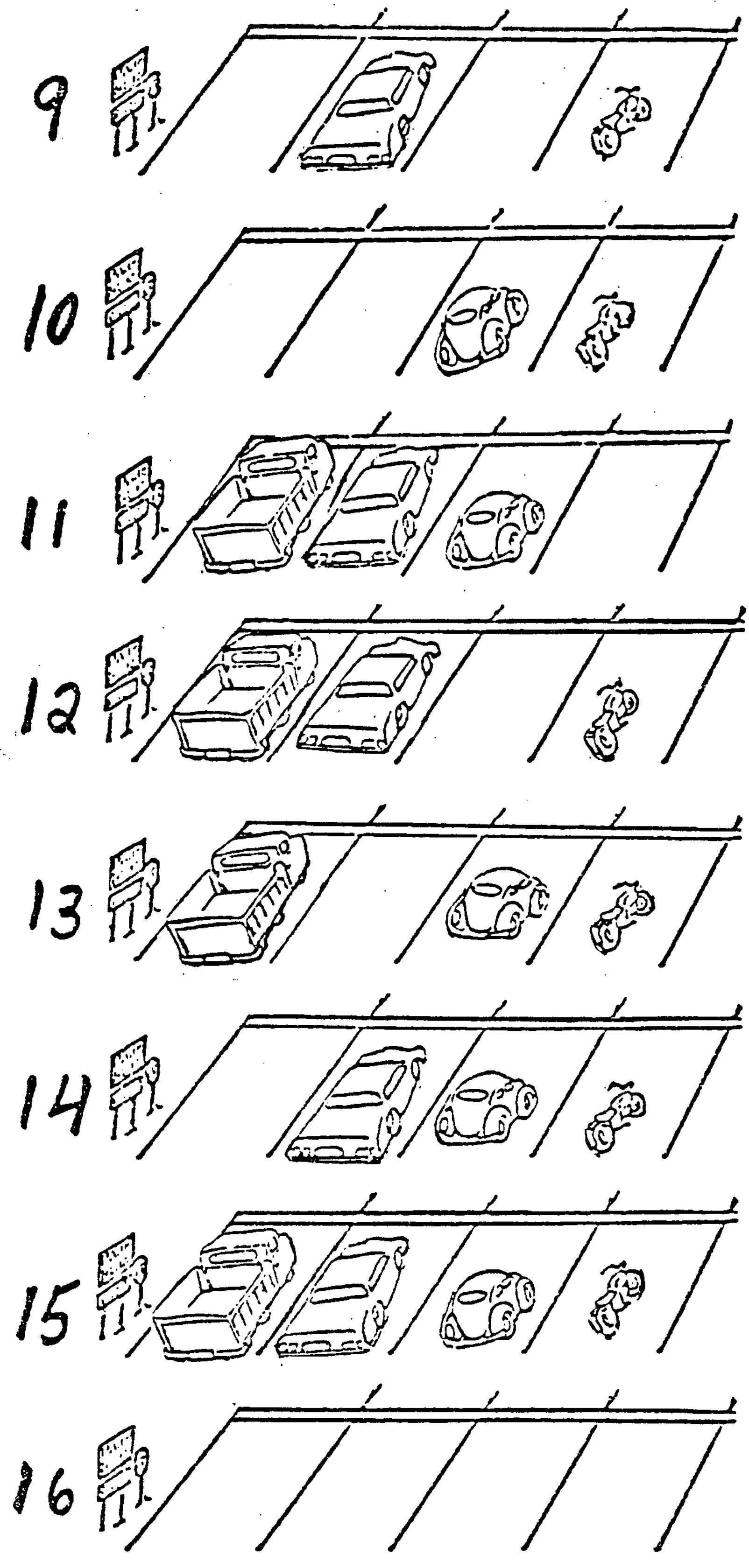

Figure 4. The bottom one half of the display of the 15 combinations of four vehicles, truck, Cadillac, Volkswagen, and motorcycle.

the four different kinds of animals or vehicles. The _S_ was advised that she had been given more cutouts than she needed and was asked to place the cutouts on the cardboard in exactly the same way as she had seen them.

Scoring. The measures of performance included three basic measures and a fourth measure which was a composite of the first three. The first basic measure was the number of different combinations reconstructed. If a combination was repeated, credit was given for only one of these combinations. For this measure, the horizontal order of the combination did not matter; for example, 132 (truck, Volkswagen, and Cadillac) would be given credit even though the correct horizontal order was 123 (truck, Cadillac, and Volkswagen).

The second and third basic measure evaluated the extent to which reconstruction reflected the system used to generate the displays. These measures can be explained in terms of Table 2, which shows part of the display of combinations of the four kinds of animals and a record of some of the combinations reconstructed by one _S_. The scoring of the preceding two sets of combinations in terms of the two systems measures is illustrated. In Table 2, the four types of animals, red dog, green dog, red cat, green cat, are indicated respectively by 1, 2, 3, 4.

The horizontal order measure provided one point for

Table 2. Sample of combinations in the original display and in a S's reconstruction, with successive pairs scored for horizontal and vertical order.

Display			Recall of S		
Combinations	Horizontal order points	Vertical order points	Combinations	Horizontal order points	Vertical order points
2 3	1		2 3	1	
)		1	)		1
2 4	1		2 4	1	
)		1	)		1
3 4	1		4 3	0	
)		1	)		1
1 2 3	1		1 2 3	1	
)		1	)		1
1 2 4	1		1 2 4	1	
)		1	)		0
1 3 4	1		2 3 4	1	
)		1	)		0
2 3 4	1		1 4 3	0	

Note: Numbers 1, 2, 3, and 4 refer respectively to red dog, green dog, red cat, and green cat.

each combination in the correct horizontal order. The vertical order measure involved comparing successive pairs of combinations (as indicated by the curved lines). One point was given for each pair in the correct vertical order regardless of whether the horizontal order of the members of the pair was correct or not.

In order to obtain the composite score, the vertical order score, which had a maximum of 14 points, was multiplied by 1.07 to make it comparable to the two other basic measures both having a maximum of 15 points. Scores on the three basic measures then were added to form the composite score. This composite score was such that the greatest credit was given to combinations reconstructed systematically in the correct vertical order, lesser credit was given to combinations reconstructed somewhat systematically in either the correct horizontal order or the correct vertical order, and least credit was given to combinations where both the horizontal and vertical orders were incorrect.

Memory Related to Permutations: Tasks 4 and 5

The ability to systematically make all the permutations of a number of objects is another manifestation of the combinatorial operations, which, as mentioned previously, are closely related to the understanding of the lattice. Piaget and Inhelder (1975) have outlined the following three stages in the development of the understanding of permutations:

1. Stage one, up to 7 or 8 years, which involves permutations found by groping with the absence of any systems.

2. Stage two, 7 or 8 to 11 or 12 years, which involves partial systems to generate some permutations with some others found by groping.

3. Stage three, after 12 years, which involves the progressive discovery of a system to generate all permutations.

The following two tasks involve displays which showed permutations of three or four items. Task 4 tested the child's memory of the six permutations of three people (father, mother, and son) seated on a chesterfield. Task 5 involved the 24 combinations of four people (father, mother, son, and daughter) similarly seated. The display of permutations in both tasks was derived by holding constant the initial member(s) of a permutation while varying the last members. For example, the second permutation, 1243, is derived from the first, 1234, by holding 1 and 2 constant and changing the position of 3 and 4.

A modified testing procedure was followed in which the S was required to reconstruct the display by working from top to bottom and was permitted to view only the last permutation she reconstructed. It was thought that this method would reduce the likelihood of the S's finding missing permutations by groping; this method might increase the probability that reconstruction of the permutations would be related to understanding of the rule inherent in the display.

The possibilities investigated were that success in Tasks 4 and 5 would be related to the understanding of the lattice and to more specific competencies. The latter included combinatorial operations involving permutations and the scientific method of holding variables constant while manipulating others to test their effects. Presumably the understanding of the lattice would be indicated by overall formal-operational understanding, as evidenced by the average of the performances on all of the Piagetian tasks. Combinatorial operations concerning permutations might be assessed by the chemical combinations task and more specifically by the basic method measure of this task. However, this assessment might be somewhat indirect. According to Piaget and Inhelder, the ability to permute, while related to the ability to make combinations, is not identical and develops at a later age; the latter ability presumably is more closely related to performance on the chemicals task than is the former.

The method of holding variables constant while manipulating others might be assessed by the pendulum task and more specifically by the basic method measure of this task. It must be noted, however, that this experimental method of holding variables constant is analogous but certainly not identical to the method of generating the display; the latter method involved holding the first member(s) constant while changing the position of the last two.

Method

Materials. The materials for the two displays were as follows:

1. Display 4, Permutations of Three People. As shown in Figure 5, this display involved six permutations of three people, father, mother, and son. Cutouts of the people, ranging from approximately two inches (father) to one and three-quarters inches (son), were stuck on chesterfields which were drawn on a cardboard sheet approximately 12 inches by 18 inches.

2. Display 5, Permutations of Four People. Figure 6 shows the first six permutations of the display of the 24 permutations of four cutout people stuck on chesterfields. The display involved two columns, each with 12 chesterfields containing people. The cutout figures ranged from approximately one and one-quarter inches (father) to three-quarters inch (daughter), and the cardboard sheet containing the chesterfield outlines measured 12 inches by 18 inches.

Procedure. The procedure in the case of Tasks 4 and 5 was identical to that followed in the memory task involving combinations with the following exceptions. Before viewing each display, the S was advised that in the testing

Figure 5. The six permutations of three people, father, mother, and son.

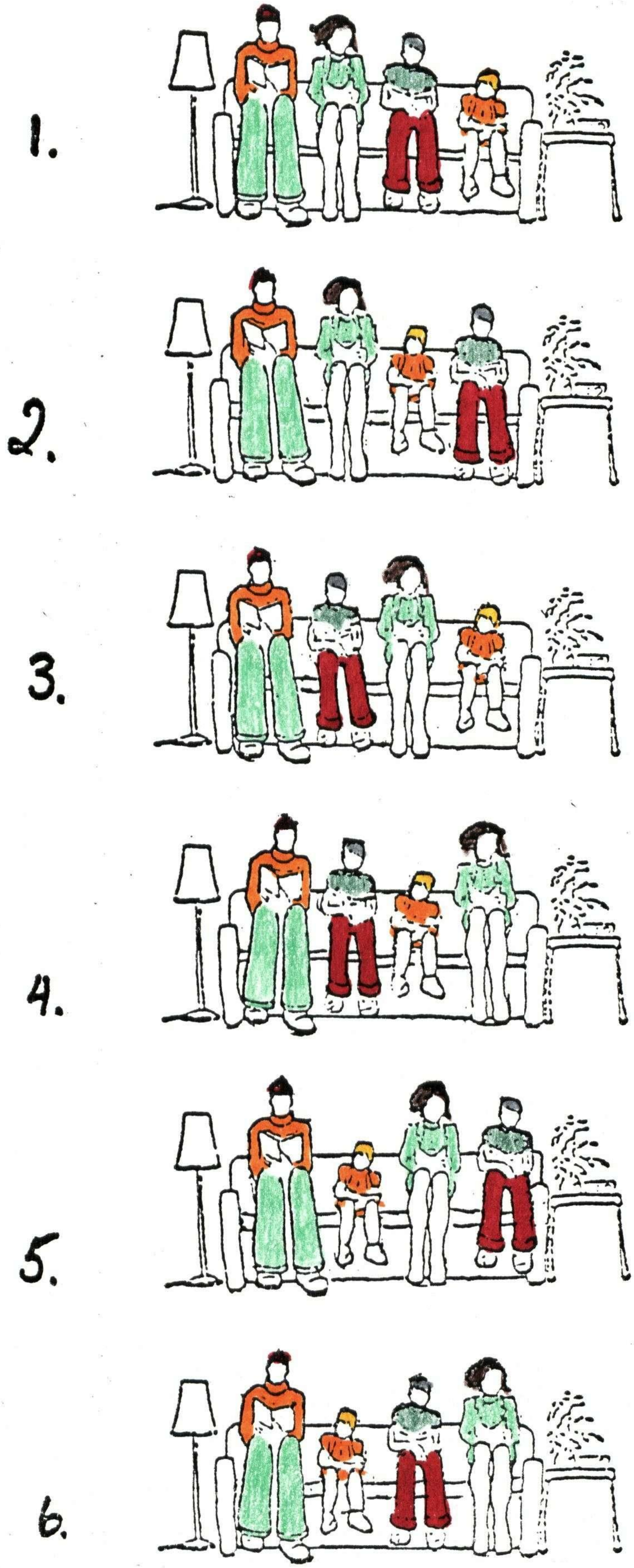

Figure 6. The first 6 permutations of the 24 permutations of four people, father, mother, son, and daughter.

period she would have to reconstruct the display by working from top to bottom. She would be permitted to see only the one chesterfield above the one on which she was placing people, and, if she skipped a chesterfield, she would not be permitted to go back.

