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ABSTRACT

This paper discusses research exploring the performance factors involved in studies which test for formal operations. It is suggested that several previous studies dealing with formal operations confound performance and competence in determining the extent of subjects' formal operations schemata. Factors which might account for performance differences are: (1) tasks chosen by the investigators to measure formal operations thought, (2) the degree to which the investigators use a direct method of task presentation and questioning, (3) the number of dimensions along which tasks vary, (4) the content area of the task, (5) sex differences, and (6) intelligence differences. Results of a series of experiments with elementary, junior high, and high school students which tested the extent to which these factors affect formal operations performance are presented. (BRT)

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Formal Operations Thinking: Now You See It, Now You Don't

Suzanne Martorano

The title of this paper reflects my alternating states of confidence when trying to understand my own research, and that of others, on formal operations thought. As any one of my research assistants will tell you, I cycle from confidence to uncertainty, to despair, and finally to renewed hope before I start over again. I might add that the period of confidence is surely the briefest part of the cycle.

In general the moods are highly correlated with the amount of time I have spent the previous day trying to decipher my own data and integrate it with the results of other studies. If we take as our standard Inhelder and Piaget's (1958) statements about the character of formal thought and its course of development, then the research literature is clearly equivocal in its support. Although early investigators (Jackson, 1965; Lovell, 1961), in agreement with Inhelder and Piaget, set the age of emergence of formal operations at between 11 and 12, more recent studies (Dale, 1970; Dulit, 1972; Keating, 1975; Martorano, 1973; Weybright, 1972) have failed to find a majority of even middle and late adolescent subjects performing at a formal level. Interpretation of these data is especially difficult because the range of within subject performance across tasks also varies between studies. While Keating (1975), Lee (1971) and Weybright (1972) have found within subject homogeneity of performance across tasks, I (Martorano, 1973) and others (Dulit, 1972; Kuhn, Langer, Kohlberg & Haan, 1972; Lovell, 1961; Lovell, 1971; Neimark, 1970) have found within subject differences across tasks.

I would like to suggest that the performance - competence distinction presented by Flavell and Wohlwill (1969) is a useful conceptual strategy for clarifying the research on cognitive development at the formal operations level.

Inhelder and Piaget's (1958) statement about the development and nature of formal operations is essentially a competence theory. That is, a formal or logical presentation of the structure of formal thought with a description of what the individual knows and does in an ideal environment. Even a brief reading of the Inhelder and Piaget (1958) book will reveal that the authors are discussing the logical structure of adolescent thinking. But, how then do we deal with the empirical data presented in the numerous subject protocols included in the book? Dulit (1972) has provided the answer by pointing out that the subject protocols were chosen not for their representativeness of subject performance in general, but for their value in illustrating the authors' explanation of the character of formal thought as revealed in performance on the formal operations tasks. Thus, I would argue that Inhelder and Piaget are describing competence, and therein lies the problem for those for us who do formal operations research.

Despite the use of the clinical method when testing subjects, I believe the formal operations data reflect an interaction between performance and competence. In discussing performance aspects of behaviour I am referring to those processes and conditions in real problem situations that facilitate or inhibit the use of the knowledge implied by a given level of competence. A performance theory therefore is concerned with specifying the conditions or strategies that facilitate or impede performance.

I'd like to turn now to an examination of some of the differences in previous formal operations studies that might account for the performance differences that I mentioned earlier. Perhaps the most striking difference between studies is the actual task or tasks chosen by the investigator to measure formal thought. Inhelder and Piaget (1958) imply that the formal operations schemata emerge synchronously and thus performance on tasks designed to elicit these schemata should be equivalent within a given subject. However, my doctoral research (Martorano, 1973) showed considerable heterogeneity across a wide range of the tasks. While it is not possible to determine if this task performance difference represents differential competence with respect to the underlying schemata tapped, or differential task difficulty, I think it is safe to say that the task an investigator uses will have an effect on whether or not evidence of formal thinking is found.

