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# A Piagetian experiment with the concrete-inquiry instruction model for acquisition and transfer of hypothetic-deductive scientific reasoning

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**HUH, HYUNG**

**A PIAGETIAN EXPERIMENT WITH THE CONCRETE-INQUIRY  
INSTRUCTION MODEL FOR ACQUISITION AND TRANSFER OF  
HYPOTHETIC-DEDUCTIVE SCIENTIFIC REASONING**

*Iowa State University*

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300 N. Zeeb Road, Ann Arbor, MI 48106

**A Piagetian experiment  
with the concrete-inquiry instruction model for acquisition  
and transfer of hypothetic-deductive scientific reasoning**

by

**Hyung Huh**

**A Dissertation Submitted to the  
Graduate Faculty in Partial Fulfillment of the  
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**Department: Professional Studies in Education**

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**1981**

## TABLE OF CONTENTS

	Page
CHAPTER I. INTRODUCTION	1
Statement of Research Problem	1
Purpose of the Study	9
Hypotheses	10
Limitations of the Study	12
Assumptions	13
Definitions	13
CHAPTER II. REVIEW OF THE LITERATURE	15
The Cognitive Developmental Level of Young Adults	15
Training Studies for Promoting Formal Operations	23
Studies on the Concrete-Inquiry Based Instruction	38
Functional Aspects of Cognitive Development and Cognitive Style	43
CHAPTER III. RESEARCH METHODS AND EXPERIMENTAL DESIGN	49
Learning Tasks	49
Concrete-Inquiry Instruction Model	53
Construction of Experimental Materials	57
Subjects	58
Criterion Measures	61
Reliability for Scoring Subject's Responses	65
Experimental Design	66
Research Variables and Experimental Procedures	68
Organization of the Data	72
Statistical Analysis of the Data	73

CHAPTER IV. RESULTS AND INTERPRETATIONS	76
Descriptive Data	76
Tests of Hypotheses	84
CHAPTER V. SUMMARY, DISCUSSIONS AND CONCLUSIONS	110
Summary	110
Discussions	116
Conclusions	121
Implications for Curriculum and Instruction	122
Suggestions for Further Research	125
BIBLIOGRAPHY	126
ACKNOWLEDGEMENTS	143
APPENDIX A: INFORMED CONSENT FORM FOR EXPERIMENTAL GROUP	144
APPENDIX B: INFORMED CONSENT FORM FOR CONTROL GROUP	146
APPENDIX C: SCRIPT FOR PENDULUM TASK	148
APPENDIX D: WORKSHEET I FOR PENDULUM TASK	179
APPENDIX E: SCRIPT FOR BENDING RODS TASK	186
APPENDIX F: WORKSHEET II FOR BENDING RODS TASK	202
APPENDIX G: PIAGETIAN LOGICAL OPERATIONS TEST	208
APPENDIX H: KEY AND CRITERIA FOR SCORING THE PIAGETIAN LOGICAL OPERATIONS TEST	221
APPENDIX I: PROBLEM-SOLVING TEST	225
APPENDIX J: KEY AND CRITERIA FOR SCORING THE PROBLEM-SOLVING TEST	232
APPENDIX K: THE GROUP EMBEDDED FIGURES TEST	238
APPENDIX L: THE CODEBOOK FOR ANALYZING THE RESEARCH DATA	242

## LIST OF TABLES

	Page
Table 1. Volunteers participating in the present study	59
Table 2. Properties of the experimental group and the control group	60
Table 3. Comparison of means and SDs for t-test between the experimental group and the control group on the ACT, the MSAT, and the GEFT	77
Table 4. Comparison of means and SDs for t-test between the male and the female groups on the ACT, the MSAT, and the GEFT	79
Table 5. Comparison of means and SDs for t-test between the two age groups on the ACT, the MSAT, and the GEFT	80
Table 6. Comparison of means and SDs among the majors on the ACT, the MSAT, and the GEFT	81
Table 7. Analysis of variance for the ACT, the MSAT, the GEFT among the majors	82
Table 8. Comparison of means and SDs for t-test between the field-dependent group and the field-independent group on the ACT and the MSAT	83
Table 9. Comparison of means and SDs for t-test between the experimental and the control groups on the posttest of the Piagetian Logical Operations Test (PLOT)	85
Table 10. Comparison of means and SDs for t-test between the male group and the female group on the posttest of the PLOT in the experimental group (N= 29)	85
Table 11. Comparison of means and SDs for t-test between the age groups on the posttest of the PLOT in the experimental group (N= 29)	86
Table 12. Comparison of means and SDs for ANOVA among the majors on the posttest of the PLOT	86

Table 13.	Analysis of variance among the majors on the posttest of the PLOT in the experimental group (N= 29)	87
Table 14.	Comparison of means and SDs for t-test between the immediate posttest and the one month delayed posttest as measured by the PLOT	89
Table 15.	Comparison of means and SDs for t-test between the immediate posttest and the one month delayed posttest of the PLOT for the male group and the female group	89
Table 16.	Comparison of means and SDs for t-test between the immediate posttest and the one month delayed posttest of the PLOT for the two age groups	90
Table 17.	Comparison of the treatment means between the immediate posttest and the one month delayed posttest of the PLOT for each major group	91
Table 18.	Comparison of means and SDs between the experimental group and the control group on the Problem-Solving Test (PST)	93
Table 19.	Comparison of means and SDs between the immediate posttest and the one month delayed posttest of the Problem-Solving Test for the experimental group	93
Table 20.	Comparison of means and SDs between the male group and the female group on the immediate posttest and the one month delayed posttest of the PST	94
Table 21.	Comparison of means and SDs between the two age groups on the immediate posttest and the one month delayed posttest of the Problem-Solving Test (PST)	95
Table 22.	Comparison of means and SDs between the immediate posttest and the one month delayed posttest of the Problem-Solving Test (PST) for each major group	96
Table 23.	Correlation matrix of the research variables	98



Table 24.	Bivariate regression of hypothetical-deductive scientific reasoning (Dependent) with field-dependent and field-independent cognitive style	100
Table 25.	Comparison of means and SDs for t-test between the field-dependent students and the field-independent students on the PLOT in the experimental group only	102
Table 26.	Comparison of means and SDs for t-test between the field-dependent students and the field-independent students on the Problem-Solving Test in the experimental group only	103
Table 27.	Multiple regression analysis of hypothetical-deductive reasoning (Dependent) with cognitive styles (GEFT), problem solving ability (PST), the ACT, and the MSAT	105
Table 28.	Bivariate regression of hypothetical-deductive reasoning (Dependent) with problem solving ability as measured by the PST	107
Table 29.	Multiple regression analysis of problem solving ability (Dependent) with the PLOT, the ACT, the MSAT, and the GEFT	109

## LIST OF FIGURES

	Page
Figures 1. Pendulum apparatus	50
Figures 2. Bending rods apparatus	52
Figures 3. Experimental procedures	69

## CHAPTER I.

INTRODUCTION<sup>1</sup>

## Statement of Research Problem

The educational process has been based upon the assumption that there are certain pieces of information, facts, skills, and attitudes that must be presented to the learner. The second assumption is also made that presenting the learner with the material and involving him with it will in turn teach him to think. Intellectual development, therefore, is considered to be a concomitant outcome.

If these assumptions are accurate, then it follows that the understanding of a task from any discipline taught will result in intellectual development. Furthermore, we can assume that if teaching can promote student's thinking or at least accelerate intellectual growth, many different kinds of problems from any subject area can be solved by learners.

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<sup>1</sup>The Iowa State University Committee on the Use of Human Subjects in Research reviewed this project and concluded that the rights and welfare of the human subjects were adequately protected, that risks were outweighed by the potential benefits and expected value of the knowledge sought, that confidentiality of data was assured and that informed consent was obtained by appropriate procedures.

Progress in school work presupposes the pupil's capacity to think. This is true no matter what school activity we have in mind, whether it is literature, mathematics, history or science. Therefore, in school we endeavour to promote and use the student's thinking by the stimulus of the teacher's words, class discussion, textbooks, and practical work.

The importance of the development of the ability to think was stressed by Piaget. Piaget's (1964) views on educational objectives in modern society are probably shared by most educators today:

The principal goal of education is to create men who are capable of doing new things, not simply of repeating what other generations have done --- men who are creative, inventive, and discoverers. The second goal of education is to form minds which can be critical, can verify, and not accept everything they are offered. The great danger today is of slogans, collective opinions, ready-made trends of thought. We have to be able to resist individually, to criticize, to distinguish between what is proven and what is not. So we need pupils who are active, who learn early to find out by themselves, partly by their own spontaneous activity and partly through material we set up for them; who learn early to tell what is verifiable and what is simply the first idea to come to them. (p. 5)

The major creative work on the logical thinking of the child was made by Inhelder and Piaget (1958). Their topic

was the operations of formal thinking and the structure of propositional reasoning. This work was seen by Bruner (1959) and Lunzer (1968) as a landmark in the study of the process of higher reasoning and as a culmination of Piaget's efforts. Inhelder and Piaget (1958) administered 15 varied tasks to illustrate the change from what they call concrete operational thought to what they call formal operational thought. According to Inhelder and Piaget (1958), the child at the concrete-operational level reasons only about the specific content of problems. There is no extension, or generalizations of operational thought from one concrete field to another. Thus there is no guarantee that if a child is capable of judging operationally in problems of quantity; for example, he will be able to extend his reasoning to questions of weight or volume. At the concrete stage, a child's thoughts reflect the elementary constraints of reality.

Towards the beginning of adolescence, the child begins to carry out logical operations on symbolic and abstract material. The formal operational stage, according to Piaget, begins at about 11 years and heralds the ability to reason about possibilities, test hypotheses, and generally to exhibit cognitive behavior which is qualitatively similar to that of an adult. He can logically manipulate his own cognitive processes as well as use his cognitive processes to manipulate concrete things.

The first and most important question most educators ask when they become familiar with Piaget's theory of intellectual development is whether cognitive processes can be accelerated by learning and teaching activities. According to Piaget (1964), cognitive change is made possible by the active interaction of the learner and his surrounding physical and social environment, of which the classroom is a part. Piaget (1964) was quite clear on this point:

Experience is always necessary for intellectual development ... but I fear that we may fall into the illusion that being submitted to an experience (a demonstration) is sufficient for a subject to disengage the structure involved. But more than this is required. The subject must be active, must transform things, and find the structure of his own action on the objects. (p. 4)

It is this cognitive reorganization made by "self inquiry" in the classroom which Piaget stressed as a crucial element. According to Piaget, the student must be actively engaged if the learning process is to be effective. For the concrete-operations child, this entails an actual concrete manipulation of the objects or task materials in question. Regardless of content area, the child should perform the actions represented by the concepts.

Considerable research based on Piaget's theory of cognitive development and education has appeared in the literature since 1970. The research projects can be classified

into two distinct areas: (a) studies in which students were trained to give correct responses on specific Piagetian tasks, and (b) studies in which emphasis was placed on a particular mental operation (e.g., controlling variables, proportional reasoning, etc.).

In the first category are research efforts by Siegler, Liebert, and Liebert (1973), Siegler and Liebert (1975), Brainerd and Allen (1971), and Bass and Montague (1972). All of these investigations met with some success, indicating that instructional procedures can be developed to teach students delimited Piagetian tasks, even when students are at the lower age limit for the attainment of formal operational thought. What was not determined by the studies was whether the mastery of tasks was permanent or transitory. This lack of retention data diminishes somewhat the usefulness of these results. In addition, these studies tell us nothing about the students' ability to generalize from the tasks learned to others similar in nature.

The second category of studies differs from the first in that investigators trained students in particular mental operations rather than on specific tasks. Of all of the mental operations, the controlling of variables and proportional reasoning have been the ones on which most research efforts have been made. Lawson (1980a), Wollman and Lawson (1978), Levine and Linn (1977), Shyers and Cox (1978), Good-

stein and Howe (1978), Johnson and Howe (1978), Douglass and Kahle (1978), Boulanger (1978), Wright (1978), Linn, Chen, and Thier (1977), Wollman (1977), Wollman and Lawson (1977), Renner and Lawson (1975), Lawson, Blake, and Nordland (1975), Bredderman (1973), Raven (1974), Case and Fry (1973), Hammond and Raven (1973), Nous and Raven (1973), Bredderman (1974) did work in this area. From the training studies reviewed above, two conclusions can be drawn. First, it is possible to teach students to control variables, although it is still questionable whether the skills on certain mental operations are transferrable and long lasting. Second, training is more successful if it is given to more mature students (college or high school students) than to younger students. These results may be due to the absence of equilibration and self-regulation in younger students. The investigators reported that the training does not harm the students and in fact may provide them the necessary experiences that at some later time will help them to acquire more easily greater mental ability.