Scoring. The measures involved three basic measures and a fourth measure which was a composite of the first three. The first measure was the number of different correct permutations reconstructed. If a permutation was repeated, credit was given for only one of these permutations.

The second and third measure took into account the system by which the permutations were reconstructed. These measures evaluated the extent to which reconstruction was based on the system used to generate the display. These measures can be explained in terms of Table 3. It shows the first eight permutations of the display of four people, a record of the first eight permutations reconstructed by one S, and the scoring of the two preceding sets of permutations in terms of the two systems measures. In Table 3, the four people, father, mother, son, and daughter, are indicated respectively by 1, 2, 3, and 4.

For both of these system measures, pairs of permutations were compared successively (as indicated by the curved lines) with all but the first and last permutations involved in two comparisons. The first of these measures, the initial members constant score (IMC),[1] involved the number of initial members of each permutation in the comparison pair which were constant (same members in the same order); the total IMC score was the sum found by considering all comparison pairs.

The other system measure, the vertical order measure, provided credit only for pairs in which the permutations were identical and in the same vertical order as those in the original display. This was a more stringent measure of the systematic nature of reconstruction. For example, in the case of the pair containing 1342 followed by 1324, two points of IMC credit were given, but no credit was given for order, as the correct order was 1324 followed by 1342. Thus for a pair to receive order credit a necessary but not sufficient prerequisite was that it receive the maximum possible IMC credit. Depending on the pair compared, IMC credit varied from 0 to 2 in the case of permutations of four and from 0 to 1 in the case of permutations of three.

In order to obtain the composite score, the vertical order score, which had a maximum of three points in the case of the permutations of three task and 32 points in the case of the permutations of four task, was transformed. In the former

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[1]This measure is based on the IMC (initial marks held constant) measure of Leskow and Smock (1970).

Table 3. Sample of permutations in the original display and in a S's reconstructions with successive pairs scored for initial members constant (IMC) and vertical order.

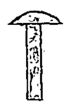
Display			Recall of S		
Permutations	IMC points	Vertical order points	Permutations	IMC points	Vertical order points
1 2 3 4			1 2 3 4		
)	2	1	)	2	1
1 2 4 3			1 2 4 3		
)	1	1	)	1	0
1 3 2 4			1 3 4 2		
)	2	1	)	2	0
1 3 4 2			1 3 2 4		
)	1	1	)	1	0
1 4 2 3			1 4 2 3		
)	2	1	)	2	1
1 4 3 2			1 4 3 2		
)	0	1	)	0	1
2 1 3 4			2 1 3 4		
)	2	1	)	0	0
2 1 4 3			4 1 2 3		

Note: Numbers 1, 2, 3, 4 refer respectively to father, mother, son and daughter.

task, the vertical order score was multiplied by 2; in the latter task, by .75. These transformations were used to make the maximum points possible on the vertical order measure equal to the maximum of the other two basic measures; these other basic measures had a maximum of 6 points in the case of the former task and 24 points in the case of the latter. The composite score then was found in each task by adding the scores on the basic measures. The composite score was such that greatest credit was given to permutations reconstructed systematically and exactly in the manner of the display, lesser credit was given to permutations reconstructed somewhat systematically, not exactly as in the display but with the initial member(s) constant; and least credit was given to permutations reconstructed in a manner not related to the system of the display.

Memory Related to the Lattice of Propositions: Tasks 6, 7, and 8

As mentioned previously, the understanding of the lattice of propositions or hypothetical possibilities is a formal-operational achievement. When presented with a problem, the formal-operational child can envisage all the possibilities and sets out to determine which of the possibilities actually does occur. The child isolates the relevant variables and tests out the effects of the various variables often by holding variables constant and manipulating others.

The following three tasks were designed to tap this general understanding of the lattice and the specific skills involving the isolation of variables and the method of holding variables constant while manipulating others. For each task the S was shown a display involving all the associations formed by the multiplication of a number of variables having two or three values. For example, in the case of Task 6, the S was shown a display of 16 screws and bolts produced by the multiplication of four variables each with two values (top, round or flat; bottom, pointed or flat; color, copper or gray; length, long or short). Two examples of the 16 associations were  and  .

In each display some of the associations were indicated as positive instances of a certain concept; others, as negative instances. For example, in the case of the screws and bolts, the positive instances, those with either a round top and flat bottom or a flat top and pointed bottom, were an example of the proposition of reciprocal exclusion, one of the propositions of the lattice. Negative instances, those with either a round top and pointed bottom or a flat top and flat bottom, provided an example of the proposition of equivalence, the complement of reciprocal exclusion.

The S was required to recall the total display, including which of the members of the display were positive and which, negative. It was thought that Ss possibly could recall each association of the display and its designation (positive or negative) by memorizing in a fairly rote fashion each of the positive and negative instances. However, successful recall, particularly over a long term, was considered possibly to require that the Ss realize that a matrix of associations was involved. Furthermore, it might necessitate that the S isolate the variables, determine which variables were relevant and irrelevant to the concepts involved, and determine what the concepts actually were. Recall of this crucial information, presumably all that would be needed to generate the display, would seem to involve far fewer units to be stored than would the recall of each association and its designation. The latter recall probably would be a very difficult feat particularly over the long term.

Thus it would seem that successful recall of each display possibly would be related to a complete understanding of what was involved in the display. This understanding possibly would depend principally on the understanding of the lattice of propositions. Each of the concepts in the displays was an example of one of these propositions. In addition, the positive and negative concepts in each display provided an example of complementary propositions. Thus it would seem that to determine those concepts and to understand their complementary nature would require considerable knowledge of the lattice.

The understanding of the display might be further related, albeit to a lesser extent, to the scheme of holding variables constant to determine the role of other variables. One method of determining the concepts in each display would be to compare nearly identical positive and negative instances to determine the factor(s) responsible for their different designations. This approach would seem to be at least analogous to the scheme of holding variables constant. While probably not necessary for successful understanding of the concepts, this approach would seem to be the most direct and efficient, particularly in the type of display used in these tasks where the concepts involved are not immediately obvious.

In summary, the principal possibility investigated was that success in Tasks 6, 7, and 8 would be related to the understanding of the lattice. This understanding presumably would be measured by the average of the performances on all the Piagetian tasks. The other possibility tentatively offered was that success in these memory tasks would involve the method of comparing nearly identical positive and negative instances to determine the factor(s) responsible for their different designations. This method might be related, at least to some extent, to performance on the pendulum task and more specifically to performance on the basic method measure of this task; the latter tested the ability to hold variables constant while manipulating others.

Method

Materials and concepts. The materials from the three tasks were as follows:

1. Display 6, Screws and Bolts. As seen in Figure 7 the display involved the 16 associations resulting from the multiplication of four variables each with two values (top, round or flat; bottom, pointed or flat; color, copper or gray; and length, long or short).

The concepts involved in this task, their propositional symbols, and the propositions to which they refer were as follows: (To understand the relationship between the concepts and the lattice of propositions in this and the next two tasks, reference can be made to Table 1, page 7.)

(a) Round top and flat bottom ($p\bar{q}$) and flat top and pointed bottom ($\bar{p}q$) were positive, reciprocal exclusion;

(b) Round top and pointed bottom (pq) and flat top and flat bottom ($\bar{p}\bar{q}$) were negative, proposition of equivalence, which is the complement of reciprocal exclusion;

(c) Length and color were unrelated to whether positive or negative, proposition of complete affirmation; in the case of length (with the propositional symbols re-assigned), tall positive (pq), short positive ($\bar{p}q$), tall negative ($p\bar{q}$), and short negative ($\bar{p}\bar{q}$), all were in the display.

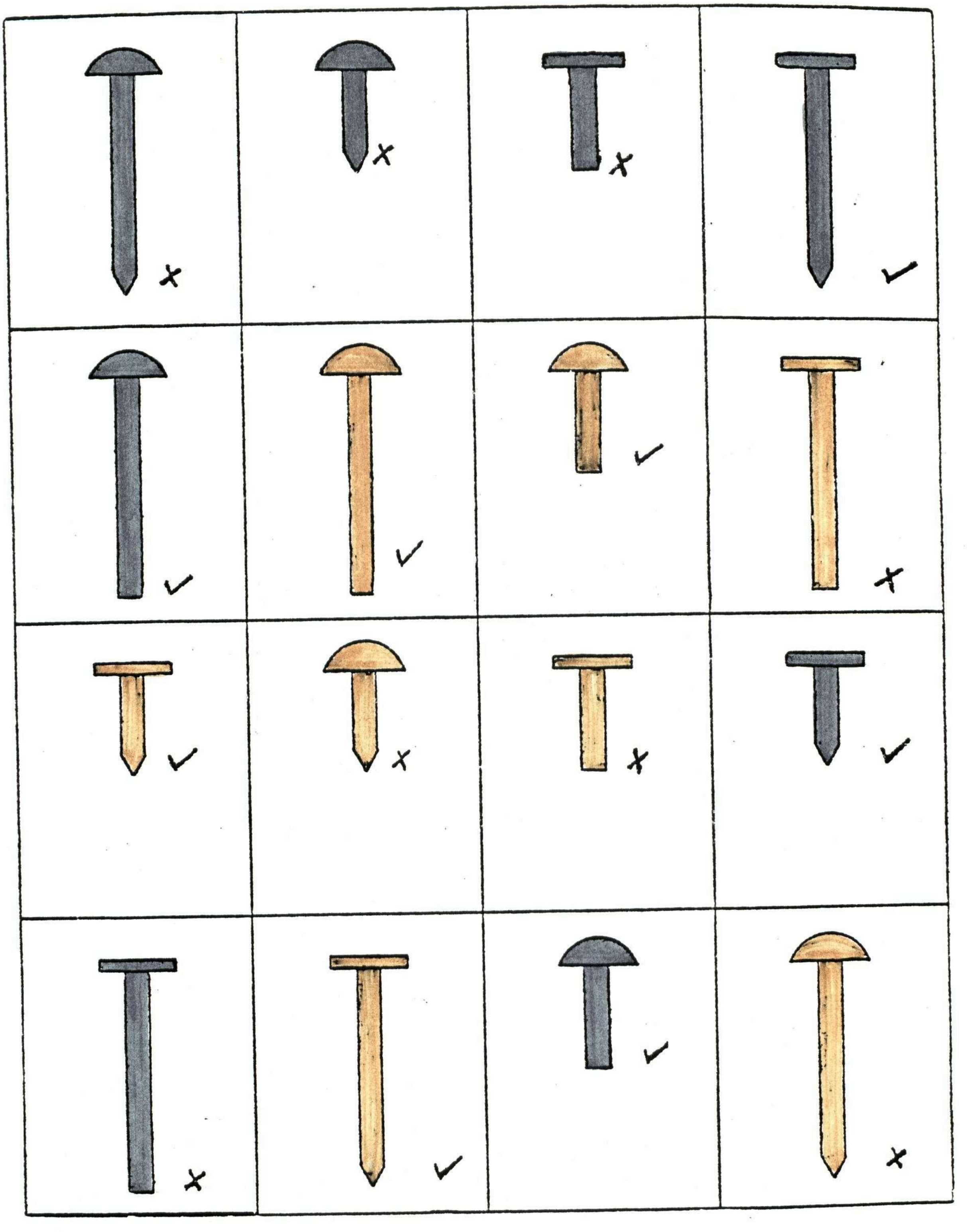


Figure 7. Association matrix of four variables, each with two values, with positive (√) and negative (x) instances shown.