Another factor that seems to vary between studies is the degree to which the investigator uses a directed method of task presentation and questioning. It is difficult to determine how great the variability is on this dimension, but a close reading of the methods sections of a number of studies leads me to suspect that there are discriminable differences. For instance, Lee (1971) utilized a very specific method of task presentation that involved a series of choice points, if the subject did not show evidence of a certain level of understanding, then the interview was terminated. I'm sure one could argue that this wa either a useful procedure (the choice points proceeded from the most simple instances of the concept to the most general) or that the procedure did not adequately allow the subject to explore all the ramifications of the problem apparatus. The point is still the same - the procedure may have affected subjects' performance in a way that was different from that in other studies where the task procedure was different. A variation on this point is the distinction between use of the actual task apparatus described by Inhelder and Piaget (1958), or a pencil and paper version. Dulit (1972) used a pencil and paper version of the chemicals task and argued that if subjects were at a formal level of thought they used a system either when combining the actual chemicals, or when simply noting which combinations were made. However, the same would not be expected of transitional subjects. Flavell and Wohlwill (1969) and Neimark (1972) have pointed out that transitional subjects may be especially susceptible to situational variables and thus very different results might be expected in these two versions of the task.

The number of dimensions along which a task varies may also affect performance. For instance, the pendulum task has two very obvious dimensions, amount of weight and length of the pendulum, while the rods problem has five; length, shape, material and diameter of the rod and amount of weight attached. Similarly, Piaget and Inhelder (1951) note that young children can systematically contruct all possible pairs of three colors but become confused when more colors are added.

The content area in which the task is set is the final task variable that I would like to mention. Piaget (1972) himself has suggested that evidence of formal thought may appear first in those content areas in which the subject has special interest or aptitude. I suspect that area of specialization is a performance variable and that it will interact with the subject's level of cognitive competence. Those subjects who have an integrated formal structure will be able to demonstrate an understanding of the operational schemata in a number of different content areas, while transitional subjects will be limited to an understanding of the concept only in those content areas in which they have special interests and aptitudes.

A second class of performance variables relates to characteristics of the subject. I will briefly mention two that have been reported in the research literature: Sex differences and intelligence.

Sex differences, when found (Dale, 1970; Dulit, 1972), indicate that males score higher than females. However, this is an elusive result and might be expected to vary as a function of the content area in which the task is set. To date no one has offered an explanation of why sex differences might occur, nor presented evidence to support their hypothesis.

Three studies have examined the effect of high IQ on formal operations performance. Two studies (Dulit, 1972; Keating, 1975) have found that high IQ is associated with higher formal operations scores when compared to performance of same age subjects of average IQ. Webb (1974) however, failed to find IQ differences. Certainly this variable should be controlled in future research.

To summarize, I have suggested that Inhelder and Piaget's (1958) description of the development of formal operations thinking is a competence theory. The data derived from research on formal operations reflects an interaction between the subject's underlying competence and a number of unspecified performance factors.

I would now like to present the results of some research I have been doing on the effects of performance factors in formal operations task situations. The first study was simply an effort to replicate a portion of the results of my doctoral dissertation. In my dissertation I had given ten of the formal operations tasks to a fairly wide age range of junior high school and high school girls. While I found a significant main effect for age, of greater interest was the significant main effect for tasks. Within subject performance across the ten tasks was not homogeneous, and in fact, there was a predictable sequence for the ten tasks. Those tasks that tapped the combinatorial and correlations schemata elicited a higher level of performance than did those tasks which tapped the schemata of multiplicative compensation, proportionality, and mechanical equilibrium. There were also differences between these other schemata, with multiplicative compensation and proportionality eliciting higher levels of performance than the tasks tapping mechanical equilibrium.

In this first study, I tested 11-, 12-, and 13-year old children on the colored tokens, permutations, and correlations tasks. The ANOVA of the data indicated that age was significant at the .05 level ($F = 3.75$, $df = 2, 48$), with the 12-year old subjects performing at a higher level than either the 11- or 13-year old subjects. The main effect for tasks was also highly significant ($F = 23.22$, $df = 2, 96$, $p = .001$), while the remaining main effect, sex, was not significant. In agreement with my doctoral data, the colored tokens task elicited significantly higher levels of performance than did either the permutations or correlations tasks. There was no significant difference between the permutations and the correlations tasks. The sex by task interaction was significant at the .05 level ($F = 3.24$, $df = 2, 96$) and is due to a crossover effect, with male subjects performing better on the correlations task, and female subjects performing better on the permutations task. Both sexes performed similarly on the colored tokens task.

