DOCUMENT RESUME

ED 168 707 PS 010 475

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TITLE Correlates of Formal Reasoning.
INSTITUTION California Univ., Berkeley.
SPONS AGENCY National Science Foundation, Washington, D.C.
PUB DATE Apr 79
GRANT NSF-SED-77-18914
NOTE 28p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, California, April 8-12, 1979)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Abstract Reasoning; *Cognitive Ability; Cognitive Style; Concept Formation; *Critical Thinking; *Developmental Stages; Divergent Thinking; Educational Research; Evaluative Thinking; Intermediate Grades; Locus of Control; *Mental Development; *Personality Assessment; Problem Solving; Psychological Studies
IDENTIFIERS *Piagetian Tests; Stanford Achievement Tests

ABSTRACT

This study of Piagetian formal reasoning in seventh grade students reports the relationships between four aspects of the ability to control variables in an experiment and the relationships between those four aspects and other constructs. The four aspects of the ability to control variables identified are: (1) set up a controlled experiment, (2) assess an experiment done by another, (3) ignore the results of an uncontrolled experiment and recognize that it is uncontrolled, and (4) indicate what variables will affect the outcome of an experiment. The 124 subjects dealt with each of those questions on three different tasks. Measures of achievement (crystallized ability), field dependency (FDI), locus of control, divergent thinking, concept identification, and the Category Width Test were also employed. Results indicate that all true variance in the measures of formal thought is explained by these ability and personality measures. The interrelations among the factors studied are discussed, and brief comments about educational implications are made. Three tables present study results. (Author/BH)

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CORRELATES OF FORMAL REASONING

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*Special thanks are due Adrianne Gans, Diane Epstein, and Marian Rice who assisted in testing. Comments on an earlier draft of this manuscript by Lee J. Cronbach and Richard Snow are appreciated.

This material is based upon research supported by the National Science Foundation under grant No. SED77-18914. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Paper presented at American Educational Research Association Meeting April, 1979, San Francisco, California, Session 26.07.

Abstract

Formal reasoning tasks tap important problem solving skills and are frequently the object of instructional programs.

Piaget's structural theory of formal thought suggest that a general construct of formal reasoning exists. The study reported here examines the correlates of one aspect of formal thought in 12 year old children. Results indicate that all true variance in this measure of formal thought is explained by certain ability and personality measures.

Analysis of three different task contexts and four question types gives a detailed interpretation of the role of certain ability and personality measures in one aspect of formal reasoning.

Introduction

When we tell parents of adolescents that we are studying adolescent reasoning, many respond, "Do they?" Our research clarifies how they do and why parents might be confused. Piaget's structural theory of formal thought suggests that a general construct of formal reasoning exists. This has led Niemark (1978) to call for a paper and pencil inventory of formal reasoning. Others have questioned whether a formal reasoning construct different from general ability exists (e.g. Keating, 1976; Linn, 1978a) and whether Piaget's theory is an accurate account of adolescent reasoning (e.g. Ennis, 1975; Siegler, 1976; Levine and Linn, 1977; Linn, note 4).

Keating (in press) has suggested that a promising approach would be to study a single aspect of formal reasoning "long enough to understand its workings" before generalizing. We concur with Keating's view. The purpose of our study is to clarify the relationship between several well established constructs and an important aspect of formal reasoning.

Previous studies of formal reasoning have been complicated by variance associated with task context (e.g. Linn, 1977b). By context we mean the characteristics of the variables and materials in the task. Most studies have used a single task to measure each formal thought strategy (e.g. long and short haired rats for correlations, bending rods for controlling variables, balance beam for proportions) thereby confounding ability with task context. Piaget (1972) argues that formal reasoning is theoretically independent of context although context may introduce variance. To examine performance independent of context we used three different task contexts. Scores were summed across tasks, relegating nonsystematic effects of context to error variance.

If Piaget's structural model of formal thought is open to question, then why are the separate formal operations strategies of interest to psychologists and educators? One important characteristic of each of the formal reasoning strategies (e.g. controlling variables, proportions, functions) is that they have practical validity. That is, problem solving in real life situations often requires formal reasoning strategies.

In the study reported here, we focus on ability to control variables. In our tasks, subjects are asked to determine what variables influence an outcome; the solution involves changing one variable and keeping all others the same. Although all the tasks employed here are taken from physical experiments, similar logical procedures can be used to determine what causes a baby's allergy, why a car doesn't work, or why a cake rises. Since these tasks have practical validity, determining relationships between these tasks and established psychological constructs will aide understanding of real problem solving.