Numerous investigations conducted during past few years have found a wide range of college student performance on Piagetian styled tasks of formal reasoning (e.g., McKinnon and Renner, 1971; Lawson and Renner, 1974; Juraschek, 1974; Griffiths, 1976; Barnes, 1977). Often large percentages of the students studied perform as though they were reasoning



about tasks using only concrete operations. Hence the studies led to a tentative conclusion that many college students (perhaps as much as 50 percent) are still operating below the Piagetian formal operational stage of intellectual development.

Neimark (1977) suggested that that conclusion is open to question. Instead he feels that adults who appear "concrete operational" on Piagetian-type tasks do so because they are field dependent, not because they are concrete operational. The findings of Diamond et al. (1977) confirm this viewpoint. They found college students' performance on Piagetian tasks to be significantly correlated with interest in science but not with their general level of intelligence. Perhaps many apparently "concrete operational" college students are indeed formal operational and the Piagetian tasks simply fail to identify the correct level due to their physical science content bias and (or) their perceptually salient misleading cues that tend to confuse the field-dependent subjects and prohibit them from using their formal reasoning abilities.

The present study was designed to assess the effectiveness of a Piagetian experiment in facilitating hypothetic-deductive scientific reasoning of controlling variables of college students. In addition, the possible relationship between level of hypothetic-deductive scientific reasoning

and the psychological trait of "cognitive style" was investigated.

In particular, the present study was designed to answer the following questions:

1. What is the proportion of a selected sample of Iowa State University freshmen and sophomores who have not achieved the level of formal operations?
2. What is the relationship between the level of cognitive growth and the following factors?:
  - (a) sex
  - (b) scholastic ability
  - (c) major area of study
  - (d) age
  - (e) cognitive style
3. Does a Piagetian experiment in which a concrete-inquiry instruction model is used facilitates cognitive growth in college students?
4. If cognitive growth occurs in the students, is cognitive growth because of:
  - (a) the Piagetian experiment employed?
  - (b) cognitive style?
  - (c) scholastic abilities?
5. If cognitive growth occurs in the students because of a Piagetian experiment through the concrete-inquiry instruction model, then:

- (a) is there evidence whether cognitive growth is permanent or transitory?
- (b) is there evidence of transfer of cognitive growth to other isomorphic tasks?

#### Purpose of the Study

The major purpose of the study was to test a series of basic hypotheses concerning college students' hypothetic-deductive scientific reasoning of controlling variables as developed by a Piagetian experiment through the concrete-inquiry instructional model. In addition, the possible relationship between the level of cognitive development and the psychological trait of field-dependence-independence cognitive style of student was investigated.

In particular the specific purposes of the study are as follows:

1. To determine whether a Piagetian experiment through the concrete-inquiry instructional model in which emphasis is placed on a particular mental operation (e.g., controlling variables of "pendulum task and bending rods task") can or cannot increase hypothetic deductive scientific reasoning capability of the students.
2. To test whether student's retention of experimental effects is permanent or transitory.

3. To determine whether the students can transfer the hypothetic-deductive scientific reasoning capability attained to another isomorphic task.
4. To identify the relationship between hypothetic deductive scientific reasoning and field-dependence-independence cognitive style of students.
5. To identify the proportion of the students entering college who have not developed formal operational thought.

### Hypotheses

The following hypotheses were generated in order to meet the above stated purposes of the study and to answer the questions stated in the first section of this chapter.

#### Hypothesis 1

College students instructed with a piagetian experiment through the concrete-inquiry instruction model will exhibit greater cognitive growth of hypothetic-deductive scientific reasoning capability by the end of the experiment than will college students not instructed with a Piagetian experiment.

#### Hypothesis 2

College students instructed with a piagetian experiment through the concrete-inquiry instructional model will

exhibit the same cognitive growth of hypothetic-deductive scientific reasoning capability one month after the initial experiment.

### Hypothesis 3

College students instructed with a Piagetian experiment through the concrete-inquiry instruction model will exhibit greater problem solving ability in solving the isomorphic problems than will college students not instructed with a Piagetian experiment through the concrete-inquiry instruction model.

### Hypothesis 4

There is a positive correlation between hypothetic-deductive scientific reasoning capability and field-dependence-independence cognitive style.

### Hypothesis 5

Field-dependence-independence cognitive style will predict hypothetic-deductive scientific reasoning capability on the Piagetian Logical Operations Test.

### Hypothesis 6

When hypothetic-deductive scientific reasoning is taught using the concrete-inquiry instruction model, the field-dependent students will perform as well as the field-independent students on the Piagetian Logical Operations Test.

### Hypothesis 7

When hypothetic-deductive scientific reasoning is taught using the concrete-inquiry instruction model, the field-dependent students will perform as well as the field-independent students on the Problem-Solving Test.

### Hypothesis 8

Field-dependence-independence cognitive style, problem solving ability, scholastic aptitude measured by American College Test and Minnesota Scholastic Aptitude Test will predict hypothetic-deductive scientific reasoning capability on the Piagetian Logical Operations Test.

### Hypothesis 9

Hypothetic-deductive scientific reasoning capability, field-dependence-independence cognitive style, and scholastic aptitude measured by American College Test and Minnesota Scholastic Aptitude Test will predict the problem solving ability on the Problem-Solving Test.

### Limitations of the Study

The present study had a limitation. Formal operational thought involved only hypothetic-deductive scientific reasoning of controlling variables. Interpretations of the results of the study could not extend beyond hypothetic-

deductive scientific reasoning of controlling variables.

### Assumptions

It is assumed that:

1. The study population is a random sample of Iowa State University freshmen and sophomores.
2. A total of two hours of a Piagetian experiment with the concrete-inquiry instruction model was sufficient input time to provide a basis for study of hypothetic-deductive scientific reasoning of controlling variables of the "pendulum task" and the "bending rods task."

### Definitions

#### Hypothetic-deductive scientific reasoning

Hypothetic-deductive scientific reasoning is the process of formulating guesses or hypotheses and then making deductive conclusions. Hence, this term refers to the scores measured by the Piagetian Logical Operations Test.

#### Cognitive growth

Cognitive growth is a change in the level of hypothetic-deductive scientific reasoning of controlling variables. It is the measure of an increase in a subject's capacity to perform successfully on the Piagetian Logical Operations Test after a Piagetian experiment with the concrete-inquiry

instruction model.

### Controlling variables

When a complex experimental problem which has many variables is provided, all the variables but one must be controlled, while the one uncontrolled variable is tested.

### Concrete-inquiry instruction model

This model is a highly structured instructional sequence, which consists of a problem and student's inquiring process leading to a student proposed design for solving the problem. The design is tested, feedback data are provided, and the student devises a conclusion.

### Cognitive style

Cognitive style is conceived primarily as the manner in which an individual perceives and analyzes a complex stimulus. The concept of field-dependence-independence cognitive style emerged from the studies of perception of upright, in space realized by Witkin and his associates (1954, 1962). In the context of the study, the term "cognitive style" refers particularly to a subject's performance on a test which is purported to measure the perceptual construct, field-independence. In essence, field-independence is a measure of a subject's ability to overcome perceptual distractions surrounding the object of this concentration.



## CHAPTER II.

## REVIEW OF THE LITERATURE

## The Cognitive Developmental Level of Young Adults

The research of Jean Piaget might lead many educators to believe that most individuals are formal thinkers by 14 or 15 years of age. Prior to this age, according to Piaget (1972), children develop the capacity to reason in terms of concrete objects and their manipulation:

The 7- to 10-year-old children when placed in an experimental situation (such as what laws concern the swing of pendulum, factors involved in the flexibility of certain materials, problems of increasing acceleration on an inclined plane) act directly upon the material placed in front of them by trial and error, without dissociating the factors involved. They simply try to classify or order what happened by looking at the results of the co-variations. The formal level children, after a few similar trials stop experimenting with the material and begin to list all the possible hypotheses. It is only after having done this that they start to test them, trying progressively to dissociate the factors involved and study the effects of each one in turn --- 'all other factors remaining constant'. (p. 4)

This is a decisive turning point, because formal reasoning process is characterized by hypothetic-deductive and propositional thinking. When confronted with a problem,

a formal level child formulates guesses or hypothesis and then deduces conclusions from them.

Numerous studies have found a wide range of college student performance on Piagetian styled tasks of formal reasoning (e.g., McKinnon and Renner, 1971; Barnes, 1977; Griffiths, 1976; Lawson and Renner, 1974; Ross et al., 1976; Juraschek, 1974). Often large percentages of these students perform as though they were reasoning about the tasks using only concrete operations.

McKinnon and Renner (1971) studied responses to tasks given 131 members of the freshman class at an Oklahoma university in which students had to think logically about problems of volume conservation, reciprocal implication of two factors, the elimination of a contradiction, the separation of several variables, and the exclusion of irrelevant variables from those relevant to problem solutions. These tasks had initially been developed by Inhelder and Piaget (1958) for determining the patterns of thought of children and the ages at which changes in those thought patterns occur. They found that 50 percent (66 of 131 freshmen) of the entering college students tested were operating completely at Piaget's concrete level of thought and another 25 percent (32 of 131 freshmen) had not fully attained the established criteria for formal thought. More specifically, the conclusions were as follows:

(1) Of the college freshmen tested, 17 percent did not conserve quantity, while another 10 percent failed to recognize equivalence of volume. (2) Reciprocal implication involved the student in the problem of reflecting a ball and the necessity to relate incident and reflected angles. This task was second only to the problem of density in the number of failures recorded--- 64 percent scored two or less. (3) The elimination of a contradiction involved the student in relating weight and volume of floating and sinking objects in a meaningful way. More than one third of those tested did not relate weight and volume. Typically, they recognized weight only. Seldom was there a proportionality expressed; 67 percent of the students tested on this task were concrete operational. (4) The separation of variables task gave evidence that 50 percent of entering college freshmen could not recognize the action of a potential variable and find a way to prove the action of that variable. (5) The task of excluding irrelevant variables showed that 33 percent of the students tested could not eliminate variables of no consequence in a swinging pendulum, while another 18 percent could do no more than order the effects of weight.

Barnes (1977) reported a study involving 338 college students in six different lower physics courses. In this study, he compared students' Piagetian levels of intellectual development as determined by a written questionnaire with

final semester grades. In order to gain insight into the students' abilities to use logical reasoning, a questionnaire having four questions was devised. The first question was patterned after the "Island Puzzle" of the American Association of Physics Teacher booklet (Collela et al., 1975) on the applications of Piagetian theory to physics. The second is similar to the "Paper-Clip Puzzle" found in the same source. Question three looks straightforward at first glance, but it was decided that it would be omitted after the answers were read. The fourth question is one concerning a letter puzzle shown. There are ten letters, each of which stands for a different number from (and including) zero to nine. The question was what the letters stand for in terms of the numbers 0-9. Barnes found that only about 10 percent of the students fell into the trap which most concrete thinkers do and 74.4 percent (67 students out of 90 in physics) exhibited formal thought on question two. Barnes (1977) also found positive but low correlations between grades awarded to students enrolled in six lower-division physics courses and their responses to the paper and pencil questionnaire of formal reasoning. Barnes concluded that factors other than logical thinking were of considerable importance in obtaining grades in the classes he studied.

Griffiths (1976) tested college students' formal operational thought structures. Sixty subjects were randomly

selected from second semester physics and chemistry courses at Rutgers University and from developmental science and physics courses at Essex County College in Newark. The task was to predict the movements or equilibrium of a skate on a variable-slope inclined plane. The last variable must be calculated not in terms of its sine: The ratio of the vertical height of the plane to the constant length of the plane (the hypotenuse). The experimental equipment was presented to the subjects and its operation was explained. The plane was set at an arbitrary position and the skate was placed in a state of equilibrium. The subjects were asked first to identify the variables that were involved in keeping the skate in equilibrium and secondly to determine a relationship between the variables. All suggestions and conclusions could be experimentally tested, and the subjects were urged to make maximum use of the equipment. The researcher willingly served as an assistant, and every effort was made to maximize the students' performance. The experimental sessions were recorded on tape, and detailed notes were assembled for independent analyses. The taped responses obtained from the participants of the plane task were analyzed according to two criteria: (1) Student's understanding of the problem as described by Piaget's stage of formal thinking, and (2) The level of technical vocabulary utilized by the subjects in response to the experimental situation. Griffiths (1976)

found that only 39 percent of the subjects were at the stage of formal operations; no significant differences existed between white and minority students.