Note: Reduced to approximately 60 percent of display size.

2. Display 7, Flowers. As seen in Figure 8, the display involves the 12 associations of three variables, leaf type, color, and stem width. The first variable had three values, one-pronged, two-pronged, or three-pronged; the second, two values, light or dark green; and the third, two values, thick or thin.

The propositions or concepts involved in the display were as follows:

(a) Dark and one- or three-pronged were positive, proposition of conjunction;

(b) Light and one-, two-, or three-pronged or dark and two-pronged were negative, proposition of incompatibility;

(c) Width unrelated to whether positive or negative, proposition of complete affirmation.

3. Display 8, Jolls. Figure 9 shows the eight associations resulting from the multiplication of three variables each with two values (nose position, $\vee$ or $\wedge$; number of eyebrows on one side, two or three; and foot position, up or down).

The concepts and the propositions to which they refer were as follows:

(a) Two eyebrows and shoulders down were positive, proposition of conjunction;

(b) Three eyebrows and shoulders up or down or two eyebrows and shoulders up were negative, proposition of

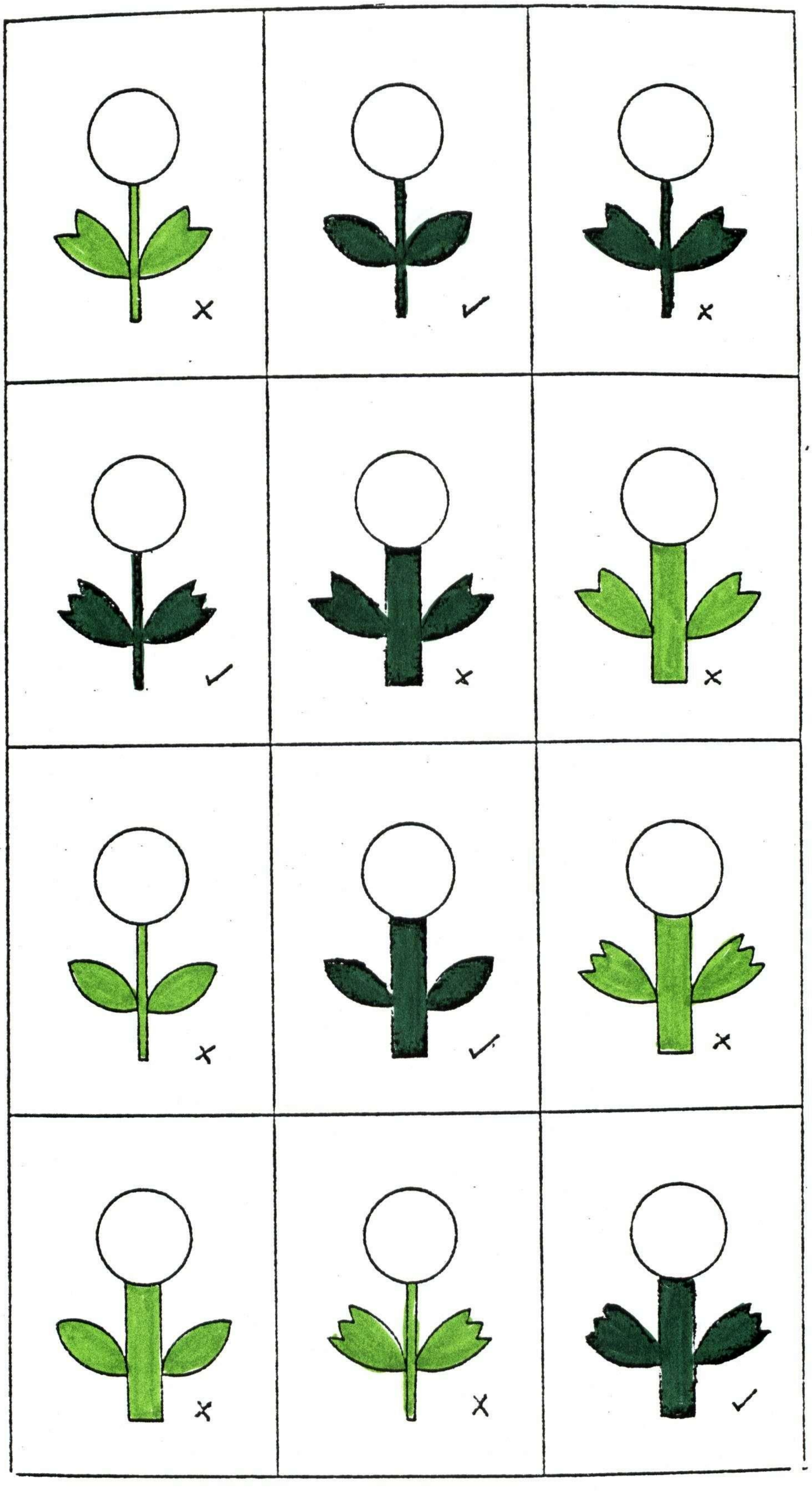


Figure 8. Association matrix of three variables, each with two or three values, with positive (√) and negative (x) instances shown.

Note: Reduced to approximately 50 percent of display size.

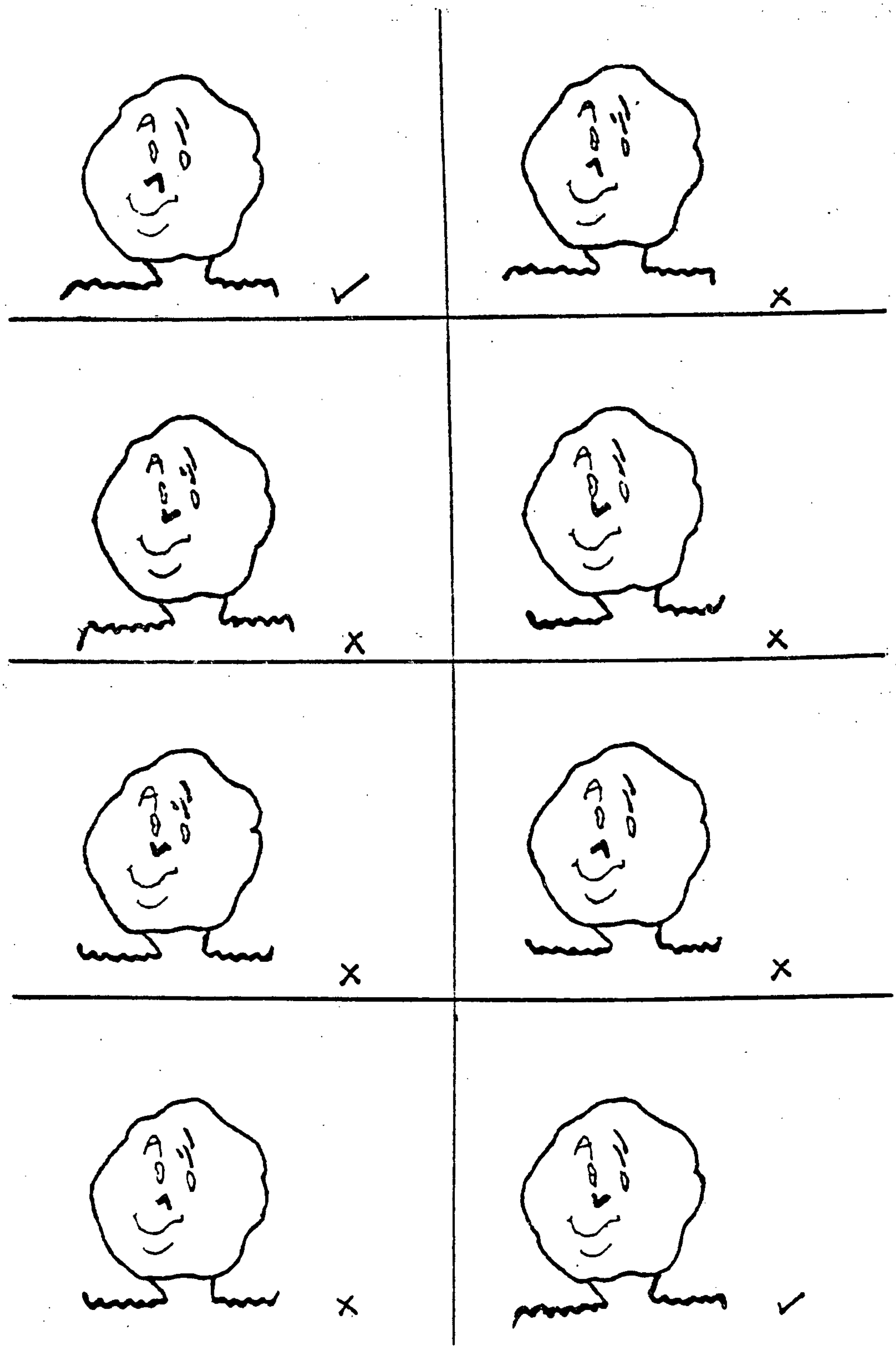


Figure 9. Association matrix of three variables, each with two values, with positive (√) and negative (x) instances shown.

Note: Reduced to approximately 80 percent of display size.

incompatibility;

(c) Nose position unrelated to whether positive or negative, proposition of complete affirmation.

Procedure. All three tasks were introduced in a similar manner. The *Ss* were told a small story concerning why certain members of the display were liked, as indicated by a √, and certain members, disliked, as indicated by a X. In the case of Task 6, a carpenter was said to like certain screws and/or bolts to fix a certain table and not to like others. In the case of Task 7, a certain bug was said to like to eat only a certain kind or kinds of flower(s). In the last task, involving the imaginary Jolls, a certain Joll named Albert was said to like only a certain kind or kinds of Joll(s) and to dislike others. In each task the *S* was asked to figure out which kind or kinds were liked and which kind or kinds were not liked, as she would be required to remember the whole display, including the designation of each member as liked or disliked.

Before the viewing period, which for each display lasted five minutes, the testing method was explained to the *Ss*. In Tasks 6 and 7, the method involved the *S* first drawing and coloring all the liked instances and then all the disliked instances. In the case of Task 8, the *S* was given a sheet containing eight Jolls with the noses, feet, and eyebrows on one side missing; the missing features were those that in the original display varied from one Joll to the next. The S was asked to reproduce the original display by drawing in the missing features and indicating whether each of the Jolls produced was liked or disliked.

Scoring. The measures of performance included two basic recall measures and a third measure which was a composite of the first two. The first recall measure was the number of drawings correctly drawn and designated by the S as liked or disliked. If drawings were repeated, credit was given only once. The second recall measure was the number of different members of the original display matrix which were drawn; whether or not the designation as liked or disliked was correct was not taken into account. The composite score was the sum of the points achieved on the first two measures. It was such that greater credit was given to drawings correctly drawn and designated and lesser credit, to drawings correctly drawn but incorrectly designated.

Overall Memory Performance Measure

In order to achieve an overall measure of memory performance, a principal components analysis was performed on the composite scores achieved by the Ss on the eight memory tasks. The first principal component is known to provide for a set of variables the single linear composite having maximal internal consistency. If a S was missing one of the composite scores, she was given the average score obtained by all Ss on that composite measure. The first principal component factor score, the measure of overall memory performance, then was derived for each S.

Chapter 3

RESULTS

This chapter will provide the results concerning (a) the assessment tasks, (b) the memory tasks, and (c) the relations between assessment tasks and memory tasks.

RESULTS: ASSESSMENT TASKS

This section will provide information concerning the following:

1. The categorizing of the Ss' performance on the Piagetian tasks and a summary of WISC vocabulary performance;

2. the unadjusted correlation matrix and the adjusted correlations, with the effects of age and WISC vocabulary performance removed, for performance on the assessment tasks;

3. the principal components analysis of the assessment tasks.