Comprehension of the relationship between ability to control variables and other ability and personality measures is likely to clarify how logical skills can be taught (e.g., Aptitude Treatment Interactions, Cronbach and Snow, 1977) and to add to understanding of how logical skills develop (e.g., Cronbach, 1975; Simon, 1976). If, as hypothesized by Linn (1978b), age and aptitude differences may be confounded in Piaget's observations, then investigations of correlates of formal thought might be used to explain variance associated with age.

Formal reasoning tasks involve complex problem solving. A promising direction for disentangling the complexities of a particular problem is to look at the various types of questions that can be used to tap reasoning in a particular area (e.g., Siegler, 1976; Linn, 1978b). For example, Linn (1978b) found that field dependency interacted with the type of question used to measure ability to control variables. In the present study four question types are used to assess aspects of the ability to control variables. The relationship between each question type and personality and ability measures will further clarify what is involved in formal reasoning.

Research on the correlates of formal thought is limited. Summarizing, Keating (in press) was led to conclude that formal operations task performance was a "behavior in need of explanation."

A number of researchers suggest that formal reasoning overlaps with general ability (Keating, 1976; 1975; Cloutier and Goldschmid, 1976; Yudin, 1966). For example, Cloutier and Goldschmid found that Raven's matrices correlated .46 with proportional reasoning; and verbal ability correlated .34. Cattell (1971) calls tests like the Raven, measures of fluid ability and tests like vocabulary measures of crystallized ability. These constructs might be useful in analyzing formal thought question types and are employed in our study.

Several studies suggest that field dependence-independence (FDI) interacts with formal thought (Saarni, 1973; Case, 1974; Linn, 1978b). The Saarni study used two measures of formal thought but is flawed by seemingly anomalous scores on FDI for several otherwise high scoring girls. The Case study showed that FDI interacts with ability to learn to control variables. The Linn study used two question types and one task to demonstrate that FDI interacts with question type. In the present study generalizability of the Linn results is increased by using three tasks and four different question types; also the relationship between FDI and formal thought is clarified by disentangling the effect of achievement. The distinction between FDI and spatial ability has been questioned (Snow, 1978); and remains a complexity of this research area.

Other possible correlates of formal thought suggested by previous research are locus of control (Lefcourt, 1976; Reiling and Massari, Note 1) and Category Width (Wallach and Kagan, 1965) which are also investigated in this study.

Subjects

The subjects were 124 seventh graders from an urban middle school of mixed SES background (61 male, 63 female; $\overline{X}$ age = 13.46, S.D. = 0.53).

Measures

Formal Reasoning

The present study was designed to analyze the relationship between four types of questions employed in assessing formal reasoning. The questions we examined are controlling, criticizing, embedded, and naming variables. Controlling requires the subject to set up a controlled experiment for a given task. For example, the subject might be asked to find out whether steel or brass rods bend more. The apparatus might consist of six rods of varying length, width, cross section, and material plus a set of weights. The subject then hangs weights from the appropriate rods and conducts an experiment. A successful responder selects rods differing only in material and uses equal weights. Criticizing requires the subject to assess an experiment conducted by someone else. For example, the subject might be shown a thick brass and thin steel rod used to test for material. The successful responder indicates that this experiment is inconclusive because the thickness of the rods is unequal.

Embedded questions emphasize the results of an uncontrolled experiment; the successful subject must ignore the results and recognize that the experiment is uncontrolled. Naming variables requires the subject to indicate what things will influence the outcome of an experiment. In Bending Rods, for example, size of weights and length of rod are variables.

The four question types employed in this study measure different aspects of ability to control variables. Naming variables is a necessary, but not sufficient aspect of controlling variables. Criticizing, controlling, and embedded each require some understanding of the formal scheme of keeping all other things equal while investigating a variable.

Previous studies have used a single formal task to measure criticizing, controlling, embedded, and naming variables, thus confounding performance with task characteristics. This study uses three different tasks (ramp, springs, bending rods) so the results can be generalized across situations.