Lawson and Renner (1974) analyzed the data related to developmental level of freshmen from a private university in Oklahoma. The sample contained 143 freshmen randomly sampled from over 300 students. The subjects had a median age of 18.6 years and were given five Piagetian type tasks. These tasks were: (1) The conservation of volume using clay. (2) Reciprocal implications. This task involves an apparatus much like a billiard table. Balls are launched with a tabular spring device that can be rotated to aim at various points along a projection wall. The subject attempts to hit objects placed at different locations by rebounding the ball off the wall. The task tests for the subject's ability to discover a generalizable law relating the angle of incidence with the angle of reflection. (3) The elimination of contradictions. (4) The separation of variables. This task tested for the subject's ability to identify and control variables, e.g.: Given six flexible rods of varying length, diameter, shape, and material and hanging weights, the subject must be able to demonstrate proof of the effect of a variable on the amount of bending of the rods. This demonstration requires understanding of the concept "all other things being equal." (5) The exclusion of irrelevant variables. The results of

these five tasks show that 51 percent were at the concrete operational stage, 27 percent were at the postconcrete state, and 22 percent were at the formal operational stage.

Ross et al. (1976) pretested 109 volunteers from four undergraduate psychology classes in the classroom setting with an adapted version of the Tisher (1971) Test of Operational Thinking. There was no set time limit, but testing time usually ranged between 20 and 45 minutes. The test is composed of three different parts, which are derived from three of the Inhelder and Piaget (1958) formal operation tasks. In the first problem, Equality of Angles, the subject must predict from a diagram what angle a tennis ball will bounce off a wall, given the angle of incidence with which the ball hit the wall. The second, Balance Problem, presented a diagram of a balance scale and weights, with seven accompanying multiple-choice questions. The third, Projection of Shadows Problem, presented a diagram of an apparatus with a light shining on a screen. Three rings with different size diameters also appear, which can be placed at three different points between the light and the screen. Ross et al. (1976) found that 52.3 percent (57 students out of 109 male and female college students) of the subjects were at the level of concrete operational thought.

Juraschek (1974) studied the performance of certain group of college students on three Piagetian tasks. His

study involved 141 prospective elementary school teachers, 19 secondary mathematics student teachers, and 11 calculus honor students. Juraschek reported that 52 percent of the prospective elementary school teachers were at the concrete operational stage, while 48 percent were at the formal operational stage. Among the mathematics student teachers, only one percent was reported at the concrete level while all of the calculus honor students were classified as formal thinkers.

Lawson (1973) analyzed the relationship between concrete and formal operational science subject matter and the developmental level of the learner. He selected 51 biology students in the tenth grade (mean age of 16.4 years), 50 chemistry students in the eleventh grade (mean age of 17.3 years), and 33 physics students in twelfth grade (mean age of 17.9 years) from a high school in Norman, Oklahoma. Six Piagetian type tasks were administered to each subject. Lawson's results show that 64.8 percent of the biology students were at the concrete operational level, while 35.2 percent were at the formal level. Twenty-two percent of the chemistry students were at the concrete operational level, while 78 percent were at the formal operational level. Of the physics students, 36.3 percent were at the concrete operational level, while 63.7 percent were at the formal operational level.



In summary, most adolescents and young adults do not appear to have attained the formal operational stage of cognitive development. The percentages of the formal operational level subjects were as follows: 25 percent (McKinnon, 1971); 74.4 percent (Barnes, 1977); 39 percent (Griffiths, 1976); 47 percent (Lawson and Renner, 1974); 48 percent (Juraschek, 1974); 47 percent (Ross et al., 1976); and 35 percent of biology students, 78 percent of chemistry students, and 64 percent of physics students (Lawson, 1973).

All of the studies except one (Barnes, 1977) employed an individualized interview approach. There are, of course, many questions still to be answered, such as: Do the questions translate the Piagetian concepts of cognitive development well? Does an individualized interview approach assess cognitive developmental level objectively and reliably? These are the kinds of questions now being speculated about as causes that might bring about the results discussed.

#### Training Studies for Promoting Formal Operations

Many Piagetian training studies relating cognitive development of formal operations have appeared in the literature since 1970. There are two types of training studies: (1) studies in which students were trained directly to give correct responses on specific Piagetian tasks (e.g., pendulum task, balance beam task, etc.). (2) studies in which

emphasis was placed on a particular mental operation (e.g., controlling variables, proportional reasonings, etc.).

These training studies will be reviewed in this section.

In the first area are studies by Siegler, Liebert, and Liebert (1973), Brainerd and Allen (1971), and Bass and Montague (1972). Siegler et al. tried to train the students on pendulum tasks. Their purpose was to determine whether middle-class American children of the ages studied by Piaget were able or unable to solve the pendulum problem and the other purpose was to determine whether a teaching procedure combining several types of intuitively useful instructional techniques would improve their performance. Subjects were 24 ten and eleven year old children, 12 boys and 12 girls, from the fifth grade class of a public school serving a middle-class community on Long Island, New York. The experimental group received the training procedure of conceptual framework, analogue problems, and measurement tools. The control group did not receive the experimental procedures. They found that the experimental group responded correctly more frequently than the control group. The lack of success experienced by control group members confirmed Inhelder and Piaget's observations that subjects of this age generally are unable to sort out the effects of length, weight, and force on the pendulum problem. On the other hand, the experimental group demonstrated that they could execute an experi-

mental procedure sufficient to determine the important factors and that, having done so, they could then draw the appropriate conclusions from their data. Given instructional guidance of several kinds, the ten and eleven year old students were able to exercise formal operations logic and to produce solutions closely resembling those cited by Inhelder and Piaget as exemplifying the highest stage of reasoning.

Brainerd and Allen (1971) attempted to train the formal operational concept of density conservation to 52 fifth grade students (mean age of 10.10 years olds) in Diamondale Elementary School in State of Michigan. Subjects identified as nonconservers of density were pretested for the presence of solid and liquid volume conservations. A 2 x 2 factorial design was employed with the factors being consecutive similar stimuli. The subjects given feedback were shown whether their answers to the experimenter's questions were correct. The subjects given consecutive similar stimuli saw clay balls of the same color on consecutive trials. This second manipulation was thought to resemble "learning set" treatments that promote tendencies to respond in particular ways by making acquisition trials as similar as possible. Independent of the "learning set" interpretation of the second manipulation, this factor was needed for appropriate counterbalancing of presentation order. The researchers

found that a highly significant ( $p < .001$ ) training effect was noted for the feedback treatment. The nontrivial nature of the training concept was demonstrated via significant ( $p < .005$ ) pretest to posttest improvements in the feedback subject's rationales for their answers (intraconcept generality) and via significant ( $p < .005$ ) transfer of density training to solid volume conservation (interconcept generality). Significant pretest to posttest improvements in the density performances of the no feedback subjects illustrated the importance of including appropriate control groups in conservation training experiments. Such clear improvements in control group performance certainly cannot be attributed to any systematically manipulated "training treatment."

Bass and Montague (1972) explored one approach to translating Piaget's developmental sequences into instructional objectives and instructional materials. The approach was applied to two problems from the general area of physical science: (1) Equilibrium in a simple see-saw type balance, and (2) Equilibrium of a cart on an inclined plane. The instructional sequences on the balance and the inclined plane were evaluated through classroom trials with 133 ninth grade physical science students. Each sequence required approximately three one hour sessions for completion. It was to be expected that the ninth grade students, most of whom were either 14 or 15 years of age, would be capable of thinking

at the formal level. Prior to instruction, the majority of the ninth-grade sample of students were already operating at least as high as substage III-A on the balance problem. The percentage of the sample operating at stage III-B increased from 45 percent on the pretest to 75 percent on the posttest. Thus the instructional sequence seemed to be effective in assisting students in their progress through the learning hierarchy on the balance problem. Research data also indicated that the sequence of instruction on the inclined plane problem was not particularly successful. One can only speculate on the causes. One cause must be the complexity of the inclined plane problem which involves three distinct variable factors, the weight of a cart, the counter-weight, and the height of the plane, as well as a confusion factor, the angle. The fact that the proposed inclined plane hierarchy did not prove valid must also play an important role.

All of these investigations met with some success, indicating that instructional procedures can be developed to teach students delimited Piagetian tasks. What was not determined by the studies was whether the mastery of tasks was permanent or transitory. This lack of retention data diminishes somewhat the usefulness of these results. In addition, these studies tell us nothing about the students' ability to generalize from the tasks learned to others similar in nature.

The second area of studies differs from the first in that investigators trained students in particular mental operations rather than on specific tasks. Of all of the mental operations, the controlling of variables has been the one on which most research has been done.

Lawson, Blake, and Nordland (1975) have explored training effects of the ability to control variables in high school biology students. Their research questions were: (1) Can the ability to control variables be taught to high school biology students who on a written test of logical operations, do not demonstrate formal reasoning? (2) Are students who are classified as early formal operational thinkers on the written test of logical operations able to benefit more from the training than students who are classified as early or late concrete operational thinkers? (3) If the ability to control variables can be learned, is it generalizable to problems utilizing novel materials? Sixty-five high school students (29 males and 36 females) enrolled in a second semester biology course at Delphi High School in Delphi, Indiana, served as subjects. The subjects' mean age was 15 years and 5 months. The tasks used during the four training sessions presented subjects with two major problems involving the control of variables. The first problem required the determination of the period of a pendulum. The variables which had to be identified and controlled for correct

solution were length of string, angle of drop, weight of bob, and amount of push given the bob. During the first session, the subjects were given an opportunity for exploration into the pendulum materials and problem. The concepts of period of the pendulum and variables were introduced (invented) during the second training session. During the third training session, the concept of a controlled experiment was introduced (invented) in relation to the identified variables in the pendulum problem. The researchers found that there were no significant differences between the experimental group and the control group at the .05 level ( $t=.48$ ;  $p>.30$ ). More specifically, the experimental group's mean score on the exclusion task (the trained task) of 3.12 was significantly greater than the control group's mean score of 2.53 ( $t=2.74$ ;  $p<.01$ ). But on the separation of variables task, the experimental group's mean score of 2.57 was not significantly different from the control group's mean score of 2.56 ( $t=.09$ ;  $p=.93$ ). The mean scores on the equilibrium task of 2.57 and 2.69 for the respective groups were also not significantly different ( $t=.72$ ;  $p=.47$ ).

Case and Fry (1973) attempted to teach scientific inquiry and criticism to a group of low stable socioeconomic status high school students. They had not yet reached Piaget's stage of formal operations. They all scored below the fiftieth percentile on the comprehension subscale of the

Nelson-Denny Reading Test. It is suspected that the students' low and unstable socioeconomic status might inhibit the growth of formal operational thought. They were taught to design controlled experiments and to criticize poorly controlled experiments. As judged by performance on a non-standardized test, they learned to do this well, and significantly outperformed matched controls ( $p < .001$ ). The results were interpreted with reference to Inhelder and Piaget's work on the origins of scientific thinking.

Bredderman (1973) designed a research project to train fifth grade and sixth grade students at Trumansburg Central School in Trumansburg, New York, the use and control of variables. Among 230 students in the two grades, based on a criterion test, 27 fifth and sixth grade students (an average age of 11 years 6 months) were selected who could not control variables. Three groups were formed. The control group received no training; a second group received training relying upon external reinforcement; and the third group received training designed to induce internal cognitive conflict. The researcher found that the groups receiving training did only slightly better than the control group on the posttest and that differences among the three groups were not significant ( $F = .41, p > .05$ ). On the retention test one month later, all three groups had almost identical scores. The mean combined retention test score was found to be sig-



nificantly greater than the pretest score ( $t= 4.50$ ;  $p < .01$  and  $t= 9.43$ ;  $p < .01$  respectively).