Categorizing of Performance on the Piagetian Tasks and WISC Vocabulary Performance

The results in this section are based on the performance of 56 Ss except in the case of the WISC vocabulary test, where two Ss did not do the test. Table 4 indicates the percentages of Ss whose performances were assigned to the various substages and stages of concrete and formal operations. These percentages are provided for each of the Piagetian tasks and for overall average performance on all the Piagetian tasks (found by summing the points obtained on each task and then finding the average). The concrete-operational stage consisted of the substages 2A, 2A-2B, 2B, and 2B-3A, while the formal-operational stage involved the substages 3A, 3A-3B, and 3B. For each substage the maximum range of points is noted. Substages not used in certain tasks to categorize performance are indicated by a dash. In the case of the balance task categories 3A, 3A+, and 3B, 3B- were collapsed to form respectively substages 3A and 3B.

As indicated by the table, performance at the formal-operational stage in the chemical combinations, pendulum, volume, and balance tasks was achieved by respectively 35.7, 39.3, 66.1, and 46.4 percent of the Ss. An overall average performance at the formal-operational level was achieved by 42.9 percent of the Ss.

In the case of the WISC vocabulary test, the average of the vocabulary scores, scaled according to age, was 9.8; the standard deviation was 2.7. The scores ranged from 5 to 17. A scaled score of 10 approximates an IQ of 100.

Table 4. Percentages of the 56 Ss whose performance on each Piagetian task and average performance on all the Piagetian tasks was assigned to each stage and substage.

Stage	Substage	Maximum Point Range	TASKS								Average of Formal Tasks	
			Chemicals		Pendulum		Volume		Balance			
Concrete Operations	2A	2.75-3.24	25.0%	64.3%	12.5%	60.7%	14.3%	33.9%	5.4%	53.6%	5.4%	57.1%
	2A-2B	3.25-3.74	—[a]		—[a]		—[a]		8.9		8.9	
	2B	3.75-4.24	26.8		32.1		19.6		32.2		10.7	
	2B-3A	4.25-4.74	12.5		16.1		—[a]		7.1		32.1	
Formal Operations	3A	4.75-5.24	23.2	35.7	26.8	39.3	28.6	66.1	39.3[b]	46.4	26.8	42.9
	3A-3B	5.25-5.74	—[a]		—[a]		—[a]		—[a]		14.3	
	3B	5.75-6.00	12.5		12.5		37.5		7.1[b]		1.8	

[a]This substage was not used when categorizing performance.

[b]Substages 3A, 3A+ and 3B-, 3B were collapsed to form respectively substages 3A and 3B.

Unadjusted and Adjusted Correlation Matrices for Assessment Tasks

Table 5 provides the main points of Table 11, Appendix A, which shows for the assessment tasks the Pearson product-moment[1] correlation matrix and the partial correlations. In the case of the latter, the effects of either age, WISC vocabulary test performance, or both age and WISC vocabulary performance were removed. When a single task was correlated with the overall average to which it contributed, this average was considered contaminated. The uncontaminated overall average resulted from the removal of the contribution of the single task (with which it was correlated); the resulting r thus was corrected for spuriousness. Table 5 shows only the unadjusted correlation matrix and the partial correlations where the effects of both age and WISC vocabulary performance are removed. These results are based on the performance of 56 _S_s except in the case of the partial correlations and the one correlation involving WISC vocabulary performance; these exceptions involved 54 _S_s due to two _S_s not doing the WISC vocabulary test.

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[1]While the scoring of the Piagetian tasks and, to a much lesser extent, the scoring of the memory tasks did not provide strictly interval data, it was decided to use the Pearson product-moment test in analyzing these data; this test is sufficiently robust to deal with data possessing less than interval strength.

As seen in Table 5 all the unadjusted correlation coefficients between the Piagetian tasks were significant.[2] These coefficients ranged from .35, $p < .01$ (chemicals-pendulum) to .59, $p < .001$ (volume-balance), this latter correlation coefficient being considerably greater than the next highest, $r = .41$, $p < .01$ (pendulum-balance). Each of the Piagetian tasks correlated significantly with the uncontaminated average of the formal tasks; the correlations involving the balance ($r = .62$, $p < .001$) and volume ($r = .59$, $p < .001$) tasks were considerably stronger than those involving the pendulum ($r = .49$, $p < .001$) and chemicals ($r = .45$, $p < .001$) tasks. Performance on the WISC vocabulary test was related significantly to performance on each of the Piagetian tasks and overall average performance; these correlations ranged from .32, $p < .01$ (chemicals-WISC vocabulary) to .44, $p < .001$ (overall average-WISC vocabulary).

With the effects of age and WISC vocabulary scores removed, all six correlations between the Piagetian tasks were reduced mainly due to the elimination of the effect of WISC vocabulary performance (see Table 11, Appendix A). All but one partial correlation, involving the chemicals and pendulum

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[2] In this study $\alpha = .05$ was the level of significance adopted. However, the probability of correlations achieving significance when the null hypothesis is true also is indicated.

Table 5. Product-moment correlation matrix and adjusted correlations, with the effects of age and WISC vocabulary scores removed, for the assessment tasks.

TASKS	Pendulum		Volume		Balance		Average of Formal Tasks		Uncontaminated Average[d] of Formal Tasks		WISC Vocabulary	
	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.
Chemicals	$.35^{b}$	.26	$.38^{b}$	$.30^{c}$	$.38^{b}$	$.30^{c}$	$.71^{a}$	$.67^{a}$	$.45^{a}$	$.37^{b}$	$.32^{c}$	
Pendulum			$.40^{b}$	$.32^{c}$	$.41^{b}$	$.33^{c}$	$.70^{a}$	$.65^{a}$	$.49^{a}$	$.40^{b}$	$.37^{b}$	
Volume					$.59^{a}$	$.54^{a}$	$.82^{a}$	$.79^{a}$	$.59^{a}$	$.52^{a}$	$.34^{c}$	
Balance							$.77^{a}$	$.74^{a}$	$.62^{a}$	$.55^{a}$	$.34^{c}$	
Average of Formal Tasks											$.44^{a}$	

$^{a}p < .001$.

$^{b}p < .01$.

$^{c}p < .05$.

[d] Uncontaminated average resulted from removing from the average of the formal tasks the contribution of the single task being correlated with the average.

tasks ($r = .26$), were significant, however. These significant partial correlations ranged from .30, $p < .05$ (chemicals-volume; chemicals-balance) to .54, $p < .001$ (volume-balance); this latter partial correlation again was considerably greater than the next strongest, $r = .33$, $p < .05$ (pendulum-balance). With adjustment all the correlations between each Piagetian task and the uncontaminated average of the formal tasks were reduced, but the partial correlations were significant; again the partial correlations involving the balance ($r = .55$, $p < .001$) and volume ($r = .52$, $p < .001$) tasks were stronger than those involving the pendulum ($r = .40$, $p < .01$) and chemicals ($r = .37$, $p < .01$) tasks.

Principal Components Analysis of Assessment Tasks

Table 6 shows the principal component loadings for the Piagetian tasks and the WISC vocabulary scaled scores. As can be seen, all the assessment tasks loaded heavily on one component. The volume and balance tasks showed the highest loadings of respectively .76 and .72, while the WISC vocabulary test showed the lowest loading, .51. The first principal component accounted for approximately 89 percent of the variance of the assessment tasks, while the second accounted for approximately 11 percent. The eigenvalue of the second component was .26, considerably less than the value of 1 generally required for including a component. This minimal eigenvalue thus precluded rotation of principal component axes.

Table 6. Principal component loadings for performance on the Piagetian tasks and the WISC vocabulary test.

Tasks	First Principal Component
Chemicals	.59
Pendulum	.65
Volume	.76
Balance	.72
WISC Vocabulary	.51

RESULTS: MEMORY TASKS

This section will provide information concerning the performance of the Ss in the various memory tasks. Table 7 provides for each memory task the maximum value of the composite measure and the original and retest means and standard deviations of each composite measure, expressed as a percentage of the maximum value. The results reported in Table 7 are based on the performance of the usual 56 and 55 Ss in respectively the original and retest periods except in the case of the volume, combinations of animals, and permutations of four tasks, which involved 54 Ss in the retest period. In the case of the volume task, three Ss in the retest session could not remember when drawing whether or how the shape was changed. When computing the composite score for the volume task, it was decided not to eliminate these Ss but to give them drawing credit; all of them chose the correct drawing in the recognition task and none of the other Ss who recognized correctly drew incorrectly.

A measure of recall or reconstruction performance can be considered to be of average difficulty if mean performance on this measure lies between 45 and 65 percent of the maximum possible score. In the case of the volume task, where the correct drawing could be chosen or drawn correctly one third of the time by chance, a measure of average difficulty could be considered one that yields average scores between 55 and 80 percent. Furthermore, a low variation of scores on a measure can be considered to be indicated by a standard deviation of less than 15 percent of the maximum score possible.

As can be seen in Table 7, in the original testing period all but the composite measure in the animals and permutations of four tasks yielded mean performance above the range of average difficulty. In the case of the measures of reconstruction or recall, performance generally fell within 15 percent of the 65 percent cutoff point; in the case of the

Table 7. Maximum possible value of each composite measure and the original and retest means and standard deviations, expressed as a percentage of the maximum value, for each memory task.

TASKS	Original		Maximum	Retest	
	$\bar{X}$	σ		$\bar{X}$	σ
Volume	82.2%	34.9%	2	80.6%	39.4%
Combinations of Animals	45.7	14.0	45	32.7	19.0
Combinations of Vehicles	75.6	17.6	45	57.1	20.5
Permutations of Three	83.3	21.4	18	67.8	28.6
Permutations of Four	59.2	19.7	72	50.7	22.8
Screws and Bolts	77.3	20.8	32	64.2	24.0
Flowers	73.3	23.4	24	58.1	23.0
Jolls	72.4	26.2	16	40.0	26.5

volume measure, mean performance was approximately two percent above the 80 percent cutoff point. In the retest period average performance on the tasks generally fell within the range of average difficulty. The exceptions were the volume and permutations of three tasks, which yielded means of less than one and three percent, respectively, above the cutoff point, and the animals and Jolls tasks, which had average performances of respectively 32.7 and 40 percent of the maximum score possible. With regard to the original and retest variations in performance, only the animals task in the original testing period yielded a standard deviation less than 15 percent of the maximum score possible.

RESULTS: RELATIONS BETWEEN ASSESSMENT TASKS AND MEMORY TASKS

This section will present the original and retest correlations, both unadjusted and adjusted, with the effects of age and WISC vocabulary performance removed, between the following:

1. overall memory performance as indicated by the factor scores and performance on the assessment tasks;

2. specific memory performance as indicated by the composite measure of memory in each memory task and overall average performance on all the Piagetian tasks;

3. specific memory performance on the various memory

tasks and performance on particular Piagetian tasks thought to be related to the memory task involved.

Overall Memory Performance and Assessment Task Performance

Table 8 summarizes the original and retest correlations and partial correlations, with the effects of age and WISC vocabulary performance removed, between the assessment tasks and overall memory performance as indicated by the factor scores. This information in addition to the partial correlations, where the effects of age or WISC vocabulary performance alone were removed, are shown in Table 12, Appendix A. Fifty-six Ss were involved in the original correlations; 55, in the retest correlations. These numbers were further reduced by two in the partial correlations, where the effects of WISC vocabulary performance were removed, due to two Ss not doing the WISC vocabulary test.

As seen in Table 8, overall average performance on the Piagetian tasks correlated significantly with overall memory performance in the original, $r = .49$, $p < .001$, and retest, $r = .32$, $p < .05$, periods. When these correlations were adjusted, the former was decreased to .47, $p < .001$, while the latter was increased to .36, $p < .01$. As seen in Table 12, Appendix A, the slight reduction and increase in respectively the original and retest partial correlations resulted from the opposing effects of the removal of age and the removal of WISC vocabulary performance. The removal of the former increased slightly the percentage of variance accounted for by the correlations. The removal of the latter decreased this variance; this decrease was less than four and two percent, respectively, in the original and retest periods.