The results of this study gave me more confidence in my dissertation data and further increased my curiosity about the colored tokens task. In this study 73% of the 11- and 13-year old subjects and 83% of the 12-year old subjects performed at an early or late formal operations level on the colored tokens task. This task, like the permutations and chemicals tasks is described by Inhelder and Piaget (1958) as tapping an understanding of the combinatorial system. The task has frequently been used as an indicator of an individual's ability to engage in formal operations thought. However, if my data are accurate, performance on this task is very different from performance on another task - permutations - that requires understanding of the same logical concept. In addition, the data from the colored tokens task indicated that formal operations thought was present in a majority of early adolescent subjects. These results are clearly inconsistent with a number of the other studies on formal operations that I mentioned earlier.

I then decided to examine the colored tokens task more fully. As described by Goodnow (1962), the colored tokens task involves presentation of piles of six different colored chips or squares of paper. The subject is instructured to make all the pairs of colors that he can think of without any repeats. The child is then allowed to lay out the different pairs of colors on the table in front of him. Scroing of the task is based on whether the pairs are made randomly, in conformity with a perceptual scheme, or in a systematic way that insures that all possible pairs will be found. A late formal operations score implies that the subject has a systematic strategy, and that he can state a general strategy for making all pairs when a different number of colors is used.

In thinking about the colored tokens task and the high percentage of formal scores obtained by young adolescents, I reasoned that perhaps the use of colored squares of paper was a particulary apt choice of stimulus materials. Children have a great deal of experience with colors from the beginning of their school careers on, and perhaps the early emergence of formal thinking on this task was due to the subjects' high degree of familiarity with the materials. Consequently, I decided to simply change the stimulus materials initially.

Unfortunately, things are never so simple. By the time I had thought of this study I had already exhausted my supply of subjects at the college campus school, and the school year was drawing quickly to a close. So I improvised. I had already tested all of the 9- and 10-year old children on the colored tokens task early in the fall and I knew that a number of the children were in a transitional phase on the problem. I decided to retest these children and include the stimulus materials factor in my design. The subjects were already categorized by age (9- vs. 10-years), sex, and classroom. Half of the subjects in each group received the original colored tokens task the second time, while the other half received the same problem but with new materials: Pictures of six different fruits and a cover story about making up new flavors of jello. Instead of asking the child in this new condition to make all the possible pairs of colors, he/she was asked to make all the possible pairs of fruit flavors.

The ANOVA tested for the effects of sex, age, time at which the task was given (fall or spring), and whether the task given in the spring used the same materials as the task given in the fall or new materials. The only effect that was significant, and it was significant at beyond the .001 level, was the time at which the task had been given ($F = 24.80$, $df = 1, 40$). In the fall 29% of the children had performed at either an early or late formal operations level on the task in contrast to a preoperations or concrete level. In the spring, 58% of the children who received the same task a second time, and 54% of the children who received the fruits variation scored at an early or late formal level. Of course it is impossible to know what experiences these children had during the 7 months that intervened between the first and second testings, however I do know that the children did not have any direct instruction on this concept.

I think one important result of this study is the fact that there was no difference between the two stimulus conditions at the second time of testing. In effect, the subjects' understanding of the concept of combinations improved regardless of whether the second task was new or the same. The result is even more powerful in light of the fact that 66% of the children performed at a preoperations or early concrete level on the initial presentation of the problem. The second important finding was the fact that there was such a dramatic improvement in performance in a group of subjects who initially demonstrated a very low level of performance.

The final study that I would like to describe carried my examination of task factors further. Once again I used 9- and 10-year old subjects and the colored tokens task. In an effort to check that stimulus materials did not have an effect if the subject had never received the colored tokens previously, I presented one group of subjects with the colored tokens task, one group with the fruits task that I used earlier, and one group with a variation on the fruits task. Two things were changed in this new task: The instructions, and the perceptual cues surrounding the layout of the task materials. The instructions were changed to a statement that different flavors of jello could be made by mixing these five flavors (strawberry, cherry, etc.) together and the task was to make all the possible new flavors of jello. Thus, the child was not given any specific instructions to make all pairs, triads, and so forth. These new instructions turn the problem into an analogue of the Inhelder and Piaget (1958) chemicals problem. In an effort to reduce the actual number of mixtures that the child would have to generate, only five kinds of fruits were used. The second change in the task - the perceptual cues - involved laying the piles of five fruits in a circle rather in a row as has been the case in previous studies.