Wollman and Lawson (1977) trained 32 fifth grade students and as many seventh grade students from a middle to upper-middle class suburban community. Subjects were chosen on the basis of a controlling variables pretest (the bending rods task, Inhelder and Piaget, 1958). For most, performance indicated a preformal stage understanding of controlling variables. The subjects were then randomly divided into experimental and control groups for both fifth grade and seventh grade samples. The average ages were 10.6 years for the fifth and 12.6 years for the seventh grade students. The subjects were trained individually in three or four sessions each lasting about 30 minutes. The seventh grade students had four sessions. Training was spread out over two weeks and included use of the bending rods apparatus. A battery of posttest tasks was administered approximately one week after the final session. The battery of posttest tasks included the bending rods task (which was used on the pretest and in the training) and two controlling variables tasks that were new to the subjects. The use of novel tasks on the posttest is necessary to determine if the training facilitated a generalizable advance in problem solving ability, i.e., can it be used to solve new (transfer) problems? The researchers found that in both the fifth and seventh grade students, the

experimental group significantly outperformed the controls on each controlling variables task (bending rods, pendulum, and spheres). Differences were more pronounced for the seventh grade students.

Linn, Chen, and Thier (1977) trained 132 racially mixed fifth grade and sixth grade students in an urban school from a generally lower-middle-class area to controlling variables. From pilot work, the researchers developed two types of experimental conditions: One was the independent condition in which each child was asked to work on his own project by himself; the other one was the peer condition in which children were told that they could work with one or two friends or work alone. To evaluate the effectiveness of the experimental treatment, all the fifth- and sixth- grade students were given the Experimentation pretest. Subjects were randomly assigned to three groups: Control, Peer condition, and Independent condition. Subjects in the Peer condition worked on the projects of their choice with one or two friends or alone for one hour. Subjects in the independent condition worked on the project of their choice by themselves for one hour. During the experiment, children were challenged to, for instance, "Make a four-layered rainbow of liquid," or "Determine which glue is strongest." They were told that once they had solved the initial challenge they could use the equipment to try to solve new challenges suggested by

their investigations, their leaders, or the printed directions for the activity.

After 10 weeks, the Experimentation posttest was administered. The controls then came to the Enrichment Center for 10 sessions. The researchers found that students in the independent experimental condition were significantly better than were the controls at interpreting experiments and controlling variables. They also have evidence that the students in the experiment were working at an appropriate logical level. Inhelder and Piaget (1958) would classify 10- and 11-years-olds as at the level of advanced concrete operations. Their observations indicate that students were performing at this level. Students tended to be able to investigate unfamiliar variables in conjunction with familiar variables.

Lawson and Wollman (1976) trained 32 fifth grade students (a mean age of 10.5 years) and 32 seventh grade students (a mean age of 12.6 years) enrolled in an elementary school and a junior high school in Lafayette, California. Their investigation addressed itself to the following questions: (1) The effectiveness of instructional procedures incorporating Piaget's idea of neurological development, (2) Training transfer to tasks involving the controlling variables, (3) If training can enable concrete students to perform at a formal level on tasks requiring the controlling variables, will this training transfer to tasks involving

different concepts but ones which also involve formal thought (nonspecific transfer)? In other words, if the training was effective, was it limited to the specific concepts involved or did it affect a more general shift from concrete to formal cognitive functioning? (4) The relationship between intellectual development and training effects. Training procedures consisted of four sessions: In the first session, subjects were introduced to the intent and format of the training. In second session, subjects were introduced to the materials and asked to perform a fair test to find out the correct variable to solve the problem. In the third session, subjects were asked to experiment with an apparatus. The concepts underlying the questions and materials were identical in all sessions. In the fourth session, the use of concrete materials as the source of activity and discussion was replaced by the use of written problems. Problems posed only in a written fashion were considered to represent an additional step away from the concrete and towards the abstract or formal level. The researchers found that the fifth grade experimental group's gain was higher than the control group's gain. These differences were highly significant ( $p < .001$ ). The seventh grade experimental group's gain was also higher than the control group's. This gain was highly significant ( $t = 0.0$ ;  $p < .001$ ). So, instruction incorporating the described procedures can affect the transition

from concrete to formal cognitive functioning in these fifth grade and seventh grade students with respect to the ability to control variables. On tasks designed to measure nonspecific transfer of training, differences between the fifth grade experimental and control groups were not significant ( $p > .10$ ). This indicated that although the training was effective in promoting formal thought with regard to one aspect of formal reasoning, it was limited in extent. They also found the difference was not due to the fact that the experimental group performed more formally because of a general advance in reasoning but that the control group performed below their capability. Possibly a personal rapport established during the training sessions among the experimenters and the experimental subjects did not develop with the control group subjects. For this reason, the control group simply did not try as hard as the experimental group did on the written examination. Further, the data indicated that the more formal subjects were somewhat more receptive to training than the more concrete subjects. The fact that specific transfer of training was significantly related to the pretest level of intellectual development was a result more closely aligned with the Piagetian position.

Ross et al. (1976) trained college students to perform formal thinking tasks. A group of 109 male and female college students (mean age of 21.11 years) were pretested

with an adaption of the Test of Operational Thinking. The 57 students scoring at the concrete stage were randomly assigned to one of three training groups or the control group. Hypotheses were drawn on the basis of the logical similarity between the three formal tasks (pendulum, balance, and chemical combination) and the training procedure, which attempted to teach the dissociation schema. The first hypothesis that there would be maximal transfer on the pendulum task was not testable due to the ceiling effect of all treatment group scores. The second and third hypotheses were supported in that there was (a) a significant ( $p < .05$ ) training effect on the chemical task, and (b) no significant training effect for the balance task. It was argued that the significant ( $p < .01$ ) effect of didactic training on the chemical task versus the moderate and nonsignificant effects of cognitive conflict and concept formation training was an indicator that direct, verbal instruction should be more effective in short-term training procedures.

Lawson (1980b) trained concrete operational seventh grade students and also concrete operational college students to determine if the probabilistic and correlational reasoning could be enhanced by a set of training exercises. He found that the concrete operational college students correctly answered nearly twice as many items as their seventh grade counterparts. These results implicated that

instruction in aspects of formal reasoning can be successful and training of concrete operational students early in the developmental period for formal operations may be premature and may be more successful if delayed.

Many of these researchers found that it is possible to teach students to control variables in certain situations. But the effectiveness of such training is still explorable. Lawson, Blake, and Nordland (1975) found that there were no significant differences between an experimental group and a control group on the separation of variables task and on the equilibrium task. Ross et al. (1976) also found that there was no significant effect for the balance task. On retention, Bredderman (1973) found that there was no retention of skill of controlling variables when he retested students one month later. On transfer of training, Lawson, Blake, and Nordland (1975) found that students were unable to transfer the skill of controlling variables from one task to another, while Lawson and Wollman (1977) found that there was some transfer of the skill to novel situations with seventh grade students. On task designed to measure nonspecific transfer of training, Lawson and Wollman reported that differences between the fifth grade experimental and control groups were not significant.

From the training studies reviewed above, two conclusions can be drawn. First, it is possible to train students

to control variables although it is still questionable whether the skill is transferrable and long lasting. Second, training is more successful if it is given to more mature students than to younger students. These results may be due to the absence of equilibration in younger students.

#### Studies on the Concrete-Inquiry Based Instruction

In many school learning settings, the teacher and teaching materials tell the students what they are expected to know. Many students in the classroom have experiences that can best be described as exposition. The assumption is made by those responsible for the curriculum that if students are to understand the concepts from the content they have to be told about them by the teachers and (or) the printed learning materials.

Within the past twenty years, a different type of curriculum project has appeared. That curriculum is designed to provide the students with experiences which would permit them to isolate the content concepts to be learned or would permit the teacher to isolate the concepts from the students' experiences. This curriculum type is usually referred to as inquiry.

In true inquiry, the individual tends to act more like a scientist. A scientist behaves in a number of ways in order to unravel the hidden relationships relative to a



problem. He originates problems, formulates hypothesis, designs investigative approaches, tests his ideas, e.g., carries out experiments, and synthesizes knowledge. In other words, he performs certain relatively sophisticated mental processes. He finally has found a set of rules that apply to solving a particular problem.

According to Piaget (1964), the development of mental structures is dependent upon the actual experiences the student has. Mental structures, therefore, are not developed by reading only, but structures developed through experience allow the assimilation of information gained through reading.

Schneider and Renner (1980) hypothesized that Piaget's (1964) theory is particularly true with the concrete operational learner. Forty-eight students were drawn from a sample of approximately 150 ninth grade students from a rural junior high school in central Oklahoma. Subjects were randomly assigned to the exposition group and the inquiry group. The exposition group's classroom procedures were: (1) Oral explanation, (2) Motion picture and filmstrips, (3) Textbook, (4) Questions and problems, (5) Supervised study, and (6) Demonstration. This teaching procedure concentrates upon presenting the students with the concepts to be learned in as thorough and complete a manner as possible. The students were never in doubt as to what was being studied or what was expected of them. The inquiry group's instructional proce-

dures were based upon the teaching concept designed and implemented by the Science Curriculum Improvement Study (SCIS) and called the learning cycle (Renner and Stafford, 1972, p. 218). The learning cycle was composed of three distinct phases for each concept taught. The concept is introduced through exploration, which consists of activities the learner is to engage in and includes the experiences of observing, measuring, experimenting, interpreting, predicting, and model building. In the second phase, the conceptual invention is made for the learner. The final phase is discovery, which consists of the same types of activities as the exploration. The researchers found that greater gains were made in intellectual development by the concrete inquiry instruction group over the formal exposition group during the experimental procedure. These results indicate that the concrete instruction technique is superior to the formal instruction technique in promoting intellectual development for the concrete operational student.

Schneider and Renner's (1980) research supported Piaget's idea that an actual concrete manipulation of the objects or task materials accelerated cognitive development of the concrete operations children. The concrete operational learners need to be provided with concrete examples to help them begin to understand conceptual knowledge.

Sheehan (1970) studied the effectiveness of concrete

and formal instructional procedures with concrete and formal operational students. One hundred and four students (mean age of 13 years) were randomly sampled from a population of all students who attended a school district in upstate New York. Some of the characteristics of the concrete instructional procedures were that real concrete materials and (or) events were used; when two or more variables were involved only one was dealt with at a time; hypothetical statements were not employed, while deductive reasoning was eliminated. With the formal instruction, propositions and hypothetical situation were used along with deductive statements; in addition the consideration of all possible variables was required. The effects of instruction were measured by students' understanding of equilibrium in the balance bar, of angles, of evidence and reflection, and of the oscillation of a pendulum. At the start of the study, Sheehan hypothesized that subjects classified as formal operational would score higher on criterion measures after formal instructional procedures. However, the reverse was found to be true. Formal operational subjects achieved significantly higher scores as a result of concrete instruction than than did those who received formal instruction. Sheehan recognized the regression effect in his discussion of the improved performance of formal operational subjects from concrete instruction, but not from formal instruction.

Sheehan's (1970) research supported the finding of Bruner et al. (1956), that adults utilize heuristic strategies which correspond roughly to concrete and logical operations and combinations of them.

Goodstein and Howe (1978) investigated to test the hypothesis that instructional methods in which concrete models and exemplars of a concept are used will lead to better understanding by students at both the concrete and formal operational levels of cognitive development. Stoichiometry, which deals with the weight relationships of chemical combinations, was chosen as the topic to be taught. This concept requires knowledge of the particulate nature of matter, understanding of the mole concept, and the ability to do proportional reasoning. The subjects were 95 students (average age of 16 years and 8 months) in four intact sections of the regular chemistry course taught in a high school. The researcher found that the concrete operational students did not profit from the use of the concrete models and exemplars. Their results suggest that (1) concrete level students can not learn concepts which require advanced formal operational thinking, no matter how the concepts are taught and (2) learning of formal operational concepts can be enhanced for formal operational students by their use of concrete models during the learning process. These conclusions are different from those of Sheehan (1970), who found that concrete in-

struction was of benefit to both concrete and formal level students.

From the research reviewed, two conclusions can be drawn. First, the concrete inquiry based instructional sequence is superior to the formal expository instruction technique in promoting cognitive development for concrete operational and formal operational students. Second, the concrete inquiry based instruction is more successful if the concepts to be taught are more adaptable to the cognitive level of the students. However, the research question of whether the concrete inquiry teaching technique is effective in experimental learning setting or in non experiment classroom setting remains unanswered.