In order to gain some understanding of why the correlations between overall memory performance and average Piagetian task performance decreased from the original to the retest period, the test-retest reliability coefficient between the factor scores in the original testing period and a new set of retest factor scores was computed. The latter factor scores, derived to ensure comparability between the original and retest factor scores, resulted from weighting the scores on the various memory tasks in the retest period in the same way these scores were weighted in the original testing period. The resulting test-retest reliability coefficient was .60, $p < .001$.

As seen in Table 8, in the original testing period, performance on the specific Piagetian tasks, with the exception of the pendulum task, showed significant positive correlations with overall memory performance. The strongest correlations involved the balance, $r = .54$, $p < .001$, and volume, $r = .46$, $p < .001$, tasks, while those involving the chemicals and pendulum tasks were respectively .30, $p < .05$, and .20,

Table 8. Original and retest unadjusted correlations and adjusted correlations, with the effects of age and WISC vocabulary performance removed, between overall memory performance and performance on the assessment tasks.

TASKS	Overall Memory: Original		Overall Memory: Retest	
	Unadj.	Adj.	Unadj.	Adj.
Average of Formal Tasks	.49[a]	.47[a]	.32[c]	.36[b]
Chemicals	.30[c]	.26	.16	.15
Pendulum	.20	.13	.13	.09
Volume	.46[a]	.45[a]	.27[c]	.33[c]
Balance	.54[a]	.52[a]	.44[a]	.49[a]
WISC Vocabulary	.22		.14	

[a] $p < .001$.

[b] $p < .01$.

[c] $p < .05$.

$p = .14$. With adjustment the correlations were slightly reduced due to the elimination of the effect of WISC vocabulary performance (see Table 12, Appendix A), and the one involving the chemicals task, $r = .26$, became not significant. Performance on the WISC vocabulary test did not correlate significantly with overall memory performance in either the original ($r = .22$) or retest ($r = .14$) period.

The same pattern of relations, although somewhat reduced, was found in the retest period between performance on specific Piagetian tasks and overall memory performance. In the retest period, however, while all unadjusted correlations were positive, only those involving the balance task, $r = .44$, $p < .001$, and the volume task, $r = .27$, $p < .05$, were significant. With adjustment these two correlations increased to respectively .49, $p < .001$, and .33, $p < .05$, due to the removal of the effects of age (see Table 12, Appendix A). The other two correlations were reduced slightly.

Performance on Specific Memory Tasks and Average Piagetian Task Performance

Table 9 presents the original and retest correlations and partial correlations, with the effects of age and WISC vocabulary performance removed, between performance on the specific memory tasks, indicated by the composite measure in each task, and overall average performance on the Piagetian tasks. Fifty-six Ss were involved in the original correlations; 55, in the retest correlations except in the case of the volume, combinations of animals, and permutations of four tasks, which involved 54 Ss. These numbers were further reduced by two in the partial correlations due to the two Ss not doing the WISC vocabulary test.

The information of Table 9 is included in Tables 13, 14, 15, and 16 in Appendix A. These tables show all the unadjusted and partial correlations between Piagetian task performance and performance on the memory tasks related respectively to volume, combinations, permutations, and the lattice. Table 17, Appendix A, provides all the unadjusted and adjusted correlations between average Piagetian task performance and scores on the component measures which were the bases of the composite measure in each memory task.

Comparison of Tables 8 and 9 indicates that in the original testing period overall Piagetian performance correlated more strongly with overall memory performance than it did with memory on any specific memory task; in the retest period with a few exceptions (unadjusted and adjusted permutations of four; unadjusted screws and bolts) a similar pattern was found.

As seen in Table 9 all the unadjusted and partial correlations in the original testing period were positive, ranging from .22 to .39; 12 of the 16 were significant. In

Table 9. Original and retest unadjusted correlations and adjusted correlations, with the effects of age and WISC vocabulary performance removed, between average performance on the Piagetian tasks and memory task performance.

MEMORY TASKS	Correlations with Average of Formal Tasks			
	Original		Retest	
	Unadj.	Adj.	Unadj.	Adj.
Volume	.28[c]	.24	.28[c]	.18
Combinations of Animals	.38[b]	.33[c]	.02	.02
Combinations of Vehicles	.27[c]	.24	.16	.21
Permutations of Three	.38[b]	.39[b]	.19	.25
Permutations of Four	.29[c]	.29[c]	.32[c]	.40[b]
Screws and Bolts	.33[c]	.26	.32[c]	.27
Flowers	.31[c]	.22	.28[c]	.22
Jolls	.26[c]	.33[c]	.17	.13

[a] $p < .001$.

[b] $p < .01$.

[c] $p < .05$.

the retest period, they also were positive. However, in the animals, vehicles, permutations of three, and the Jolls tasks the values of both the unadjusted and partial correlations were less than their counterparts in the original testing period; in fact they were considerably less in the case of the latter three tasks. In the retest period four correlations and one partial correlation were significant.

Performance on Specific Memory and Specific Piagetian Tasks

Table 10 presents the unadjusted correlations and partial correlations, with the effects of age and WISC vocabulary performance removed, between the composite measure of memory performance in each memory task and performance on the particular Piagetian task(s) thought to be related to each memory task. The correlations between the basic method measure[3] in each of the chemicals and pendulum tasks and the specific memory tasks postulated to be related to these Piagetian tasks were omitted; none was significant and nearly all were less than the correlations involving complete performance on the Piagetian tasks. The information of Table 10 in addition to the partial correlations, where the effects of age and WISC vocabulary performance alone were removed, are

[3] In each of the chemicals and pendulum tasks a basic method measure and solution measure were integrated to form the substages of performance.

provided in Tables 13, 14, 15, and 16; these tables deal respectively with memory tasks related to volume, combinations, permutations, and the lattice of propositions.

The unadjusted correlations were based on the performance of the usual 56 and 55 Ss in respectively the original and retest periods except in the case of the volume, combinations of animals, and permutations of four tasks, which involved 54 Ss in the retest period. In the case of the partial correlations, where the effect of WISC vocabulary performance was removed, these numbers were reduced by two due to two Ss not doing the WISC vocabulary test.

Comparison of Tables 9 and 10 indicate that generally performance on each memory task correlated more strongly with average Piagetian task performance than with performance on particular Piagetian task(s) thought to be related to the particular memory task. The only clear exception involved the memory task related to volume, where the original and retest correlations and partial correlations between memory performance and volume conservation were all higher than their counterparts (in terms of testing time and whether adjusted or not) involving average Piagetian task performance.

As seen in Table 10, the majority of the unadjusted and partial correlations were positive but, with the exception of those involving the memory task related to volume and the volume conservation task, they were not significant. It is

Table 10. Original and retest unadjusted correlations and adjusted correlations, with the effects of age and WISC vocabulary performance removed, between memory task performance and performance on particular Piagetian tasks.

PIAGETIAN TASKS	MEMORY TASKS			
	Volume			
	Original		Retest	
	Unadj.	Adj.	Unadj.	Adj.
Volume	.34[b]	.32[c]	.35[b]	.29[c]
Subtask 5	.11	.11	.17	.16

PIAGETIAN TASKS	Combinations of Animals				Combinations of Vehicles			
	Original		Retest		Original		Retest	
	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.
Chemicals	.20	.14	-.09	-.11	.17	.13	.20	.23

PIAGETIAN TASKS	Permutations of Three				Permutations of Four			
	Original		Retest		Original		Retest	
	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.
Chemicals	.26	.24	-.07	-.06	.19	.17	.11	.13
Pendulum	.17	.14	.06	.07	.09	.06	.10	.11

PIAGETIAN TASKS	Screws and Bolts				Flowers				Jolls			
	Original		Retest		Original		Retest		Original		Retest	
	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.	Unadj.	Adj.
Pendulum	.12	.02	.14	.04	.26	.18	.20	.14	-.08	- 08	.10	.06

[a] $p < .001$.

[b] $p < .01$.

[c] $p < .05$.

interesting to note that the volume and/or balance task predicted performance best on many of the memory tasks not postulated to be closely related to these Piagetian tasks; many of these correlations were significant. (See Tables 13, 14, 15, and 16, Appendix A.)

Chapter 4

DISCUSSION

FORMAL OPERATIONS AND MEMORY

Results of the study justify the statement that it was successful in achieving both of its major aims. Present findings permit identification of individual differences with respect to a unified formal-operational structure; they also allow these differences to be related to predictable differences in memory performance on a variety of tasks designed in the Piagetian tradition of memory research. Discussion of findings relevant to the unified structure of formal operations will be followed by consideration of the relationships found between formal-operational competency and memory.

Unified Structure of Formal Operations

Two hypotheses concerning the unified structure of formal operations were investigated and both were confirmed by the obtained data. First, significant positive correlations were found between performance on each of the four formal-operational tasks and the average of performance on the other three tasks. Second, a principal component analysis revealed that the first principal component accounted for a substantial 89 percent of the variance of the assessment tasks.

The present finding of consistency of performance across the Piagetian tasks is in agreement with the results of the majority of studies cited (e.g., Arlin, 1974, 1977; Hughes, 1965; Lovell, 1961; Tomlinson-Keasey, 1970) which also found such consistency. Unlike the present study, however, these previous ones finding consistency failed to control for both age and IQ. In fact, of these studies mentioned, only three (Arlin, 1974, 1977; Hughes, 1965) controlled, at least to some extent, for age, while another three (Bart, 1971; Jackson, 1965; Lovell and Shields, 1967) had some control for IQ. As a result of the failure of these previous studies to control for these variables, the present findings provide the principal support for the contention that observed consistency of performance is due to operative understanding rather than to skills unrelated to formal operations but related to age and/or IQ. Thus the concept of a unified structure of formal operations, independent of age or IQ, is supported by the present study.

The positive findings of the present study also support the suggestion that reported failures (e.g. Neimark, 1970; Ross, 1973) to find significant relationships across Piagetian tasks may be attributed to methodological weaknesses in these investigations. These weaknesses included use of subjects too young to be expected to be at the formal-operational stage; use of procedures that deviated considerably from those of Inhelder and Piaget; considerable variation in difficulty among the Piagetian tasks employed; and selection of tasks that were poor measures of formal-operational thought.

Present findings have important implications for the selection of tasks which are especially suitable measures of formal-operational ability. The substantial correlation found between the volume and balance tasks indicates that they are measuring the same competency, according to Inhelder and Piaget (1958), the INRC group. This finding furthermore suggests that either task is a suitable measure of this competency. Other results argue that the balance and volumes tasks also are the best indices of general formal-operational ability, described by Inhelder and Piaget in terms of the integrated INRC group-lattice structure. In general, this overall ability presumably would be most adequately assessed by average Piagetian task performance and first principal component scores. Thus the findings that the volume and balance tasks showed the strongest correlations with average Piagetian task performance and loaded the most heavily on the first principal component argues that, of the four tasks employed, they are the best indices of general formal-operational ability. This argument is further supported by other findings showing that these results were not due simply to the substantial correlation between the balance and volume tasks. These tasks also were related significantly to the chemicals and pendulum tasks, which moreover showed the lowest intertask correlation.

Formal-Operational Competency and Memory Performance

With regard to the second major aim of the study, concerning the relationship between formal-operational competency and memory performance, obtained data provide evidence to support the principal hypothesis investigated. Average Piagetian task performance accounted for approximately 25 percent of the variance in overall memory performance in the original testing period. In the retest period, it accounted for about 10 percent of this variance. These percentages changed only slightly to 22 percent and 13 percent when the effects of age and IQ were removed. Overall performance on the Piagetian tasks also was related to performance on the specific memory tasks. All the correlations were positive, and, particularly in the original testing period, many of them were significant.

Together these data suggest that both overall memory performance and performance on specific memory tasks were related to differences in general formal-operational ability, presumably measured by average performance on all the Piagetian tasks.

Further support for the importance of volume and balance task performance as indices of formal-operational development comes from the findings that the largest contribution to predictable variance in both overall memory performance and performance on specific memory tasks was made by the balance and volume tasks. Balance and volume task performance, when compared with overall Piagetian task performance, showed, respectively, slightly higher and lower correlations with overall memory performance. Either or both of these tasks predicted best, and often significantly, performance on many specific memory tasks including those not hypothesized to be closely related to the specific schemes tapped by these tasks. In general, these findings might be best interpreted as further evidence of the predictive power of general formal-operational ability. The volume and balance tasks and the various memory tasks generally shared in common only their hypothesized relationship to general formal-operational ability. Thus this ability, rather than less general competencies not considered to be related to most of these tasks, probably mediated the majority of the relationships found between memory performance and the balance and volume tasks.