Bending Rods. The bending rods task developed by Inhelder and Piaget (1958) has been widely used as a measure of controlling variables. First, subjects investigate the apparatus and are asked to name variables that affect flexibility of the rod. The variables are thickness of the rod, the amount of weight hung at the end, the material from which the rods were made, the diameter of the rod, and the form of its cross-section (round vs. square). Subjects are asked to set up controlled experiments for three of the variables (thickness of rods, weight hung on rods, material of rods). Subjects are asked to explain why they did each experiment. To pass these controlling questions, subjects must set up a controlled experiment and justify the experiment by indicating that the variables not under investigation were held constant.

Following each controlling question, an experiment is demonstrated and the subject was asked whether this was a good way to find out about the variables in question. To pass these criticizing questions, the subject must say whether the experiment is fair or unfair and correctly explain why.

The embedded question involves two new rods painted blue and red. Unequal weights are hung from the rods at unequal distances. The subjects are asked if the rod which bends the most is the most flexible. Successful subjects point out that they cannot tell because the weights and lengths are unequal.

Ramp. The ramp problem was developed as a group task by Warren Wollman (1977 a,b) to examine the ability to control variables using spheres rolling down a ramp. It was modified for interview format by Linn and Levine (1978). In the task, marbles released from various heights on a ramp are allowed to roll down and hit a target sphere. The child is asked controlling and criticizing questions about how each variable (height of release point, weight of marble, and weight of target) influences how far the target sphere is moved by the marble. The embedded question requires the subject to recognize that a marble released from behind a screen to hit a target may not have been released from the same position each time. Scoring is similar to bending rods.

Springs. The springs task was constructed as an analogy to the bending rods task. It is described in detail elsewhere (Linn, 1977a; Linn and Rice, 1979). The procedure and scoring system are identical to that for bending rods.

Achievement

The achievement measure assesses ability to perform school related tasks and is a good measure of crystallized ability. The language, reading, and mathematics subtests of the Stanford Achievement Test were employed. A single score was obtained by taking the mean standard score across the three tests for each child.

Field Dependence/Independence

The cognitive style of field dependency reflects the ability to analytically structure information into a highly articulated framework in the face of perceptual or previous learned factors which could lead to an incorrect response (Witkin, Dyk and Faterson, 1962). Witkin suggests that one characteristic of field dependent reasoners is difficulty in selecting all the relevant information to reason about.

A model of field dependency developed by Pascual-Leone (note 2) suggests that field dependent persons, when choosing a strategy for a task, will tend to adopt the simplest, most salient strategy even if it is less appropriate than another one. The field independent person will tend to adopt or construct a more complex, less salient strategy. Considerable evidence suggests this to be the case in general (Pascual-Leone, note 2) and for formal operations in particular (Linn, 1978; Pulos and Adi, note 3).

In the current study, the protable rod and frame (Oltman, 1968) and a locally developed modification of the Gottschaldt figures were employed to measure field dependency. The field dependency score was obtained by computing the average standard score on the two tests. The Gottschaldt figures are a version of "hidden figures" and are also sometimes employed to measure fluid ability.

Locus of Control

Locus of control assesses the perceived site of behavioral causality. At the internal end of this dimension are individuals who perceive themselves as causing their own behavior. At the external end are individuals who perceive their own behavior as being caused by factors beyond their control, e.g., luck, fate, social factors. Since internals perceive tasks as being under their own control, they are more likely to attend to and utilize the information in the task than externals (Fanelli, 1977; Rotter, 1966; Lefcourt, 1976).

The locus of control task employed was developed by Crandall, Katkousky and Crandall (1965). This form focuses primarily upon locus of control in academic situations.

Category Width Test (CWT)

The CWT is a measure of the breadth of instances a person will include in a category when given the opportunity to form either wide or narrow categories. The test used was developed by Wallach and Kogan (1965) for use with children of approximately the same age as employed in the current study.

Previous research (Parsons, 1973; Taylor and Leviti, 1967) indicates that category width correlates positively with the amount of stimulus material the subject prefers to use in solving a problem. Accordingly, for our tasks, individual differences in the CWT may be reflected in the number of variables considered in the task and hence in the number of variables controlled.

Divergent Thinking

To examine divergent thinking, Torrance's circles task (Torrance,

1974) was employed. Subjects were presented with an $8\frac{1}{2} \times 11$ sheet of paper which contained a grid of 42 circles arranged in 7 rows and 6 columns. Subjects were instructed to draw as many different objects as possible in which a circle was a requisite part. Subjects were encouraged to be creative and were informed that lines could be used both inside and outside the circle and that more than one circle could be employed to create an object. In addition, subjects were requested to write a short label beneath each picture for identification purposes. Ten minutes were allowed for the task.