#### Functional Aspects of Cognitive Development and Cognitive Style

According to Pascual-Leone's (1969) general functional theory of cognition, whether an individual actually solves a particular problem depends on the following factors: (1) the subject's tendency to utilize the full mental power which he has available. This assumes that some subjects are habitually low mental processors. That is, they prefer to look at or to respond to problems in the simplest manner possible with a set of operations involving the least mental effort;

(2) the relative weight which the subject gives to cues from the perceptual field, as opposed to cues from other sources, in selected schemes.

The most critical feature of Pascual-Leone's theory is as follows. The individual differences described in the two factors above are assumed to be highly correlated and together can account for the dimension of cognitive style which Witkin (1962) has called field-dependence-independence.

Witkin and his associates (1962) have propounded a theory of psychological functioning which has been used extensively to study cognitive styles of children and adults.

According to Witkin (1962), cognitive style is conceived primarily as the manner in which an individual perceives and analyzes a complex stimulus. The concept of field-independent and field-dependent cognitive style emerged from studies of perception of upright, in space realized by Witkin and his associates (1950, 1962). These studies were RAT (Room-Adjustment Test), BAT (Body-Adjustment Test), and RFT (Rod-and Frame Test).

The distinction between field-independent and field-dependent cognitive styles has been defined differently by researchers in the area. Witkin and his associates (1962) stated that:

The person with a more field-independent way of perceiving tends to experience his surroundings analytic-

cally with objects experienced as discrete from their background.

The person with a more field-dependent way of perceiving tends to experience his surroundings in a relatively global fashion, passively conforming to the influence of the prevailing field or context (p. 35).

Goodenough and Eagle (1963) defined the field-independent and field-dependent cognitive style as: "The ability to overcome an embedding context in perception." This statement, according to Witkin (1954), means that subjects who easily break up an organized perceptual field ... who can readily separate an item from its content ... are called field-independent (FI); subjects who readily accept the prevailing field or content ... who have difficulty in separately an item from its context ... are called field-dependent (FD).

In short, cognitive style is the characteristic, self-consistent modes of functioning which individual show in their perceptual and intellectual activities (Kogan and Kogan, 1971). In a FD mode of perceiving, perception is strongly dominated by the overall organization of the surrounding field and parts of the field are experienced as fused. In a field-independent way of perceiving, parts of the field are experienced as discrete from an organizing ground.

Numerous studies have attempted to explore the relationship between the field-dependence and field-independence

cognitive style and the cognitive development of formal reasoning.

Saarni (1973) administered two formal operational tasks and the Rod and Frame Test to 64 middle class young adolescents, evenly divided according to sex and grade. Their performance on two complex, multistep problems was evaluated according to level of field independence tested within level of cognitive development. The results indicated that Piagetian developmental level significantly predicted problem solving performance, whereas level of field independence did not appear to clarify individual differences in a meaningful way.

Ghuman (1977) explored the relationship between the cognitive variables, as measured by Piagetian tests and Standard Raven Matrics, and Witkin's field-dependence and field-independent dimension (FD-EID). He found that there are significant correlations between Witkin's dimension and the cognitive variables, including factor B of the Children's Personality Questionnaire (CPQ). The scores from Raven Matrics, Piagetian conservation tests and factor B (intelligence) did correlate significantly with the field-dependence and field-independence dimension. These results supported Witkin's arguments that cognitive styles are the characteristic self-consistent modes of functioning found pervasively throughout an individual's cognitive activities.



Lawson and Wollman (1977) explored the relationship between performance on Inhelder and Piaget's (1958) bending rods and balance beam tasks and degree of field-dependence and field-independence. Fifty-four students (mean age of 11.6 years) from sixth grade classes in Berkely, California, served as subjects. The bending rods and balance beam tasks were administered in individual interviews of approximately 20 minutes in length. High correlations were found between the Group Embedded Figures Test and the bending rods and balance beam tasks ( $r = .65$  and  $r = .60$ ,  $p < .001$ ), respectively, and with the conservation of weight task ( $r = .46$ ,  $p < .001$ ). These results supported Pascual-Leone's research, which found success on many of Piaget's concrete operational tasks was significantly restricted by field-dependence. Even adult field-dependent subjects did poorly on concrete conservation and class inclusion tasks.

Lawson (1980b) also found that formal operational reasoning and field-independence are significantly correlated. In this research, Lawson trained college students (mean age of 22.6 years) enrolled in two sections of "Biological Science for the Elementary Teacher" at Arizona State University. Subjects were trained in an inquiry oriented instructional sequence. They were given a good deal of freedom to conduct investigations of their own design. The finding was that none of the field-independent subjects were at the

concrete operational level.

Douglass and Kahle (1978) found that field-independent students who used an inductive sequence of instruction reached a higher level of achievement than did the other students ( $F= 3.66, p < .05$ ) in their training research. The recommendation of the present study was to individualize instruction in such a way that global (field-dependent) students are matched with deductive materials and analytic (field-independent) students are matched with inductive materials.

From the studies reviewed above, we can conclude that there is positive correlation between cognitive developmental levels and cognitive style. Further study exploring instructional design promoting formal reasoning of field-dependent students is needed.

## CHAPTER III.

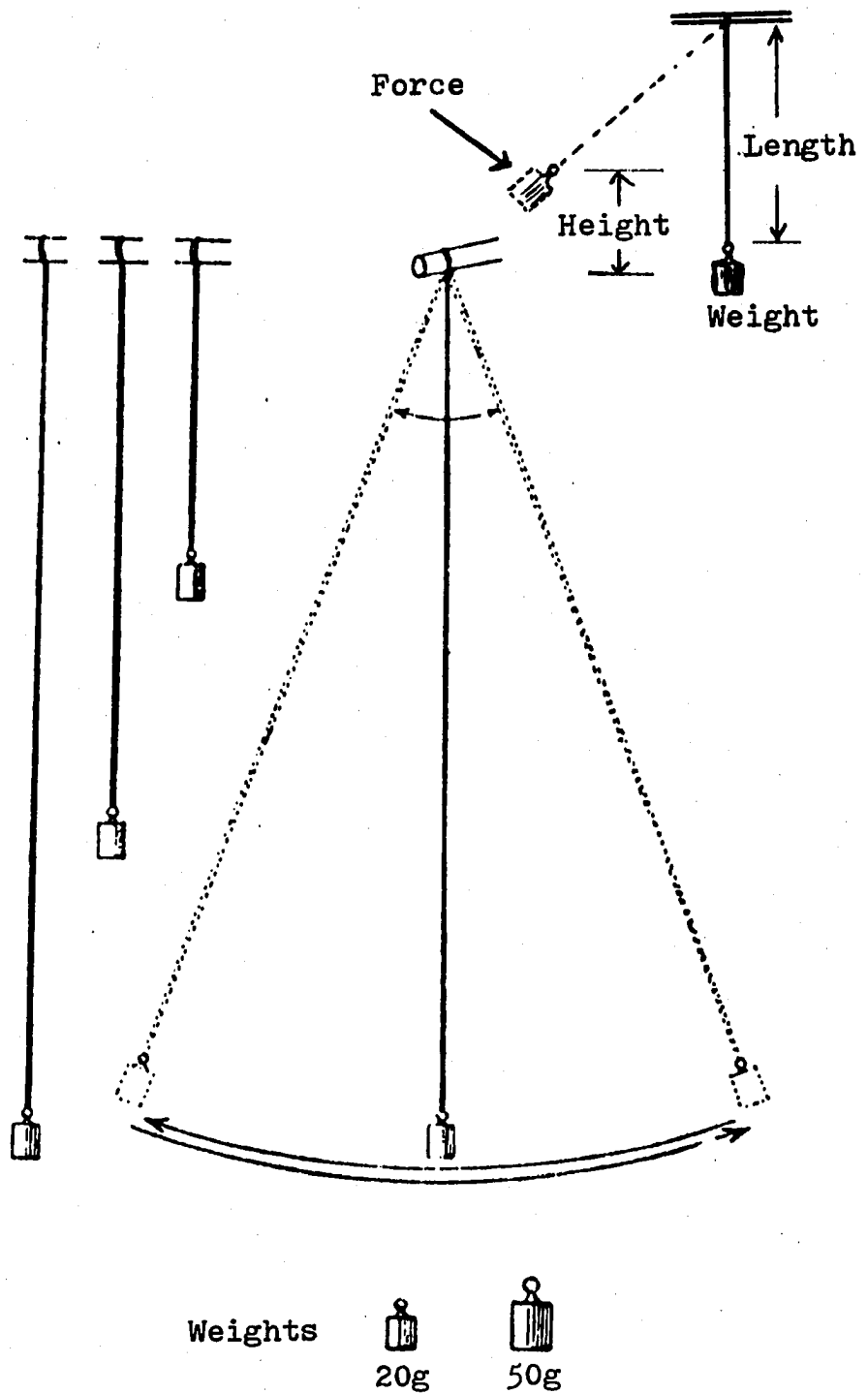
## RESEARCH METHODS AND EXPERIMENTAL DESIGN

## Learning Tasks

Two Piagetian tasks were employed as learning tasks for training hypothetic-deductive scientific reasoning of controlling variables. One was the pendulum task and the other was the bending rods task. These two tasks were used by Inhelder and Piaget (1958) for identifying the concrete operational child and the formal operational child who has the capability of separation and control of variables. The instructional objective of these tasks was as follows: Given a relative complex problem situation, the student will be able to produce hypothetic-deductive scientific reasoning of controlling variables by stating a hypothesis, making valid comparisons, designing a fair test, and empirically verifying the problem solution.

Pendulum Task

The apparatus for the pendulum task (Figure 1) consists of three strings with a pendulum bob (Inhelder and Piaget, 1958; pp. 67-79). Strings of 10 cm, 20 cm, and 30 cm in length with 20 g and 50 g weighted pendulum bob were presented to the subjects. The meaning of the "frequency" of a



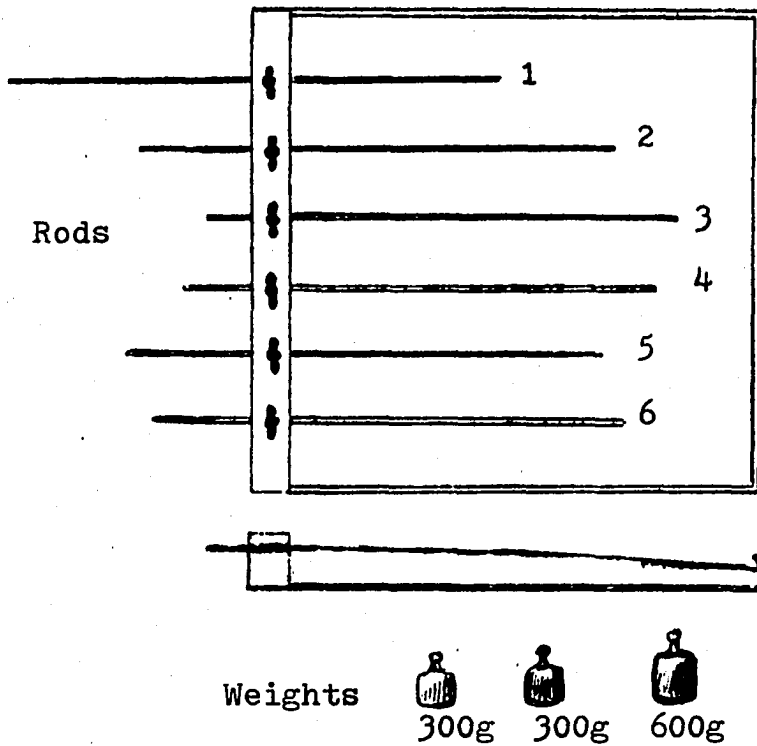
The pendulum utilizes a simple apparatus consisting of a string, which can be shortened or lengthened, and a set of varying weights.

Figure 1. Pendulum apparatus

pendulum was carefully explained. The term itself is unimportant but the concept must be comprehended. Subjects were shown that a simple pendulum could be constructed with the string and weights. The subjects were asked to identify the possible variables what might affect the frequency of the pendulum bob. The four possible variables which might affect the number of swings of the pendulum bob were as follows: (1) the force used to impel the pendulum bob, (2) the height at which the pendulum bob is released, (3) the weight of the pendulum bob, and (4) the length of the string. Subjects were asked to conduct their own experiment with the pendulum apparatus to determine which variable or variables affect the frequency of oscillation of the pendulum.