Once again, the ANOVA revealed no main effect for the age variable. Sex was significant ($F = 7.87$, $df = 1, 60$, $p = .01$) with males performing at a higher level than females. The task main effect was also significant ($F = 4.60$, $df = 2, 60$, $p = .02$). Once again, colored tokens performance was not significantly different from the fruits problem in which only the stimulus materials were changed. Both tasks produced significantly higher levels of performance than did the fruits task that varied instructions and perceptual cues. None of the ANOVA interactions were significant.

Forty-six percent of the subjects who received the colored tokens task performed at early or late formal operations and 42% of the subjects who received the simple fruits task performed at early or late formal operations. However, only 17% of the subjects who received the complex fruits task (ie. both instructions and perceptual cues varied) scored at an early or late formal operations level. Two factors make this result even more impressive. In the complex fruits task only five different fruits were presented while the colored tokens and simple fruits tasks required the subjects to make pairs from an initial base of six fruits or colors. Secondly, the same scoring criteria used for the other two tasks were applied to the complex task. That is, if a subject systematically made all the possible pairs of the five fruits, he/she received a score of early formal operations. Actually, the task presented asked the subject to make all possible three-way mixtures, four-way mixtures, and the mixture of all five fruits together in addition to all the pairs of fruits. My decision to use the same scoring criteria was based on the fact that only 7 of the 24 subjects who received the complex fruits problem produced anything other than pairs of fruits and then they only produced a small number of random three-way mixtures.

I am fairly confident that this striking result is not due to the simple fact that the instructions were too ambiguous. I have some pilot data of college students' performance on the same task, and in all cases the students produced three-way, four-way, and the five-way mixtures in addition to the pairs.

These results seem to clearly argue that young adolescents are not very systematic at all in using a combinatorial schema unless you specifically tell them to do so. Further, they do not seem to spontaneously think of more than two elements varying at a time.

Let me quickly integrate my introductory section with the results of these studies. I have suggested that there are a number of performance factors active in the experimental situations in which we have tested for formal operations thinking. In most cases these factors have not been specified and we presently have little understanding of how they affect the underlying competence for formal operations thought that the subject brings to the experimental setting. The results of the studies I have presented suggest that the tasks used to test formal operations thinking elicit different levels of performance. Secondly, that while stimulus materials per se do not seem to affect performance, the amount of structure given to the subject in the instructions about what he is to do, and the perceptual configuration of the stimulus materials do affect performance. In order to go beyond our present normative studies, we need to develop more standard procedures and adequate controls for the performance factors that affect the manifestation of the formal properties of adolescent thought.

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Design Summary

Study 1

Sex	Age	Colored Tokens	Permutations	Correlations	Within
Male	11				
	12				
	13				
Female	11				
	12				
	13				

Study 2

Sex	Age	No Change		Change		Within
		Time 1 (Fall)	Time 2 (Spring)	Time 1 (Fall)	Time 2 (Spring)	
Male	9	Colored Tokens	Colored Tokens	Colored Tokens	Simple Fruits	
	10					
Female	9					
	10					

* Simple Fruits - identical instructions, perceptual cues, new stimulus materials

Study 3

Sex	Age	Colored Tokens	Simple Fruits	Complex Fruits
Male	9			
	10			
Female	9			
	10			

Complex Fruits - new stimulus materials, perceptual cues, and instructions

SUMMARY OF RESULTS

STUDY 1

Age	11 3.07	= 13 < 12 3.22 3.59		p.05
Sex	NS			
Tasks	colored tokens 4.63 >	permutations 2.85	= correlations 3.00	p<.01

STUDY 2

Age	NS		
Sex	NS		
Change-No Change	NS		
Time	Fall 2.50	Spring 3.60	p< .001

STUDY 3

Age	NS			
Sex	Male 3.30	Female 2.39		p<.01
Tasks	Colored Tokens 3.42 =	Simple Fruits 2.91 >	Complex Fruits 2.20	p<.025