Scores were determined by summing the total number of unique responses, an internally valid measure, reflecting the number of responses that occurred no more than 5 times within the sample.

Concept Identification

To examine non-causal hypothesis testing, subjects were given a modified version of Levine's concept identification task (Levine, 1966). This is considered a measure of fluid ability. Subjects were presented, in groups of 25, with a series of four-dimensional discrimination learning problems. The same four dimensions (size, color, shape, position) were employed in each problem. The stimuli for each trial were presented on display boards measuring 18 x 24 inches, where the small and large figures measured $1\frac{1}{2}$ and 3 inches high respectively.

The stimuli were constructed according to a procedure developed by Levine (1966), in which the four bivalued dimensions yield precisely eight different stimulus pairs. Subjects were presented with a series of eight 12-trial problems, in which feedback was given on every trial. The score was the number of the trial on which the subject made the last error.

RESULTS

Measures of Formal Thought

Means, standard deviations, and correlations for scores on criticizing, controlling, embedded and number of variables questions for each task are given in Table 1. Standard scores for Ramp, Springs, and Bending Rods were summed to yield total criticizing, controlling, embedded and number of variables scores; these scores are used in subsequent analyses.

Insert Table 1 about here

Reliability

Reliabilities (Cronbach's alpha) were moderate for each of the formal scores (Controlling = .60; Criticizing = .65; Embedded = .59; Number of Variables = .50). These reliabilities are acceptable considering the small number of items. Since each score is a composite of three tasks, task context factors are included in error variance. These moderate reliabilities for interview-based performance suggest the need to look for systematic effects of task context factors.

Correlation Matrix

Correlations between all the measures used in the study are given in Table 2. The correlations vary from .0 to .67; each measure correlates with some but not all of the other measures suggesting the presence of several factors in the data.

Insert Table 2 about here

Formal Scores

The correlations between the four formal scores suggest that controlling and criticizing are similar tasks but embedded and number of variables measure somewhat different abilities than controlling and criticizing. The regression analysis (Table 3) supports this contention and also suggests that controlling is more complex than criticizing. Based on the magnitude of the score reliabilities, the regression analysis accounts for most of the true variance in each test. In this situation, where context factors are relegated to error variance, no evidence for separate variance associated with the formal thought construct is found.

Insert Table 3 about here

Controlling and criticizing have similar correlations with most other measures except controlling has slightly higher correlations with divergent thinking and category width. In the regression analysis both are predicted by Achievement, FDI, and Locus of Control; controlling also is predicted by divergent thinking, hypothesis testing, and category width. These additional predictors of controlling are most likely associated with ability to generate alternatives in designing an experiment. Both scores appear to be associated with what Cattell (1971) calls crystallized intelligence as measured by achievement. Controlling seems also to include fluid ability as measured by concept identification. Both are predicted by FDI which suggests the importance of strategy selection. Locus of Control, according to Lefcourt (1976) is related to ability to adjust performance to directions and ability to be self critical both of which are important in these tasks and may not be measured by achievement.

The embedded score compared to criticizing and controlling is less correlated with achievement and locus of control and more correlated with field dependency and category width. The embedded questions are similar to criticizing questions but easier because the directions suggest that a variable is uncontrolled, so presumably less achievement related knowledge is required for performance. Also these questions come last so task directions should by now be well understood, reducing the effect of locus of control. The embedded questions, however, emphasize the results of the uncontrolled experiment which is irrelevant to solving the problem and presumably field dependent subjects and subjects who have limited category descriptions are also confused by this irrelevant information. Category width predicts both controlling and embedded, suggesting the importance of considering all the variables in solving both these tasks.

Naming variables correlates with the other formal questions and with field dependency as shown in the correlation matrix and regression analysis. The low correlation with achievement suggests that naming variables measures preference for considering each variable rather than familiarity with or actual knowledge of the variables, consistent with previous studies (Linn and Levine, 1978; Linn, in press). Subjects all know, for instance, that weight makes a difference in how far a rod bends but not all subjects name weight when asked what makes a difference. Since the preference for naming all the variables is strongly related to FDI, it may help explain what FDI predicts in the other formal questions. Partial correlations between FDI and the other formal questions when naming variables is removed are controlling $r = .21$; criticizing $r = .23$ and embedded $r = .32$, dropping each correlation by about .10.