#### Bending Rods Task

In the bending rods experiment, subjects were presented with six rods which vary in length, material, cross section shape, and thickness (Figure 2). Subjects were shown weights which can be hung from the rods and were asked to use the weights to find out which rod bends the most. Inhelder and Piaget (1958, pp.46-66) found that concrete operational subjects can describe the results of their experiments, including the fact that two explanations are possible for the same outcome, but cannot use the "other things equal" scheme. Thus, the subjects, in describing what Piaget calls a serial



The bending rods apparatus consists of a metal frame into which six different types of aluminum and brass rods are inserted. These six rods are different in terms of the cross section shape, the materials, the thickness, and the lengths.

Properties of the rods

<u>Rod</u>	<u>Length</u>	<u>Material</u>	<u>Shape</u>	<u>Thickness</u>
1	long	aluminum	round	thick
2	long	aluminum	round	thin
3	long	brass	round	thick
4	long	aluminum	square	thick
5	short	aluminum	round	thick
6	long	brass	square	thick

Figure 2. Bending rods apparatus

ordering, might note, "This rod bends more because it has more weight and it's thinner than this rod," but could not set up a fair test to show that thin rods bend more than thick rods. Formal operational subjects attempt to prove something (control variables) rather than describe the reality that they use. Subjects who have just reached the formal level organize proofs with "all other things equal" only in certain cases and even then not for all of the relevant factors. The definition of formal operational thought proposed by Piaget requires a reasonable amount of explanation when applied to actual experiments. The apparatus, number of variables, and type of variable might influence whether subjects separate and control variables.

#### Concrete-Inquiry Instruction Model

The instruction of the present study was based upon the teaching concept of controlling variables designed by the inquiry based teaching sequence that is called the concrete-inquiry instruction model. The concrete-inquiry instruction model composed of six distinct phases for each concept taught. In this model, the learning concept is learned through concrete-inquiry, which consists of activities the learner is to engage in and includes the experiences of hypothesizing, designing, experimenting, observing, measuring, interpreting, predicting, and model building. After the con-

crete-inquiry process, the learner had an opportunity to review his own experiment through the feedback process provided by the video tape cassette. The learner can check the entire process of his own experiment to determine the accuracy of the solution. At the end of the experimental process, by presenting summary and conclusion, the video tape helped the learner to insure that the learning concept was thoroughly mastered before subsequent learning tasks were started.

The phases of the instructional sequence used were as follows:

#### Presenting the problem

During this phase the terms used in the problem situation and the definition of the problem were presented clearly to the learner:

... Now, I am going to begin with this apparatus. Do you know what this is called? This is called a pendulum. Compare yours with this one.

As you can see, the pendulum consists of a string from this stand and the pendulum bob that can be hooked on the end of the string. This is called a pendulum string and this is called a pendulum bob. Notice that yours is similar to this one. This swings like the pendulum bob of the wall clock. If you push the pendulum bob like this, the pendulum bob swings back and forth like this ... (Omission) ... Set the stopwatch to begin and push the bob like this. One, two, three, four, five. This pendulum bob swings five times for five seconds. This number of swings is called frequencies.



Now, I would like to ask a question. What affects the number of times the pendulum will swing back and forth in a five seconds period of time? Can you guess the possible variable or variables which might affect the frequencies of the pendulum bob? ... Do your own experiment with your pendulum apparatus, and answer question one on your worksheet (Appendix C).

As can be seen from the script, the concept of pendulum and frequencies was presented and also the problem situation that learner should solve was clearly presented to learner.

#### Forming hypothesis

After realizing the problem situation and exploring the solution, the subjects were asked to establish their own hypotheses about the required problem. Through this phase the subjects predicted the results of the experiments and formal ideas on the subject. The video tape required the subjects to make their own hypotheses. The explanation was as follows:

... Now, let's suppose that the force used to impel the pendulum bob affects the frequency of the pendulum bob. Can you devise a hypothesis about this problem? Establish your hypothesis on the line of question two on your worksheet (Appendix C).

### Designing and experimenting

After forming an hypothesis, the students were asked to design the method for testing the hypothesis and to conduct their own experiment according to the design for solving the problem. During this phase, subjects were allowed to gather data about the problem and develop understanding of the concept being inquired through concrete experiences, usually using manipulative apparatus and materials. This phase is inquiry, which consists of; exploration, designing, observing, measuring, experimenting, and interpreting.

In this phase, the subjects were asked to conduct the experiment like this:

... Now, test your hypothesis. Be sure that the independent variable which you manipulate this time is the length of the string (Appendix C).

- 1) Write down your experimental design for testing the hypothesis.
- 2) Write down the data that you've got in the experiment.
- 3) Write down your conclusion from this experiment (Appendix D. Worksheet I).

### Feedback

The feedback phase was designed to reveal the particular difficulties or incorrect responses encountered by some of the subjects, and to reinforce the learning of those subjects through immediate feedback.

The feedback was provided to the subjects like this:

... Now, let's review the process of testing the hypothesis of your experiment. As you know, to test the hypothesis we must use two lengths of string. One is the 10 cm long string and the other is the 30 cm long string. Be sure that the other independent variables are held as constant (Appendix C).

### Summary and conclusion

The final phase of the instructional model in the present study was summary and conclusion of the experiment for solving problems. The video tape provided the subjects with opportunities for review of the process of problem solving and presented the conclusion of the experiment.

### Construction of Experimental Materials

The Piagetian experiment of controlling variables in the present study was conducted with the concrete-inquiry instruction model. To eliminate the instructor's bias, all the instructional sequences were presented through video tape presentation. Therefore, the major instructional material consisted of a video tape cassette, worksheets, and experimental apparatus (pendulum apparatus and bending rods apparatus).

The video tape cassette was in color and had a running time of 51 minutes, 33 minutes for the pendulum task and

18 minutes for the bending rods task, respectively. Worksheet I for the pendulum task (Appendix D) and Worksheet II for the bending rods task (Appendix F) were constructed for helping the subjects describe their hypothesis, solution, design, and experimental data.

Experimental apparatus were also constructed. The pendulum apparatus (Figure 1 on page 50) was consisted of one 10 cm long string, one 20 cm long string, and one 30 cm long string with two 20 g weighted bobs and one 50 g weighted bob. The bending rods apparatus (Figure 2 on page 52) consisted of a metal frame into which six different metal rods are inserted.

### Subjects

Fifty-seven volunteers from nine undergraduate psychology classes participated in the study. Table 1 indicated numbers of volunteer from the psychology classes at Iowa State University, Ames, Iowa.

Fifty-seven volunteers signed up on the appointment schedule. The volunteers were randomly assigned to the experimental group and the control group. In other words, 29 volunteers who signed up on the odd numbers became the experimental group and the 28 volunteers who signed on the even numbers were assigned to the control group. The properties of the experimental group and the control group were as shown in Table 2.

Table 1. Volunteers participating in the present study

Class	Numbers of volunteer
General Psychology	
Section A	17
Section B	19
Section C	2
Psychology of Thinking	2
Developmental Psychology	
Section A	10
Section B	4
Section E	1
Consumer Psychology	2
Total	57

Table 2. Properties of the experimental group and the control group

Group	N	Age	Sex	Grade <sup>a</sup>	Major <sup>b</sup>
The Experimental Group	29	$\bar{X} = 20.19$ SD = 1.78	Male = 19 Female = 10	1 = 12 2 = 16 3 = 1	1 = 8 2 = 8 3 = 5 4 = 6 5 = 2
The Control Group	28	$\bar{X} = 19.59$ SD = 0.95	Male = 17 Female = 11	1 = 19 2 = 7 3 = 2	1 = 6 2 = 8 3 = 6 4 = 6 5 = 2
Total	57	$\bar{X} = 19.90$ SD = 1.54 Mdn = 19.63	Male = 36 Female = 21	1 = 31 2 = 23 3 = 3	1 = 14 2 = 16 3 = 11 4 = 12 5 = 4

<sup>a</sup>Grade: 1 = Freshmen, 2 = Sophomore, 3 = Junior  
<sup>b</sup>Major: 1 = Engineering, 2 = Natural sciences, 3 = Social studies,  
4 = Business administration, 5 = Architecture and interior design

## Criterion Measures

### Piagetian Logical Operations Test (PLOT)

The Piagetian Logical Operations Test (Appendix G) aims at measuring hypothetic-deductive scientific reasoning capability of controlling variables. It has 15 items. Thirteen of the items were originally developed by Staver (1978, pp.129-138), and the other items were originally developed by Lawson (1978, pp. 1-10). The higher the score is on this test, the stronger the reasoning capability of controlling variables and vice versa.

The 13 items employed from Staver (1978) are the objective multiple-choice test items with four alternatives per question. Staver developed the Piagetian Logical Operations Test, which consists of four individual scales: (1) Conservation of volume by liquid displacement; (2) Separation and control of variables; (3) Combinatorial analysis; and (4) Proportional thought. The conservation scale represents a trait of late concrete thought proposed by Karplus and Lavatelli (1969). The three remaining scales each represents a trait of formal thought proposed by Inhelder and Piaget (1958). Each scale consists of three item types, content questions that assess the subject's comprehension of a task, decision questions which require a cognitive decision by the student, and reason questions which identify reason for cognitive decision. At least one reason question is designed to

specifically rate subject reasoning patterns on each decision question. All PLOT question are similar to questions asked in clinical interviews, the principal difference being the format. Thus, the logic necessary to answer the questions may be assumed identical to the logic required to solve the corresponding clinical tasks.

The researcher of the present study employed 13 items from the second part, separation and control of variables, of the Piagetian Logical Operations Test developed by Staver (1978). The correlation between the PLOT total score and the total clinical interview score, .59, is comparable with higher validity diagonal values (Staver and Gabel, 1979). The internal consistency reliability (alpha) value for the PLOT total score is .85 (Staver and Gabel, 1979). According to the criteria set forth by Davis (1964) for individual differences measurement, the reliability for the PLOT total score is acceptable.

The researcher also employed two items from Lawson's (1978) Classroom Test of Formal Operations. These two items, originally developed by Inhelder and Piaget (1958, Chapter 4), are concerned with the pendulum task while Staver's (1978) items are concerned with the bending rods task. The correlation between controlling variables and formal reasoning interview tasks is .65 (Lawson, 1978, p. 19). The Kuder-Richardson 20 estimate of reliability was .78 (Lawson, 1978,



p. 17). This value, although not as large as might be hoped for, represents an adequate degree of reliability.

The researcher of the present study also analyzed the internal consistency of the items and got the reliability coefficient KR-20 of .64. The coefficient alpha was calculated by the following format:

$$\text{Alpha} = \frac{k}{k - 1} \left( \frac{1 - \sum_{i=1}^k S_i^2}{S_T^2} \right)$$

Where  $S_i^2$  is the variance of the measuring instrument item  $i$ , and  $S_T^2$  is the variance of the sum over the  $k$  items.

The standardized item alpha was .68. The computational formula is given by

$$\text{Alpha (s)} = \frac{k\bar{r}}{1 + (k - 1)\bar{r}}$$

Where  $\bar{r}$  is the average correlation between items.

#### The Problem-Solving Test (PST)

The Problem-Solving Test (Appendix I) aims at measuring the degree of transfer of hypothetic-deductive scientific reasoning capability of controlling variables. This test consisted of three problems. Each problem was selected from previously conducted research or valid resources (Karplus, et al., 1977; Heller, 1977). Each problem requires the students to either first respond 'yes', or 'no', or 'can't tell, or make a choice and then explain in writing how they arrived

at the answer. Each problem was scored twice, once for the correct choice and once for the correct explanation in writing how they arrived at the choice. Therefore, the highest possible score of this test was six.

The researcher of the present study analyzed the internal consistency of the items and calculated the reliability coefficient. The reliability coefficient alpha of this test was .70 and the standardized item alpha was .71.

#### The Group Embedded Figures Test (GEFT)

The Group Embedded Figures Test (GEFT)(Appendix K) was designed to provide an adaptation of the original individually administered Embedded Figures Test, which would make possible group testing. The use of the individually administered EFT is often impractical where large numbers of subjects must be tested for screening on the field-dependence dimension or for carrying out large-scale correlational research in the field of personality. With the GEFT, the scores for many individuals may be obtained in a single 20 minute testing session.

The test includes 18 complex figures and is divided into three parts. The first part includes seven simple figures and is used to familiarize the student with the test. The second part includes nine figures and the third part includes nine figures. The figures in each part become

successively more complex. The test manual explains that subjects should try to locate the simple figure within the complex one using a pencil to trace the original figure.