Obtained data did not confirm the hypothesis that performance on particular Piagetian tasks thought to be measuring specific formal-operational schemes or concepts would be significantly related to performance on particular memory tasks also thought related to the schemes. The correlations between the specific Piagetian tasks and the supposedly related memory tasks generally were positive. But, significant correlations were obtained only in the case of the relationship between the memory task related to volume and the volume conservation task. This significant relationship, however, cannot be interpreted as exemplifying the mediation of memory performance by the understanding of specific schemes. There is no evidence that the conservation of occupied volume, the specific concept hypothesized to mediate this relationship, in fact did so. Performance on subtask 5[1] of the volume conservation task, considered to be the most direct measure of this scheme, showed only a minimal correlation with performance on the memory task related to volume. The significant relationship, then, might

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[1]Subtask 5 required the S to predict whether the water level would remain the same or would change when the metal bricks of a building constructed under water were rearranged.

be best considered as simply another example of the indiscriminate predictive power of the balance and volume tasks with regard to performance on specific memory tasks. As such it probably would be best interpreted as being mediated by general formal-operational ability.

Thus in the present study, there was no evidence that the understanding of specific logical schemes, such as combinatorial operations, the conservation of occupied volume, and the method of holding variables constant, mediated performance on the specific memory analogues of these schemes. Possible reasons for this lack of positive findings are detailed in Appendix B.

Data did not confirm the final hypothesis, which was that the magnitude of the correlations between Piagetian task performance and both overall memory performance and performance on specific memory tasks would be greater one month after presentation of the displays rather than immediately following the presentation. In fact, the relationship between average Piagetian task performance and overall memory performance was clearly reduced from the original to the retest period. In addition, in only the permutations of four task was there an increase in both the unadjusted and partial correlations over time. The interpretation of these findings, however, is somewhat equivocal due to the limited retest reliability of the memory tasks, as indicated by the test-retest coefficient between the Ss' overall factor scores ($r_{tt} = .60$).

There are at least two possible reasons for this reduced reliability which also would explain the decrease in the relationship between Piagetian task performance and memory performance. First, some of the displays may have been poor items for testing long term memory. Two of the four memory tasks which showed retest reductions in both the unadjusted and partial correlations involving overall Piagetian task performance yielded average retest performance below the psychometrically optimal range of means for test items. Thus in the case of these tasks (the only two showing such low mean performance) there would have been a floor effect, which probably was at least partly responsible for the observed reduction in correlations. Second, on each memory task, a fairly high percentage of Ss (ranging from 7 to 31 percent) showed improvement. Improvement occurred considerably more often among concrete-operational Ss than among transitional Ss (2B - 3A) and formal-operational Ss. Thus the overall effect of these improvements would be to reduce the retest correlation between Piagetian task performance and memory performance. The explanation for these improvements cannot be determined from the data available. One possibility is that they resulted from cognitive development on the part of some of these Ss during the test-retest interval (see Piaget and Inhelder, 1968). Another possibility is that some Ss may have discussed the memory tasks after the initial testing period.

Overall, however, the explanatory role of cognitive development, as proposed by Piaget, was extended successfully in the present study. Differences in memory performance supposedly related to the development from preoperational to concrete-operational thought have been studied fairly extensively (e.g., Furth and Milgram, 1973; Piaget and Inhelder, 1968; Prawat and Cancelli, 1976; Tomlinson-Keasy et al., 1975). The present study, however, represents an advance in that it shows that changes in memory performance in a variety of tasks also are related to the achievement of formal operations. Furthermore, by controlling for the effects of age and IQ, the present investigation permits specific attribution of these phenomena to changes in operative level.

Moreover, the results lend some support to the often-made distinction between the Piagetian and the psychometric concepts of intelligence (e.g., Furth, 1973; Kohlberg and DeVries, 1974; Kuhn, 1976). Performance on the formal-operational tasks was found to be significantly related to assessed IQ. This finding is in agreement with the results of other studies (e.g., Bart, 1971; Jackson, 1965; Kuhn, Langer, Kohlberg, and Haan, 1972). On the other hand, average performance on the Piagetian tasks correlated more highly with overall memory performance than did WISC vocabulary scores.

In fact, for both the original and retest periods, only nonsignificant correlations were found between the WISC vocabulary scores and overall memory performance. Furthermore, when the effects of WISC vocabulary performance (which correlates .78 with the WISC full scale) were removed, the variance in original and retest memory performance accounted for by average Piagetian task performance was reduced by less than four and two percent, respectively. Thus the present study demonstrated that Piaget's concept of intelligence, when defined operationally, had predictive validity that not only exceeded but was almost independent of that of the psychometric concept of intelligence, also defined operationally.

UNIVERSALITY OF FORMAL OPERATIONS

On the basis of research conducted in Geneva, Inhelder and Piaget (1958) concluded that formal-operational thought develops through the ages 11 to 15 years. Equilibrium was considered achieved by the age of 15 years by 75 percent of adolescents; this percentage was considered to indicate universality (Piaget, 1952). A considerable body of research (e.g., Jackson, 1965; Tomlinson-Keasey, 1970), however, did not support the Inhelder and Piaget conclusion. In fact a number of studies (e.g., Arlin, 1974; Elkind, 1962) found that fewer than 75 percent of even college students showed such achievement. The high success rate reported by Inhelder and

Piaget was generally considered (e.g., Lovell, 1961) to be due to their selection of an unrepresentative sample of adolescents from privileged schools. Piaget (1972) has acknowledged this lack of random sampling and the dearth of evidence supporting his and Inhelder's findings and tentatively restated his position. All normal people now were considered to achieve formal operations, if not by 15 years, in any case by 20 years, but in different areas according to their aptitudes and professional specializations. Thus the traditional assessment tasks, which are scientifically oriented, would underestimate formal-operational achievement in the case of individuals not having much aptitude or specialization in science.

In the present study, almost one-half the Ss performed at the formal-operational level even though they were relatively young (average age, 13.1 years) and generally came from a working class or lower middle-class background. This proportion of formal-operational Ss is higher than that normally found with such young Ss (e.g., Elkind, 1961b) or even with older Ss of a higher socio-economic level (e.g., Dulit, 1972). The disparate findings of the present study may be due to the fact that this study, as compared to many others, administered the tasks in a manner more closely related to that of Inhelder and Piaget (1958).

A general overview of the various studies investigating formal operations indicates that the methodology of many of them deviated in one or more significant ways from that of Inhelder and Piaget (1958). Subjects sometimes were given very little time to experiment (Lee, 1971) or were not questioned during their experimentation in the manner of Inhelder and Piaget (Tomlinson-Keasey, 1970). In some cases the method of scoring differed considerably from Inhelder and Piaget's; first, considerable available information was not taken into account and/or second, the scoring criteria were too strict. An example of the first difference in scoring occurred in the cases where the S's performance during experimentation was ignored, and only the S's final conclusion was scored (Arlin, 1974, 1977). Another example occurred in the assessment of volume conservation (Elkind, 1961b, 1962) where the categories of performance involved no differentiation between interior volume conservation and the conservation of occupied volume, both of which had been tested. Both narrowness and strictness in scoring were evident in the chemicals task when a performance had to include the complete set of 15 combinations to be classified as 3B, and no credit was given for understanding of the roles of the various chemicals (Dulit, 1972).

All the preceding deviations from the methodology of Inhelder and Piaget might serve to reduce the percentage of Ss who appeared to perform at the formal-operational level.

In the case of the chemicals task, for example, the simple question asked in the present study "Is there anything else you could do?" produced for many Ss a considerable increase in the number of combinations made. That only one question produced such a facilitating effect suggests that the above-mentioned studies would have classified many more Ss as formal-operational if procedures more similar to those of Inhelder and Piaget had been followed.

The present argument is not that the use of procedures similar to those of Inhelder and Piaget would result necessarily in universal performance at the formal-operational stage on the part of normal adult Ss. Rather, the argument is that there is no basis for the current overall pessimism that only a small proportion of adolescents or even adults are capable of operating at the formal-operational level on traditional assessment tasks. It becomes unclear whether these tasks, when administered in the manner of Inhelder and Piaget, underestimate formal-operational achievement as seriously as Piaget would seem to suggest they do. In the present study, certainly not all of the relatively high percentage of Ss showing formal-operational performance on these tasks would be expected to have considerable aptitude or specialization in science; in fact, certain of the Ss classified as formal-operational indicated by their comments a lack of interest in science and hence, possibly in some cases, minimal scientific aptitude. Comparative studies of performance on tasks specialized according to the individual's aptitudes and professional specialization and on the traditional tasks administered in the manner of Inhelder and Piaget would seem to be required. Such studies would shed light on the issue of whether or not the latter tasks thus administered would produce substantial underestimation of formal-operational achievement. Such studies also would indicate if universality of performance at the formal-operational level would appear among adults when either specialized or traditional tasks measured cognitive level.

Also bearing on this issue of universality is the observation made in this study that many pilot Ss who did poorly initially in the Piagetian tasks caught on quickly when the correct procedure for experimenting was explained to them. This observation suggests, contrary to Piaget's position, that special training procedures might be efficient in teaching formal-operational thinking. In fact such training procedures might be far more effective than those designed to produce performance at the concrete-operational level. The environment by nature of the structure of the physical world would seem to "force" the development of concrete operations upon every normal human being. Such "forcing" would not appear to occur in the case of formal operations. In fact, it is the E's opinion, based on teaching experience, that formal instruction, even at the secondary school level, seldom "forces" formal-operational thinking. Furthermore, unlike the younger child, the adolescent should be capable of understanding instruction at a fairly abstract level. Such abstract instruction might promote nonspecific transfer, which presumably would not be found in the case of <u>S</u>s receiving training in concrete operations.

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APPENDIX A

Table 11. Product-moment correlation matrix and partial correlations for the assessment tasks.

TASKS	Pendulum				Volume				Balance				Average of Formal Tasks				Uncontaminated Average of Formal Tasks[d]				WISC Vocabulary			
		Effects removed of:				Effects removed of:				Effects removed of:				Effects removed of:				Effects removed of:				Effects removed of:		
	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age
Chemicals	.35[b] (54)	.26 (51)	.35[b] (53)	.26 (50)	.38[b] (54)	.30[c] (51)	.37[b] (53)	.30[c] (50)	.38[b] (54)	.30[c] (51)	.37[b] (53)	.30[c] (50)	.71[a] (54)	.67[a] (51)	.70[a] (53)	.67[a] (50)	.45[a] (54)	.37[b] (51)	.44[a] (53)	.37[b] (50)	.32[c] (52)	-	.31[c] (51)	-
Pendulum					.40[b] (54)	.32[c] (51)	.39[b] (53)	.32[c] (50)	.41[b] (54)	.33[c] (51)	.41[b] (53)	.33[c] (50)	.70[a] (54)	.65[a] (51)	.70[a] (53)	.65[a] (50)	.49[a] (54)	.40[b] (51)	.48[a] (53)	.40[b] (50)	.37[b] (52)	-	.36[b] (51)	-
Volume									.59[a] (54)	.54[a] (51)	.58[a] (53)	.54[a] (50)	.82[a] (54)	.79[a] (51)	.81[a] (53)	.79[a] (50)	.59[a] (54)	.52[a] (51)	.58[a] (53)	.52[a] (50)	.34[c] (52)	-	.29[c] (51)	-
Balance													.77[a] (54)	.74[a] (51)	.77[a] (53)	.74[a] (50)	.62[a] (54)	.55[a] (51)	.61[a] (53)	.55[a] (50)	.34[c] (52)	-	.32[c] (51)	-
Average of Formal Tasks																					.44[a] (52)	-	.41[b] (51)	-

Note: ( ) indicates degrees of freedom.

[a]$p < .001$.