DISCUSSION

The four question types investigated measure somewhat different abilities. The question types are differentially predicted by FDI, fluid ability, crystallized ability, locus of control, and category width. These results indicate the advantages of carrying out an analysis by question type rather than by task. Specific hypotheses concerning when and how the abilities measured are related to formal reasoning questions can be assessed and compared to observations during the formal reasoning assessments. In this section we report "observations". These are based on analysis of written protocols of each subject's performance on each task. Three staff members independently noted trends in performance; only observations noted by all staff members are reported.

In line with previous research FDI was a significant predictor of all 4 of the questions. Results show FDI measures something other than achievement (or crystallized ability). Pascual-Leone's suggestion that FDI is associated with strategy selection is supported in that FDI was most strongly associated with the embedded questions which provide confusing cues concerning which strategy is appropriate. Witkin's suggestion that field dependent subjects do not process all the information in a situation is also supported since FDI is a predictor of naming variables. Research on concept attainment and FDI suggests that field dependent subjects are also less likely to consider all the variables in this task (e.g. Dickstein, 1968).

The study supported the idea that controlling is more complex than criticizing consistent with our observations of performance on controlling and criticizing. In solving a controlling task, our observations suggest, subjects may need to "redesign" an experiment they have planned because the conditions they want are not available. For example, in Bending Rods consider a subject doing an experiment to investigate thickness of the rod; the subject may decide to use brass rods of different thickness and find no thin brass rod. It is necessary, then, for the subject to redesign and use steel rods to get a fair test of thickness. It seems likely that redesigning experiments would require divergent thinking ability as well as FDI.

Criticizing is easier to teach and more likely to be learned than controlling (Linn, in press), consistent with the finding that controlling is predicted both by divergent thinking and by abilities which Cattell describes as fluid. Divergent thinking and fluid are considered less trainable than crystallized abilities (Cattell, 1971).

Both controlling and embedded are predicted by CWT consistent with our observations of performance on these tasks. To solve a controlling task, using the all other things equal strategy, subjects need to keep all the variables in the problem in a sort of "register" and make sure that each of the variables is controlled (Figure 1). If subjects do <u>not</u> use the all other things equal strategy, this procedure would not apply. The register concept is comparable to Siegler's (1976) concept of encoding in that it emphasizes the information that the subject selects to use in a strategy. Subjects who do not have a variable in their register will not check to see if it is controlled. The register is less important for criticizing tasks because subjects don't need to keep one variable controlled while checking for another. Variables can be checked in any order and can even be checked several times to solve a criticizing task. For embedded tasks, the register is important because the results of the experiment discourage consideration of all the variables. Subjects who do check all variables in their register are more likely to be successful.

Three of the question types employed in this study require the formal scheme of "all other things equal". The analysis shows that controlling and criticizing have considerable overlap, and are strongly related to divergent thinking, and crystallized ability (measured by achievement). Also shown is that controlling is most related to fluid ability as measured by concept identification. Clarification of the relationship between FDI, fluid ability, and controlling variables awaits replication with additional measures of fluid and FDI. These results are consistent with Cloutier and Goldschmidt (1976) and clarify what might be represented when formal tasks and general ability measures overlap. No evidence for specific variance in formal reasoning unrelated to other ability measures was found.

Since controlling variables has practical validity it follows that training and investigations of aptitude treatment interactions should be sensitive to varied information presentation formats. It should be noted that since all 3 tasks employed here involved physical science variables, generalization to more natural tasks should be done cautiously. Subjects who are field dependent may need specific training to consider all the task information and make accurate strategy selections. Preliminary work, (e.g., Case, 1974; Linn, 1978b; Linn, in press) suggests that the success of training depends on FDI and on learning to select the appropriate strategy. The importance of crystallized ability (achievement) in controlling, criticizing, and embedded questions suggests that instruction might emphasize information concerning the relationships between specific variables. Studies generalizing these findings to more realistic settings, and examining the role of task content (e.g. Osherson's (1977) semantic rather than syntactic dimension) are needed.