Reliability for the test was obtained by correlation between parallel forms with identical time limits. Correlations between the nine item second section scores and the nine item third section scores were computed and corrected by the prophecy formula, producing a reliability estimate of .82 (Witkin, et al., 1971). The validity of the GEFT has been tested against the EFT. The correlations were .82 for males and .63 for females (Witkin, et al., 1971, p. 28).

#### Reliability for Scoring Subject's Responses

Items 2 and 4 on the Piagetian Logical Operations Test (Appendix G) and all items of the Problem-Solving Test (Appendix I) were provided for the subjects' open responses. To obtain the evidence assuring reliability for scoring the students' responses on the items, the following procedures were administered.

#### Establish the criteria for scoring students' responses

The researcher described the characteristics of the correct responses and presented the criteria for scoring the responses. Some examples of correct and incorrect responses were used (Appendix H and J).

### Identify the expert for scoring students' responses

The researcher found an expert for scoring the students' responses independently. He was a Ph.D candidate in the Psychology Department and an instructor of general psychology at Iowa State University. He was very familiar with Piagetian theory and research.

### Sampling the students' tests and scoring

Eleven subjects' tests (about 20 %) were sampled from the 57 tests. The subjects' tests were randomly sampled by 5 intervals of the subjects' ID numbers, that is 5, 10, 15, . . . ., 55. The responses were scored separately by the researcher and the expert. This procedure produced a concordance coefficient value of .99.

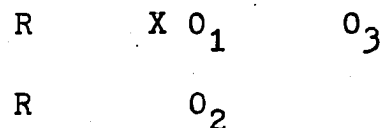
### Experimental Design

As recommended by Campbell and Stanley (1963), the posttest only control-group experimental design was employed to test the teaching effects of a Piagetian experiment through the concrete-inquiry instruction model for improving the hypothetic-deductive scientific reasoning capability of controlling variables. The steps involved in the posttest-only control-group design are as follows: (1) Randomly assign subjects to the experimental and the control groups, (2) Administer the treatment to the experimental group but not

to the control group, and (3) Administer the posttest to both groups.

The reason for this design in the present study is that the pretest may have an effect on the experimental treatment. In addition, the posttest only control group design was considered as the best design for the present study because random assignment is most effective in equating groups when large numbers of subjects are involved, and the researcher had a large pool of subjects available.

The experimental design for the present study is represented by the following diagram:



Where R: Random assignment of the subjects

X: The experimental treatment

$O_1$ : Immediate posttest measurement of the dependent variable for the experimental group

$O_2$ : Immediate posttest measurement of the dependent variable for the control group

$O_3$ : One month delayed post-posttest measurement of the dependent variable for the experimental group

The major point of the present study was to test the hypothesis of  $O_1 > O_2$  and  $O_1 = O_3$ .

## Research Variables and Experimental Procedures

### Research variables

Many research variables were included in the present study. A Piagetian experiment with the concrete-inquiry instruction model for improving hypothetic-deductive scientific reasoning capability of controlling variables was the treatment variable of the present study. The student's cognitive style characteristics, student's sex, age, grade, and major were treated as the independent variables of the study. The subjects' performances on the pretest and posttest of the Piagetian Logical Operations Test and the Problem-Solving Test were analyzed as the dependent variables. The subject's American College Test (ACT) scores and Minnesota Scholastic Aptitude Test (MSAT) scores were also analyzed as the dependent variables of the study.

### Experimental procedures

The experimental procedures are shown in figure 3. The 57 volunteers from the Psychology pool of Iowa State University were randomly assigned into the experimental group and the control group. Each subject in the experimental group met with the experimenter for approximately two hours of individual training.

Psychology pool (about 350 students),  
Iowa State University

Volunteers (57) signed up for  
participating in the experiment

Randomly assigned into  
two groups

Procedures	Experimental group(29)	Control group(28)
Data collection for the independent variables	GEFT scores ACT scores MSAT scores	GEFT scores ACT scores MSAT scores
Experimental treatment	Treatment	No treatment
Immediate posttest	PLOT PST	PLOT PST
One month delayed post-posttest	PLOT PST	No test

Figure 3. Experimental procedures

Administering Group Embedded Figures Test (GEFT)

Subjects were given the Group Embedded Figures Test (GEFT) test booklet and a set of sharpened soft black pencil with erasers. As soon as the identifying information on the cover page had been filled in, the experimenter said: "Now start reading the directions, which include two practice problems for you to do. When you get to the end of the direction on page 3, please stop. Do not go beyond page 3."

When the subjects finished reading the directions on page 3 the experimenter said: "Before I give the signal to start, let me review the points to keep in mind." The experimenter read the statements at the bottom of page 3. After that, the experimenter asked, "Are there any questions about the directions?" The experimenter then said: "When I give the signal, turn the page and start the first section. You will have two minutes for the seven problems in the first section. Stop when you reach the end of this section. Go ahead!"

After two minutes the experimenter said: "Stop ... whether you have finished or not. When I give the signal, turn the page and start the second section. You will have five minutes for the nine problems in the second section. You may not finish all of them, but work as quickly and accurately as you can. Ready, go ahead."

After five minutes the experimenter said: "Stop ...



whether you have finished or not. When I give the signal, turn the page, and start the third section. You will have five minutes for the nine problems in the third section. Ready, go ahead!"

After five minutes the experimenter said: "Stop ... whether you have finished or not. Please close your test booklet."

### Experimental treatments

After administering the GEFT, the subjects in the experimental group were guided to a small room, in which they could conduct their own individual experiments with the pendulum apparatus and the bending rods apparatus, while viewing the TV screen with the VTR deck. The session began by giving the subjects a brief introduction to the intent and format of the experiment. They were told that the video tape cassette can be played by touching the 'PLAY' button and 'PAUSE' button of the VTR deck. They also were given Worksheet I for the pendulum task (Appendix D) and Worksheet II for the bending rods task (Appendix F). During the experimental treatment, the subjects engaged in the experiences of seeing the video tape cassette, conducting their own experiments, recording the data on the Worksheets, and reviewing the process of the experiment. The subjects started the pendulum task first and then continued to the

bending rods task. They usually spent about 107 minutes of experimental time (Range= 80-120 minutes and mean of 107).

#### Administering immediate posttest

After finishing the experimental treatment, the subjects took the immediate posttests. One was the Piagetian Logical Operations Test, and the other was the Problem-Solving Test (about 30 minutes for each subject).

#### Administering one month delayed post-posttest

One month after the experimental treatment, the subjects met the experimenter at the appointed time and took the delayed post-posttest of the Piagetian Logical Operations Test and the Problem-Solving Test ( about 30 minutes for each subject).

#### Organization of the Data

Seven sets of data from the subjects were collected in the present study: Immediate posttest of the PLOT, one month delayed post-posttest of the PLOT, immediate posttest of the PST, one month delayed post-posttest of the PST, the GEFT, ACT, and MSAT. In addition, information on the amount of input time for participating in the experiment and the amount of input time for taking tests was checked and collected.

The scores of the Group Embedded Figures Test (GEFT) were categorized into two groups, the field-dependent student group and field-independent student group. According to the GEFT MANUAL (Witkin, et al., 1971), the students with score 1 through 12 are field-dependent students and those with score 13 through 18 belong to the field-independent group.

The subjects were classified according to sex and to age. The age divisions were 20 years and under and over twenty. The students' majors were categorized into five groups: Engineering, natural sciences, social studies, business administration, and architecture and interior design

All the data were analyzed by sex, age, major, cognitive style, and the experimental and the control groups.

#### Statistical Analysis of the Data

The Statistical Package for the Social Sciences (Nie, Hull, Jenkins, Steinbrenner & Brent, 1975) and The SPSS Update (Hull & Nie, 1979) were used in the analysis of the data. The specific statistical methods were:

1. Means and standard deviations
2. t-test
3. Reliability coefficients (alpha)
4. Multiple correlation coefficient (R)

5. Multiple regression analysis
6. Oneway analysis of variance
7. Multiple classification analysis of variance

The following specific null hypotheses of the present study were tested at the statistical significant level of .05 and .01.

1. There is no difference between the Piagetian Logical Operations Test of the students instructed with the concrete-inquiry instruction model and the students not instructed with the concrete-inquiry instruction model.
2. There is no difference between the scores of the immediate posttest and the one month delayed post-test of the Piagetian Logical Operations Test.
3. There is no difference between the Problem-Solving Test scores of the students instructed with a Piagetian experiment with the concrete-inquiry instruction model and the students not instructed.
4. There is no positive correlation between the scores of the Piagetian Logical Operations Test and the Problem-Solving Test.
5. Performance on the Group Embedded Figures Test will not predict hypothetic-deductive scientific reasoning on the Piagetian Logical Operations Test.

6. There is no difference between the scores of field-dependent students and field-independent students on the immediate posttest of the Piagetian Logical Operations Test.
7. There is no difference between the scores of field-dependent students and field-independent students on the immediate posttest of the Problem-Solving Test.
8. Performance on the Group Embedded Figures Test, the Problem-Solving Test, American College Test, and Minnesota Scholastic Aptitude Test will not predict hypothetic-deductive scientific reasoning capability on the Piagetian Logical Operations Test.
9. Performance on the Piagetian Logical Operations Test, the Group Embedded Figures Test, American College Test, and Minnesota Scholastic Aptitude Test will predict the problem solving ability on the Problem-Solving Test.

## CHAPTER IV.

## RESULTS AND INTERPRETATIONS

This chapter will be divided into two sections. The first section includes descriptive data of the subjects, in terms of the American College Test (ACT) scores, the Minnesota Scholastic Aptitude Test (MSAT) scores, and field-dependent and field-independent cognitive styles. The second section contains the analysis and results of the null hypotheses testing.

## Descriptive Data

The ACT scores scores and the MSAT scores for the subjects were obtained from the Test and Evaluation Services of Iowa State University. The Group Embedded Figures Test (GEFT) for measuring field-dependence-independence cognitive styles was given to both the experimental and the control group. All of above test scores were analyzed for both groups.

Table 3 shows that the ACT scores and the MSAT scores for the control group were higher than for the experimental group, and the GEFT scores for the experimental group were higher than for the control group. But there was no significant difference between the groups statistically.

Table 3. Comparison of means and SDs for t-test between the experimental group and the control group on the ACT, the MSAT, and the GEFT

Tests	Experimental group			Control group			t-value
	Mean	SD	Range	Mean	SD	Range	
ACT	22.10	5.00	11-29	23.23	4.40	15-19	-0.67
MSAT	38.57	11.52	18-62	42.92	11.00	21-59	-1.09
GEFT	15.21	3.23	7-18	12.96	4.90	2-18	2.05

Table 4 shows that the ACT scores and the MSAT scores for the male group were significantly higher than for the female group (ACT,  $t=3.19$ ,  $p<.01$ ; MSAT,  $t=2.67$ ,  $p<.01$ ). But there was no significant difference between the male group and the female group on the GEFT.

Table 5 shows that the ACT scores, the MSAT scores, and the GEFT scores were not significant different between the age groups statistically.

The researcher of the study compared the means and the SDs among the majors on the ACT, the MSAT, and the GEFT. Table 6 shows that, in case of the ACT mean scores, the natural sciences majors ( $\bar{X}=25.71$ ,  $SD=2.06$ ) and the engineering majors ( $\bar{X}=24.50$ ,  $SD=2.78$ ) were the highest groups, the business and administration majors ( $\bar{X}=21.13$ ,  $SD=6.33$ ) and the social studies majors ( $\bar{X}=20.56$ ,  $SD=4.80$ ) were the middle groups, and the architecture and interior design majors ( $\bar{X}=18.00$ ,  $SD=1.41$ ) was a lowest group. Table 6 also shows that the MSAT mean scores of the engineering majors and the natural sciences majors were higher than that of other majors. But, in case of the GEFT, the mean scores were not very different from each of the other major groups.

Table 7 indicates that the F ratio obtained by analysis of variance (ANOVA) shows no significant differences among the major groups on the ACT, the MSAT, and the GEFT.



Table 4. Comparison of means and SDs for t-test between the male and the female groups on the ACT, the MSAT, and the GEFT

Tests	Male			Female			t-value
	N	Mean	SD	N	Mean	SD	
ACT	21	24.33	3.45	13	19.62	5.19	3.19**
MSAT	21	44.00	9.98	13	34.15	11.15	2.67**
GEFT	36	14.64	4.16	21	13.19	4.34	1.09

\*\*  $p < .01$ .