[b]$p < .01$.

[c]$p < .05$.

[d]Uncontaminated average resulted from removing from the average of the formal tasks the contribution of the single task being correlated with the average.

APPENDIX A

Table 12. Original and retest unadjusted and partial correlations between Piagetian task performance and overall memory performance.

TASKS	Overall Memory : Original				Overall Memory : Retest			
	Unadj.	Effects removed of: WISC	Age	WISC and age	Unadj.	Effects removed of: WISC	Age	WISC and age
Average of Formal Tasks	.49[a] (54)	.45[a] (51)	.52[a] (53)	.47[a] (50)	.32[c] (53)	.29[c] (50)	.42[b] (52)	.36[b] (49)
Chemicals	.30[c] (54)	.25 (51)	.31[c] (53)	.26 (50)	.16 (53)	.13 (50)	.21 (52)	.15 (49)
Pendulum	.20 (54)	.13 (51)	.20 (53)	.13 (50)	.13 (53)	.08 (50)	.17 (52)	.09 (49)
Volume	.46[a] (54)	.42[b] (51)	.49[a] (53)	.45[a] (50)	.27[c] (53)	.23 (50)	.39[b] (52)	.33[c] (49)
Balance	.54[a] (54)	.51[a] (51)	.55[a] (53)	.52[a] (50)	.44[a] (53)	.42[b] (50)	.53[a] (52)	.49[a] (49)
Volume: Subtask 5	.28[c] (54)	.28[c] (51)	.29[c] (53)	.30[c] (50)	.11 (53)	.10 (50)	.15 (52)	.15 (49)

Note: ( ) indicates degrees of freedom.

[a] $p < .001$.

[b] $p < .01$.

[c] $p < .05$.

APPENDIX A

Table 13. Original and retest unadjusted and partial correlations between Piagetian task performance and performance on the memory task related to volume conservation.

TASKS	Original Memory				Retest Memory			
		Effects removed of:				Effects removed of:		
	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age
Average of Formal Tasks	$.28^{c}$ (54)	.23 (51)	$.28^{c}$ (53)	.24 (50)	$.28^{c}$ (52)	.17 (49)	$.28^{c}$ (51)	.18 (48)
Chemicals	-.02 (54)	-.08 (51)	-.01 (53)	-.07 (50)	.06 (52)	-.04 (49)	.05 (51)	-.04 (48)
Pendulum	$.27^{c}$ (54)	.23 (51)	$.28^{c}$ (53)	.23 (50)	.23 (52)	.13 (49)	.23 (51)	.13 (48)
Volume	$.34^{b}$ (54)	$.31^{c}$ (51)	$.35^{b}$ (53)	$.32^{c}$ (50)	$.35^{b}$ (52)	$.28^{c}$ (49)	$.35^{c}$ (51)	$.29^{c}$ (48)
Balance	.23 (54)	.18 (51)	.23 (53)	.19 (50)	.19 (52)	.10 (49)	.19 (51)	.10 (48)

Note: ( ) indicates degrees of freedom.

$^{a}p < .001$.

$^{b}p < .01$.

$^{c}p < .05$.

APPENDIX A

Table 14. Original and retest unadjusted and partial correlations between Piagetian task performance and performance on the memory tasks related to combinations.

TASKS	ANIMALS								VEHICLES							
	Original Memory				Retest Memory				Original Memory				Retest Memory			
		Effects removed of:				Effects removed of:				Effects removed of:				Effects removed of:		
	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age
Average of Formal Tasks	$.38^{b}$ (54)	$.32^{c}$ (51)	$.39^{b}$ (53)	$.33^{c}$ (50)	.02 (52)	-.01 (49)	.07 (51)	.02 (48)	$.27^{c}$ (54)	.24 (51)	$.28^{c}$ (53)	.24 (50)	.16 (53)	.16 (50)	.24 (52)	.21 (49)
Chemicals	.20 (54)	.14 (51)	.20 (53)	.14 (50)	-.09 (52)	-.11 (49)	-.06 (51)	-.11 (48)	.17 (54)	.13 (51)	.17 (53)	.13 (50)	.20 (53)	.20 (50)	.25 (52)	.23 (49)
Pendulum	.10 (54)	.02 (51)	.11 (53)	.02 (50)	-.05 (52)	-.08 (49)	-.03 (51)	-.09 (48)	.16 (54)	.12 (51)	.16 (53)	.12 (50)	.08 (53)	.07 (50)	.11 (52)	.07 (49)
Volume	$.36^{b}$ (54)	$.31^{c}$ (51)	$.38^{b}$ (53)	$.33^{c}$ (50)	.04 (52)	.02 (49)	.11 (51)	.08 (48)	.16 (54)	.12 (51)	.17 (53)	.13 (50)	.02 (53)	.01 (50)	.11 (52)	.08 (49)
Balance	$.47^{a}$ (54)	$.43^{b}$ (51)	$.48^{a}$ (53)	$.44^{a}$ (50)	.16 (52)	.15 (49)	.21 (51)	.17 (48)	$.39^{b}$ (54)	$.37^{b}$ (51)	$.40^{b}$ (53)	$.37^{b}$ (50)	.19 (53)	.20 (50)	.26 (52)	.23 (49)

Note: ( ) indicates degrees of freedom.

$^{a}p < .001$.

$^{b}p < .01$.

$^{c}p < .05$.

APPENDIX A

Table 15. Original and retest unadjusted and partial correlations between Piagetian task performance and performance on the memory tasks related to permutations.

TASKS	Permutations of three								Permutations of four							
	Original Memory				Retest Memory				Original Memory				Retest Memory			
		Effects removed of:				Effects removed of:				Effects removed of:				Effects removed of:		
	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age	Unadj.	WISC	Age	WISC and age
Average of Formal Tasks	.38[b] (54)	.38[b] (51)	.40[b] (53)	.39[b] (50)	.19 (53)	.21 (50)	.26 (52)	.25 (49)	.29[c] (54)	.28[c] (51)	.31[c] (53)	.29[c] (50)	.32[c] (52)	.37[b] (49)	.38[b] (51)	.40[b] (48)
Chemicals	.26 (54)	.24 (51)	.26 (53)	.24 (50)	-.07 (53)	-.07 (50)	-.04 (52)	-.06 (49)	.19 (54)	.17 (51)	.20 (53)	.17 (50)	.11 (52)	.12 (49)	.14 (51)	.13 (48)
Pendulum	.17 (54)	.14 (51)	.17 (53)	.14 (50)	.06 (53)	.07 (50)	.09 (52)	.07 (49)	.09 (54)	.06 (51)	.10 (53)	.06 (50)	.10 (52)	.11 (49)	.12 (51)	.11 (48)
Volume	.41[b] (54)	.40[b] (51)	.42[b] (53)	.41[b] (50)	.24 (53)	.26 (50)	.32[c] (52)	.32[c] (49)	.28[c] (54)	.26 (51)	.31[c] (53)	.29[c] (50)	.31[c] (52)	.34[c] (49)	.38[b] (51)	.38[b] (48)
Balance	.30[c] (54)	.29[c] (51)	.31[c] (53)	.29[c] (50)	.36[b] (53)	.38[b] (50)	.41[b] (52)	.42[b] (49)	.31[c] (54)	.30[c] (51)	.33[c] (53)	.31[c] (50)	.50[a] (52)	.53[a] (49)	.54[a] (51)	.56[a] (48)

Note: ( ) indicates degrees of freedom.

[a] $p < .001$.

[b] $p < .01$.

[c] $p < .05$.

APPENDIX A

Table 16. Original and retest unadjusted and partial correlations between Piagetian task performance and performance on the memory tasks related to the lattice.

TASKS	Screws and Bolts							
	Original Memory				Retest Memory			
	Unadj.	Effects removed of: WISC	Age	WISC and age	Unadj.	Effects removed of: WISC	Age	WISC and age
Average of Formal Tasks	.33^{c} (54)	.25 (51)	.35^{b} (53)	.26 (50)	.32^{c} (53)	.23 (50)	.38^{b} (52)	.27 (49)
Chemicals	.32^{c} (54)	.25 (51)	.32^{c} (53)	.25 (50)	.26 (53)	.19 (50)	.29^{c} (52)	.20 (49)
Pendulum	.12 (54)	.02 (51)	.13 (53)	.02 (50)	.14 (53)	.04 (50)	.16 (52)	.04 (49)
Volume	.27^{c} (54)	.19 (51)	.29^{c} (53)	.22 (50)	.28^{c} (53)	.21 (50)	.35^{b} (52)	.27 (49)
Balance	.31^{c} (54)	.24 (51)	.32^{c} (53)	.25 (50)	.32^{c} (53)	.25 (50)	.36^{b} (52)	.28^{c} (49)

TASKS	Flowers							
	Original Memory				Retest Memory			
	Unadj.	Effects removed of: WISC	Age	WISC and age	Unadj.	Effects removed of: WISC	Age	WISC and age
Average of Formal Tasks	.31^{c} (54)	.22 (51)	.30^{c} (53)	.22 (50)	.28^{c} (53)	.21 (50)	.28^{c} (52)	.22 (49)
Chemicals	.19 (54)	.12 (51)	.19 (53)	.12 (50)	.28^{c} (53)	.23 (50)	.28^{c} (52)	.23 (49)
Pendulum	.26 (54)	.18 (51)	.25 (53)	.18 (50)	.20 (53)	.14 (50)	.20 (52)	.14 (49)
Volume	.26 (54)	.19 (51)	.25 (53)	.19 (50)	.16 (53)	.09 (50)	.16 (52)	.10 (49)
Balance	.22 (54)	.15 (51)	.22 (53)	.15 (50)	.25 (53)	.19 (50)	.25 (52)	.19 (49)

TASKS	Jolls							
	Original Memory				Retest Memory			
	Unadj.	Effects removed of: WISC	Age	WISC and age	Unadj.	Effects removed of: WISC	Age	WISC and age
Average of Formal Tasks	.26 (54)	.30^{c} (51)	.31^{c} (53)	.33^{c} (50)	.17 (53)	.13 (50)	.16 (52)	.13 (49)
Chemicals	.17 (54)	.18 (51)	.19 (53)	.19 (50)	.12 (53)	.09 (50)	.11 (52)	.09 (49)
Pendulum	-.08 (54)	-.08 (51)	-.07 (53)	-.08 (50)	.10 (53)	.06 (50)	.09 (52)	.06 (49)
Volume	.32^{c} (54)	.35^{b} (51)	.38^{b} (53)	.39^{b} (50)	.14 (53)	.11 (50)	.13 (52)	.11 (49)
Balance	.37^{b} (54)	.40^{b} (51)	.40^{b} (53)	.42^{b} (50)	.16 (53)	.13 (50)	.16 (52)	.13 (49)

Note: ( ) indicates degrees of freedom.

$^{a}p < .001$.

$^{b}p < .01$.

$^{c}p < .05$.

APPENDIX A

Table 17. Original and retest unadjusted and partial correlations between average Piagetian task performance and performance on the component measures in each memory task.