TABLE 1

Means, Standard Deviations and Correlations of Scores

On Bending Rods, Ramp, and Springs

Task	Mean	Standard Deviation	Maximum Possible Score	Correlations Bending Rods	Springs
			Controlling		
Ramp	1.57	1.35	3	.41	.33
Bending Rods	1.20	.97	3		.26
Springs	2.08	.92	3		
			Criticizing		
Ramp	1.98	1.14	3	.25	.41
Bending Rods	1.98	1.07	3		.44
Springs	2.15	.94	3		
			Embedded		
Ramp	2.63	1.22	3	.25	.41
Bending Rods	1.80	1.48	3		.43
Springs	2.48	1.46	3		
			Number of Variables		
Bending Rods	2.98	.86	5		
Springs	3.53	1.12	5		

Table 2. Means, Standard Deviations and Pearson Correlations

	Con	Cri	Emb	#Var	Ach't	FDI	L-C	H-Testing	Diver	CWT
Controlling (Con)		.67	.43	.32	.46	.32	-.33	.41	.34	.11
Criticizing (Cri)			.36	.25	.43	.31	-.37	.36	.23	.00
Embedded (Emb)				.29	.40	.40	-.07	.34	.20	.34
Number of Variables (#Var)					.09	.39	.08	.18	.07	.05
Achievement (Ach't)						.14	-.41	.42	.34	-.01
Field Dependency/Independency (FDI)							.14	.37	.37	.01
Locus of Control (L-C)								.37	.09	.01
Hypothesis Testing (H-Testing)									-.09	.03
Divergent Thinking (Diver)										-.14
Mean							14.4	35.7	4.9	65.6
Standard Deviation							4.1	13.7	4.5	13.3

Significance of correlations, r = .17 p .05; r = .23 p .01

TABLE 3

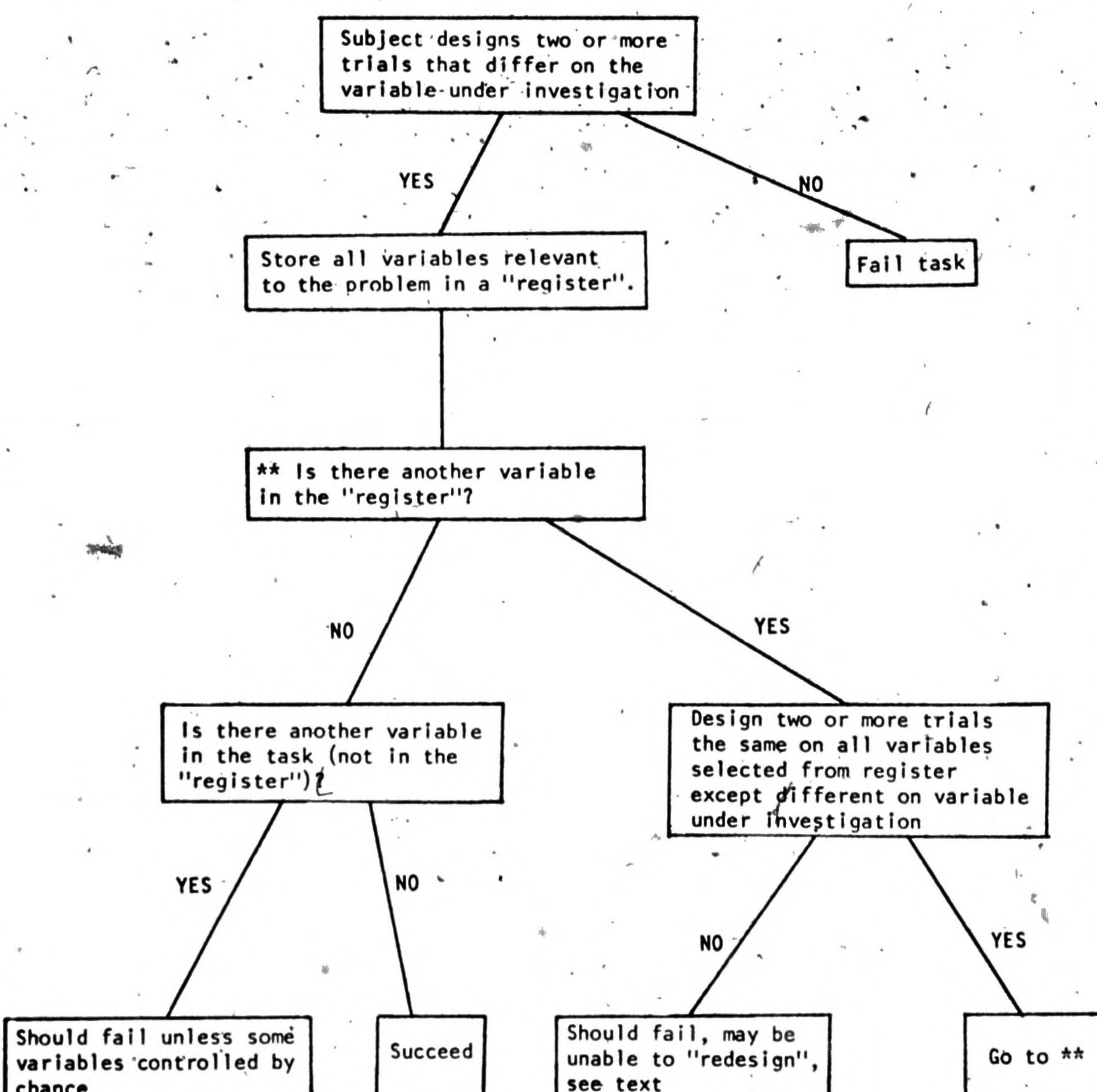
Results of Stepwise Multiple Regression

Test	Variable	Multiple R[1]	R^2	R^2 Change	F to Enter	Significance
Controlling	Ach[1]	.46	.21	.21	32.4	.000
	FDI	.52	.28	.07	11.0	.001
	Locus	.57	.32	.05	8.0	.006
	Divergent	.59	.35	.03	5.0	.027
	H testing	.61	.38	.03	5.5	.020
	CWT	.63	.40	.02	4.5	.037
Criticizing	Ach[1]	.43	.19	.19	28.0	.000
	FDI	.50	.25	.06	10.1	.000
	Locus	.57	.32	.08	13.4	.000
Embedded	Ach[1]	.27	.07	.07	9.3	.003
	FDI	.45	.20	.13	20.2	.000
	CWT	.57	.32	.12	21.5	.000
Number of Variables	Ach[1]	.09	.01	.01	1.0	.321
	FDI	.41	.17	.16	23.1	.000

[1] Achievement and FDI were entered first, followed by most significant predictors.

Figure 1

Diagram of the "register" concept for subjects employing the controlling variables schema.



Reference Notes

NOTE 1: Reiling, A. M. and Massari, D. J. Internal versus external control and formal thought. Paper presented at the Meeting of the Society for Research in Child Development, Philadelphia, 1973.

NOTE 2: Pascual-Leone, J. A neo-Piagetian process-structural model of Witkins psychological differentiation. Paper given at the International Association for Cross-Cultural Psychology, Kingston, 1974.

NOTE 3: Pulos, S. M. and Adi, H. Individual difference in formal operations among post-adolescents. AESOP Project, Lawrence Hall of Science, University of California, Berkeley, Report No. 45, 1977.

NOTE 4: Linn, M. C. Final Report for the NIE-SRCD Conference on Future Research in Adolescent Reasoning, 1978

References

Case, R. Structures and Strictures: Some functional limitations on the course of cognitive growth. Cognitive Psychology, 1974, 6, 544-573.

Cattell, R. B. Abilities: Their structure, growth, and action. Boston: Houghton Mifflin, 1971.

Cloutier, R. and Goldschmid, M. Individual differences in the development of formal reasoning. Child Development, 1976, 47, 1097-1102.

Crandall, V. C., Katkowsky, W., and Crandall, V. J. Children's belief in their own control of reinforcement in intellectual-academic achievement situations. Child Development, 1965, 39, 91-109.

Cronbach, L. J. Beyond the two disciplines of scientific psychology. American Psychologist, 1975, 116-127.

Cronbach, L. J. and Snow, R. E. Aptitudes and Instructional Methods: A Handbook for Research on Interactions. New York: Irvington, 1977.

Dickstein, L. S. Field independence and conceptual differentiation in concept attainment. (Doctoral dissertation, Yale University.) Ann Arbor, Mich.: University Microfilms, 1966, No. 66-74, 968.

Ennis, R. H. Children's ability to handle Piaget's propositional logic: A conceptual critique. American Educational Research Journal, 1975, 45, 1-41.

Fanelli, J. C. Locus of control. In S. Bell (Ed.), Motivation in Education. New York: Academic Press, 1977.