TASKS	Measure	Correlations with Average Piagetian Performance							
		Original				Retest			
		Unadj.	Effects removed of:			Unadj.	Effects removed of:		
			WISC	Age	WISC and age		WISC	Age	WISC and age
Volume[d]	Levels drawn correctly	.19 (54)	.15 (51)	.19 (53)	.16 (50)	.25 (49)	.15 (46)	.24 (48)	.16 (45)
	Levels recognized correctly	$.31^c$ (54)	.26 (51)	$.32^c$ (53)	.27 (50)	$.33^c$ (52)	.22 (49)	$.32^c$ (51)	.23 (48)
Animals[e]	No. combina-tions	.23 (54)	.17 (51)	.26 (53)	.19 (50)	.05 (52)	−.02 (49)	.06 (51)	−.00 (48)
	Horizontal order	$.42^b$ (54)	$.38^b$ (51)	$.43^a$ (53)	$.39^b$ (50)	.01 (52)	.03 (49)	.07 (51)	.01 (48)
	Vertical order	$.34^c$ (54)	$.28^c$ (51)	$.33^c$ (53)	$.28^c$ (50)	.01 (52)	.01 (49)	.07 (51)	.06 (48)
Vehicles[e]	No. combina-tions	.24 (54)	.21 (51)	.25 (53)	.22 (50)	.12 (53)	.10 (50)	.19 (52)	.14 (49)
	Horizontal order	.26 (54)	.23 (51)	$.27^c$ (53)	.24 (50)	.16 (53)	.16 (50)	.24 (52)	.21 (49)
	Vertical order	$.27^c$ (54)	.23 (51)	$.27^c$ (53)	.23 (50)	.14 (53)	.16 (50)	.22 (52)	.20 (49)
Permuta-tions of three[f]	No. permuta-tions	.24 (54)	.24 (51)	.23 (53)	.23 (50)	.12 (53)	.12 (50)	.14 (52)	.13 (49)
	Initial Members Constant	$.33^c$ (54)	$.29^c$ (51)	$.31^c$ (53)	$.28^c$ (50)	.13 (53)	.12 (50)	.16 (52)	.14 (49)
	Vertical Order	$.38^b$ (54)	$.41^b$ (51)	$.43^a$ (53)	$.44^a$ (50)	.21 (53)	$.27^c$ (50)	$.29^c$ (52)	$.33^c$ (49)

Note: ( ) indicates degrees of freedom.

[a] $p < .001$.

[b] $p < .01$.

[c] $p < .05$.

d, e, f, and [g] See pages 69-70, 76-78, 84-87, and 97, respectively, for detailed explanations of the component measures of these tasks.

APPENDIX A

Table 17. (continued)

TASKS	Measure	Original: Unadj.	Original: Effects removed of: WISC	Original: Effects removed of: Age	Original: Effects removed of: WISC and age	Retest: Unadj.	Retest: Effects removed of: WISC	Retest: Effects removed of: Age	Retest: Effects removed of: WISC and age
		Correlations with Average Piagetian Performance							
Permutations of four[f]	No. permutations	.31[c] (54)	.28[c] (51)	.32[c] (53)	.29[c] (50)	.28[c] (52)	.28[c] (49)	.31[c] (51)	.30[c] (48)
	Initial Members Constant	.32[c] (54)	.31[c] (51)	.35[b] (53)	.32[c] (50)	.33[c] (52)	.39[b] (49)	.39[b] (51)	.42[b] (48)
	Vertical Order	.20 (54)	.20 (51)	.23 (53)	.22 (50)	.14 (52)	.21 (49)	.19 (51)	.24 (48)
Screws and Bolts[g]	No. members matrix drawn	.37[b] (54)	.29[c] (51)	.38[b] (53)	.30[c] (50)	.37[b] (53)	.29[c] (50)	.39[b] (52)	.31[c] (49)
	No. correct liked and disliked drawn	.26 (54)	.17 (51)	.27[c] (53)	.19 (50)	.23 (53)	.15 (50)	.22 (52)	.14 (49)
Flowers[g]	No. members matrix drawn	.35[b] (54)	.26 (51)	.36[b] (53)	.27 (50)	.31[c] (53)	.25 (50)	.31[c] (52)	.24 (49)
	No. correct liked and disliked drawn	.23 (54)	.17 (51)	.24 (53)	.18 (50)	.21 (53)	.15 (50)	.20 (52)	.14 (49)
Jolls[g]	No. members matrix drawn	.26 (54)	.32[c] (51)	.26 (53)	.32[c] (50)	.21 (53)	(18) (50)	.21 (52)	.17 (49)
	No. correct liked and disliked drawn	.25 (54)	.28[c] (51)	.25 (53)	.27 (50)	.10 (53)	.07 (50)	.10 (52)	.07 (49)

Note: ( ) indicates degrees of freedom.

[a] $p < .001$.

[b] $p < .01$.

[c] $p < .05$.

d, e, f, and [g] See pages 69-70, 76-78, 84-87, and 97, respectively, for detailed explanations of the component measures of these tasks.

APPENDIX B. Minimal Correlations between Performance on Specific Piagetian and Memory Tasks: Possible Reasons

There would seem to be two basic reasons why performance on specific Piagetian tasks postulated to be related to specific memory tasks did not predict well performance on these memory tasks. First, the specific schemes or understandings may have been assessed inadequately by the particular Piagetian tasks. Secondly, the abilities required to figure out or generate the displays may be in some way different from the Piagetian schemes thought related to the displays.

Table 18 (p. 155) provides an outline of the principal relationships predicted between memory task performance and performance on specific Piagetian tasks. The possible reasons for the lack of relationships found are indicated by a tick. These reasons include the first basic explanation, concerning the possibly inadequate assessment of the specific Piagetian schemes, and four subcategories of the second basic explanation. These subcategories will be explained in greater detail when their relevance to the various memory tasks is discussed.

In the case of the first reason, the possibility exists that all the specific schemes were assessed inadequately. These schemes included the conservation of occupied volume, the abilities to combine and permute, and the method of holding variables constant to test the effects of others; these schemes were considered to be assessed most directly by, respectively, the volume conservation, chemical combinations, and pendulum tasks. As the inadequacy of assessment would seem most apparent in the case of the conservation of occupied volume and the combinatorial operations, only the problems with their assessment will be discussed.

In the memory task related to volume, there was only a mimimal relationship between memory performance and performance on subtask 5. On the other hand, there was a strong relationship between memory performance and the nature of the Ss' responses when the Ss were questioned after completion of the drawing and recognition tests. A high percentage of Ss who did one or both of these tests incorrectly explained that the weight or volume of the clay was changed when the shape was modified. An equally high percentage of Ss who drew and recognized the display correctly said the volume (or weight) had not changed. It is recognized that the E's questioning may have prompted post hoc reasoning on the part of some Ss; such reasoning presumably would not have mediated memory performance. However, it is possible that in some cases the Ss' responses to these questions reflected an understanding or lack of understanding which was responsible for memory performance.

The question then becomes why performance on subtask 5 did not assess adequately the understanding or lack of understanding of these latter Ss. Possibly a more adequate assessment might have occurred if the Ss had been given credit only if they justified their decisions and persisted with the decision despite counterarguments on the part of the E. It was the E's opinion that a number of the Ss might have been dissuaded in either direction.

It also is possible that assessing the conservation of occupied volume by the method of rearranging blocks under water might yield different results than a method involving changing the shape of the clay. Some limited postexperimental testing indicated that the relationship between the results of these two methods was not as high as would have been expected. It may be, as suggested by P. K. Arlin (personal communication), that the apparent success of some Ss when they have been assessed by the method involving clay was based, not on volume conservation, but on the conservation of weight. This suggestion is supported by the finding in the present study of some Ss who said the water levels in the glasses were the same because the weight of the clay remained the same.

Similarly, in the case of the memory tasks related to combinations, it is possible that the assessment of combinatorial ability through the chemical combinations task and its basic method measure was inadequate. The instructions in the chemicals task to reproduce the yellow color by using the liquids from the bottles may have been misleading. The instructions seem to have suggested to the Ss to simply reproduce the color and not to find all the ways to make the color. Thus many Ss stopped after making the color one way and often did not recommence after the E's questioning whether there was anything else they could do. It was the E's opinion that many of them would have done better if they had been instructed to find all the ways of making the yellow color.

It may be argued that the chemicals task, with its instructions as provided, may have tapped general formal-operational thinking, including the ability to operate within the framework of the hypothetico-deductive method and to consider not only the real but also the possible. This thinking presumably should not be influenced greatly by minor changes in instructions. However, it also can be argued that the chemicals task may not have tapped adequately the combinatorial scheme, particularly if one questions the validity of the postulated connection between this scheme and the lattice structure.

The possible inadequacy of the chemicals task in assessing combinatorial ability also might be responsible for the lack of relationship found between the chemicals task and the memory tasks related to permutations. In addition, even if combinatorial ability had been assessed adequately by the chemicals task, the relationship between this task and the memory tasks related to permutations might be indirect. According to Piaget and Inhelder (1975), the ability to permute, while closely related to the ability to make combinations, is not identical and develops at a later age. It would seem that the latter ability is more closely related to performance on the chemicals task than is the former.

Possibly, the use of assessment tasks more closely related to the ability to combine or to permute might result in a fairly strong relationship between these tasks and the recall or reconstruction of combinations or permutations. Examples of such tasks might be found in Piaget and Inhelder (1975). For example, Ss might be required to make all the permutations or pair-wise combinations of n different objects.

The four subcategories of the second basic explanation for the lack of significant relationships include the following. First, the figurative component of the display possibly could have been relatively simple. Thus higher order mnemonic schemes might not have been required to remember the display. This possibility would seem to pertain particularly to the memory task related to volume. Operations concerning the conservation of occupied volume might not have been activated, or if activated, the resulting understanding might have been negated due to the simple nature of the display. Furthermore, the figurative aspect of the display might have been emphasized by the procedure, which required the S during the initial display to note twice that the water levels were equal.

Secondly, the figurative component of the display might not have been necessarily simple. However, certain higher-order mnemonic schemes thought optimally efficient for memory may not have been used or required for successful memory performance. In the case of the memory tasks related to the lattice, the method of comparing nearly identical positive and negative instances of a concept to determine the factors responsible for their designation may not have been used by many, if any, _S_s. This method, which possibly was related to the Piagetian operation of holding variables constant while manipulating others, had been considered to be optimally efficient but not necessary for successful memory performance.

Thirdly, it is possible that operations assessed by specific Piagetian tasks are somewhat different from and possibly require more on the part of the _S_s than do seemingly similar mnemonic abilities. This might be the case in the memory tasks related to combinations and permutations. The abilities required to spontaneously generate all the possible combinations and permutations might differ from the abilities needed to "catch on" to the system of a display of combinations or permutations presented to the _S_. These former abilities may involve operations at a higher level than do their memory task counterparts, which may require mnemonic skills which are somewhat trivial in comparison.

There is some very indirect evidence supporting the distinction between the abilities to combine and permute and their mnemonic counterparts. According to Piaget and Inhelder (1975), the ability to combine develops earlier than the ability to permute. Thus, if these operations are related to mnemonic abilities, it would seem that the ability to recall or reconstruct a display of combinations might develop earlier than the ability to recall or reconstruct a display of permutations. In the case of the present study, it might be expected that Ss who do well on the memory tasks related to permutations also should do well on the tasks related to combinations. Subjects who do well on the latter tasks need not do well on the former. The results, however, did not support this expectation.

This possible distinction between the abilities to combine and permute and their mnemonic counterparts may have been due to the latter abilities being somewhat trivial. However, there is a fourth reason why the abilities required to figure out or generate the displays might be somewhat different from the Piagetian schemes thought related to the displays. It is possible that the mnemonic schemes used to generate or figure out the displays were not necessarily trivial but were only superficially analogous to the operations assessed by the specific Piagetian tasks.

This explanation would seem relevant to the lack of

APPENDIX B

Table 18. Possible reasons for the lack of relationships between performance on specific memory tasks and specific Piagetian tasks.

	MEMORY TASKS RELATED TO:				
	Volume	Combinations	Permutations		Lattice
PIAGETIAN TASKS	Volume: Subtask 5	Chemicals	Chemicals	Pendulum	Pendulum
Explanations					
Piagetian operations inadequately assessed	✓	✓	✓	✓	✓
Memory display figuratively simple	✓				
Higher order mnemonic schemes efficient but not necessary					✓
Mnemonic schemes trivial in comparison to Piagetian counterparts		✓	✓	✓	
Mnemonic schemes only analogous to Piagetian counterparts				✓	✓

Note: Relevant reasons indicated by ✓.

relationships found between the pendulum task and the memory tasks related to permutations and the lattice of propositions. The method of holding variables constant while manipulating others to test their effects was presumed to be assessed by the pendulum task and, more particularly, by its basic method measure. This experimental method might be only superficially similar to the method of generating the displays of permutations by holding the first member(s) constant while changing the position of the last two. Similarly, this method might be only analogous to the method of comparing nearly identical positive and negative instances to determine the factor(s) responsible for their different designations. This latter method had been predicted to be optimally efficient in "figuring out" the concepts involved in the displays relating to the lattice.