Inhelder, B. and Piaget, J. Growth of Logical Thinking From Childhood to Adolescence. New York: Basic Books, 1958.

Keating, D. P. Precocious cognitive development at the level of formal operations. Child Development, 1975, 46, 276-280.

Keating, D. P. A Piagetian approach to intellectual precocity. In D. P. Keating (Ed.), Intellectual Talent: Research and Development. Baltimore: Johns Hopkins University Press, 1976.

Keating, D. P. Adolescent thinking. In J. P. Adelson (Ed.), Handbook of Adolescence. In press.

Lefcourt, H. M. Locus of Control. Hillsdale, New Jersey: Lawrence Earlbaum Associates, 1976, 158-184.

Levine, D. Hypothesis behavior by humans during discrimination learning. Journal of Experimental Psychology, 1966, 1, 331-338.

Levine, D. I. and Linn, M. C. Scientific reasoning ability in adolescence: Theoretical viewpoints and educational implications. Journal of Research in Science Teaching, 1977, 14 (4), 371-384.

Linn, M. C. A measure of ability to control variables: The springs task. Formal Operator, 1 (1), 10.

Linn, M. C. Scientific reasoning: Influences on task performance and response categorization. Science Education, 1977b, 61 (3), 357-369.

Linn, M. C. Formal operations: Construct or conglomerate. Formal Operator, 1978, 1 (4), 2-4.

Linn, M. C. Cognitive style, training and formal thought. Child Development, 1978b, 49, 874-877.

Linn, M. C. Teaching children to control variables: Some investigations using free choice experiences. In S. Modgil and C. Modgil (Eds.), Toward a Theory of Psychological Development Within the Piagetian Framework, NFER, in press.

Linn, M. C. and Levine, D. I. Adolescent reasoning: Influence of question format and type of variables on ability to control variables. Science Education, 1978, 62 (3), 377-388.

Linn, M. C. and Rice, M. A measure of scientific reasoning: The springs task. _Journal of Educational Measurement_, 1979, _16_.

Neimark, E. D. On the measurement of formal operators. _Formal Operator_, 1978, _1_ (3), 10.

Oltman, P. K. A portable rod-and-frame apparatus. _Perceptual and Motor Skills_, 1968, _26_, 503-506.

Osherson, D. N. _Logical Abilities In Children_, Vol. 3, _Reasoning in Adolescence Deductive Inference_. New Jersey: Lawrence Erlbaum Associates, 1975.

Parsons, R. J. Category width and the learning of multiattribute paired associates. _The Journal of General Psychology_, 1973, _89_, 133-140.

Piaget, J. Intellectual Evolution from Adolescence to Adulthood. _Human Development_, 1972, _15_, 1-12.

Rotter, J. Generalized expectancies for internal versus external control of re-inforcement. _Psychology Monographs_, 1966, _80_, (whole no. 609).

Saarni, C. I. Piagetian operations and field independence as factors in children's problem solving performance. _Child Development_, 1973, _44_, 338-345.

Siegler, R. S. Three aspects of cognitive development. _Cognitive Psychology_, 1976, _8_, 481-520.

Simon, H. A. Identifying basic abilities underlying intelligent performance of complex tasks. In L. B. Resnick (Ed.), _The Nature of Intelligence_, Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1976.

Snow, R. E. _Toward a theory of aptitude_. Paper presented at the American Educational Research Association Annual Meeting, Toronto, Canada, March 1978.

Taylor, R. L. and Levitt, E. E. Category breadth and the search for variety of experience. Psychological Record, 1967, 17, 349-352.

Torrance, E. P. Torrance Tests of Creative Thinking. Lexington, Mass.: Ginn and Company, 1974.

Wallach, M. A. and Kogan, N. Modes of Thinking in Young Children. New York: Holt, Rinehart and Winston, 1965.

Witkin, H. A., Dyk, R. B. and Faterson, H. F. Psychological Differentiation, New York: Wiley, 1962.

Wollman, W. Controlling variables: Assessing levels of understanding. Science Education, 1977a, 61 (3), 371-383.

Wollman, W. Controlling variables: A neo-Piagetian developmental sequence. Science Education, 1977b, 61 (3), 385-391.

Yudin, L. W. Formal thought in adolescence as a function of intelligence. Child Development, 1966, 37, 697-708.