Table 5. Comparison of means and SDs for t-test between the two age groups on the ACT, the MSAT, and the GEFT

Tests	Mean age of 19.14			Mean age of 21.42			t-value
	N	Mean	SD	N	Mean	SD	
ACT	23	21.74	4.61	11	24.18	4.79	-1.43
MSAT	22	39.45	11.88	12	41.67	10.71	- .54
GEFT	36	13.92	4.69	21	14.43	3.44	- .44

Table 6. Comparison of means and SDs among the majors on the ACT, the MSAT, and the GEFT

Majors	ACT			MSAT			GEFT		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Engineering	8	24.50	2.78	7	45.71	10.12	14	14.07	4.31
Natural Sci.	7	25.71	2.06	9	44.78	7.84	16	13.69	4.69
Social Stud.	9	20.56	4.80	9	35.00	10.14	11	14.45	2.81
Busi. admin.	8	21.13	6.33	7	36.71	16.17	12	13.58	5.26
Architec. & Interior Design	2	18.00	1.41	2	36.50	2.12	4	16.50	3.00
Total	34	22.53	4.74	34	40.24	11.36	57	14.11	4.25

Table 7. Analysis of variance for the ACT, the MSAT, and the GEFT among the majors

Variables	Analysis of Variance				
	Source	DF	SS	MS	F-Ratio
ACT	Between groups	4	193.95	48.49	2.57
	Within groups	29	546.53	18.85	
	Total	33	740.47		
-----					
MSAT	Between groups	4	757.20	189.30	1.57
	Within groups	29	3502.91	120.79	
	Total	33	4260.11		
-----					
GEFT	Between groups	4	30.36	7.59	0.40
	Within groups	52	981.01	18.87	
	Total	56	1011.37		

The researcher of the study also compared the ACT scores and the MSAT scores between the field-dependent cognitive styled group and the field-independent cognitive styled group. Table 8 shows that the ACT mean score and the MSAT mean score for the field-independent group were higher than for the field-dependent group, but that the differences were not significant at the 0.05 level of confidence.

Table 8. Comparison of means and SDs for t-test between the field-dependent group and the field-independent group on the ACT and the MSAT

Tests	Field-dependent			Field-independent			t-value
	N	Mean	SD	N	Mean	SD	
ACT	10	20.50	6.26	24	23.38	3.79	-1.65
MSAT	11	36.00	12.39	23	42.26	10.52	-1.53

There was no set time limit to test the Piagetian Logical Operations Test (PLOT) and the Problem-Solving Test (PST). The testing time, including the 15 minute testing session for the GEFT, usually ranged between 30 and 60 minutes. The mean testing time for the experimental group was 34 minutes and the mean testing time for the control group was 45 minutes. The difference between groups was statistically significant ( $t = -4.70, p < .01$ ).

## Tests of Hypotheses

### The effectiveness of the experimental treatment

One of the main objectives of the present study was to validate the effectiveness of a Piagetian experiment through the concrete-inquiry instruction model on the students' hypothetic-deductive scientific reasoning improvement.

For this objective of the study, the first hypothesis was established:

The students instructed with a Piagetian experiment through the concrete-inquiry instruction model will exhibit greater cognitive growth of hypothetic-deductive scientific reasoning by the end of the experiment than will the students not instructed with a Piagetian experiment.

The following null hypothesis was stated:

There is no difference between the Piagetian Logical Operations Test scores of the students instructed with the concrete-inquiry instruction model and the students not instructed with the concrete-inquiry instruction model.

The results of the experimental treatment are shown in Table 9. The table indicates that the hypothetic-deductive scientific reasoning as measured by the Piagetian Logical Operations Test was significantly higher for the experimental group than the control group ( $t=4.14$ ,  $p < .01$ ). The null hypothesis was rejected.

Table 9. Comparison of means and SDs for t-test between the experimental and the control groups on the posttest of the Piagetian Logical Operations Test (PLOT)

Treatment	N	Mean	SD	t-value
Experimental group	29	15.03	1.66	4.14**
Control group	28	13.11	1.85	

\*\*  $p < .01$ .

The results shown in Table 9 demonstrate that the concrete-inquiry instruction model was effective in enabling the subjects to perform at a higher level on the training tasks.

The researcher compared the means and the standard deviations for t-test between the the independent variables in the experimental group for the extensive comparing. Table 10 indicates that there were significant differences between the male group and the female group on the posttest of the Piagetian Logical Operations Test (PLOT).

Table 10. Comparison of means and SDs for t-test between the male group and the female group on the posttest of the PLOT in the experimental group (N= 29)

Sex	N	Mean	SD	t-value
Male	19	15.47	1.26	2.08*
Female	10	14.20	2.04	

\*  $p < .05$ .

Table 11 indicates that there was no significant difference between the age groups. One age group's mean age was 19.14 years (Range= 18.58 - 19.92) and the other age group's mean age was 21.42 (Range= 20.08 - 26.08).

Table 11. Comparison of means and SDs for t-test between the age groups on the posttest of the PLOT in the experimental group (N= 29)

Mean age	N	Mean	SD	t-value
19.14	16	15.20	1.24	0.48
21.42	13	14.77	2.09	

The researcher of the study compared the means and the standard deviations among the majors on the posttest of PLOT in the experimental group. Table 12 shows that the means and the SDs among the majors on the posttest of the PLOT.

Table 12. Comparison of means and SDs for ANOVA among the majors on the posttest of the PLOT

Major	N	Mean of the PLOT	SD
Engineering	8	15.88	0.83
Natural sciences	8	13.88	2.30
Social studies	5	14.80	0.84
Business administration	6	15.17	1.47
Architecture and Interior design	2	16.50	0.71
Total	29	15.03	1.66



Table 13 indicates that the F ratio obtained by analysis of variance techniques shows no significant differences among the major groups on the posttest of the PLOT in the experimental group. Scheffe's method of test was used for comparing the means among the majors.

Table 13. Analysis of variance among the majors on the post-test of the PLOT in the experimental group (N= 29)

Source	N	SS	MS	F-Ratio
Between groups	4	21.08	5.27	2.26
Within groups	24	55.88	2.33	
Total	28	76.97		

These findings obtained from the analyzed data concerning the first hypothesis support the hypothesis that a Piagetian experiment through the concrete-inquiry instruction model enhanced the subjects' hypothetic-deductive scientific reasoning capabilities in the experimental group to think critically and to reason.

There was no difference between the age groups and the majors. These results indicate that the two age groups are the identical groups in terms of cognitive development. But The PLOT scores for the male group were significantly higher than for the female group.

### The retention effects of the experimental treatment

One of the objectives of the present study was to determine whether the improvements of hypothetic-deductive scientific reasoning capability by the concrete-inquiry instruction model was permanent or transitory.

For this objective, the second hypothesis was established:

The students instructed with a Piagetian experiment through the concrete-inquiry instructional model will exhibit the same cognitive level of hypothetic-deductive scientific reasoning capability one month after the initial experiment.

The following null hypothesis was stated:

There is no difference between the scores of the immediate posttest and the one month delayed posttest of the Piagetian Logical Operations Test.

The null hypothesis was tested with the results on the immediate posttest of the PLOT and the one month delayed posttest of the PLOT. Table 14 indicates that the null hypothesis was accepted ( $t=.79$ ,  $p > .05$ ) and there was no significant difference between the immediate posttest and the one month delayed posttest. A paired t-test was used for testing this null hypothesis. Therefore, the hypothesis that the training effects will be lasting was supported by the one month delayed posttest results of the Piagetian Logical Operations Test.

Table 14. Comparison of means and SDs for t-test between the immediate posttest and the one month delayed posttest as measured by the PLOT

Measures	N	Mean	SD	Paired t
Immediate posttest of the PLOT	29	15.03	1.66	.79
One month delayed posttest of the PLOT		14.34	4.15	

Table 15 indicates that the one month delayed posttest results shown the training effects were lasting in both the male and the female group.

Table 15. Comparison of means and SDs for t-test between the immediate posttest and the one month delayed posttest of the PLOT for the male group and the female group

Sex	Measures	N	Mean	SD	Paired t
Male	Immediate posttest of the PLOT	19	15.47	1.26	1.00
	One month delayed posttest of the PLOT		14.21	5.07	
Female	Immediate posttest of the PLOT	10	14.20	2.04	- 0.53
	One month delayed posttest of the PLOT		14.60	1.43	

Table 16 shows that there is no difference in the training effects between the immediate posttest and the one month delayed posttest of the PLOT for the two age groups. One group's mean age was 19.14 years (Range= 18.58-19.92) and the other group's mean age was 21.42 (Range= 20.08-26.08). A paired t-test was used for testing this hypothesis.

Table 16. Comparison of means and SDs for t-test between the immediate posttest and the one month delayed posttest of the PLOT for the two age groups

Mean age	Measures	N	Mean	SD	Paired t
19.14	Immediate posttest of the PLOT	16	15.25	1.24	1.08
	One month delayed posttest of the PLOT		14.13	4.00	
21.42	Immediate posttest of the PLOT	13	14.76	2.10	0.10
	One month delayed posttest of the PLOT		14.62	4.48	

Table 17 indicates that there is no difference in the treatment effects between the immediate posttest and the one month delayed posttest of the PLOT for each major group.

From the analyzed research data, the researcher concluded that the mastery of hypothetic-deductive scientific reasoning capability was retained until at least one month after the initial experiment.

Table 17. Comparison of the treatment means between the immediate posttest and the one month delayed posttest of the PLOT for each major group

Major	Measures	N	Mean	SD	Paired t
Engineering	Immediate posttest of the PLOT	8	15.88	0.84	.91
	One month delayed posttest of the PLOT		13.88	5.67	
Natural Sciences	Immediate posttest of the PLOT	8	13.88	2.30	-2.30
	One month delayed posttest of the PLOT		15.50	.93	
Social studies	Immediate posttest of the PLOT	5	14.80	.84	-.53
	One month delayed posttest of the PLOT		15.20	1.48	
Business administration	Immediate posttest of the PLOT	6	15.17	1.47	.54
	One month delayed posttest of the PLOT		14.83	1.83	
Architecture & Interior design	Immediate posttest of the PLOT	2	16.50	.71	1.13
	One month delayed posttest of the PLOT		8.00	11.31	

### The transfer effects of the experimental treatment

One of the objectives of the present study was to determine whether the improved hypothetic-deductive reasoning capability of the students trained by the concrete-inquiry instruction model could be transferred to solving the isomorphic problems.

For this objective, the third hypothesis was established:

The students instructed with a Piagetian experiment through the concrete-inquiry instruction model will exhibit greater problem solving ability in solving the isomorphic problems than will the students not instructed with a Piagetian experiment through the concrete-inquiry instruction model.

The following null hypothesis was stated:

There is no difference between the Problem-Solving Test scores on isomorphic problems of the students instructed with the concrete-inquiry instruction model and the students not instructed with the concrete-inquiry instruction model.

The null hypothesis was tested with the results on the Problem-Solving Test (PST) between the experimental group and the control group. Table 18 indicates that the null hypothesis was rejected and the students' problem solving ability was significantly higher for the experimental group than the control group ( $t = 3.79, p < .01$ ).

Table 18. Comparison of means and SDs between the experimental group and the control group on the Problem-Solving Test (PST)

Treatment	N	Mean	SD	t-value
Experimental group	29	4.69	1.37	3.79**
Control group	28	3.21	1.57	

\*\*  $p < .01$ .

Table 19 indicates that the transferred problem solving ability was retained until at least one month after the test. There is no significant difference in the problem solving ability between the immediate posttest and the one month delayed posttest of the Problem-Solving Test.

Table 19. Comparison of means and SDs between the immediate posttest and the one month delayed posttest of the Problem-Solving Test for the experimental group

Measures	N	Mean	SD	Paired t
Immediate posttest of the PST	29	4.69	1.37	-.11
One month delayed posttest of the PST		4.72	1.67	

Table 20 indicates that the transferred problem solving ability was retained until at least one month after first test of problem solving in both the male and the female groups.

There was no difference between the immediate posttest and the one month delayed posttest of the Problem-Solving Test.

Table 20. Comparison of means and SDs between the male group and the female group on the immediate posttest and the one month delayed posttest of the PST

Sex	Measures	N	Mean	SD	Paired t
Male	Immediate posttest of the PST	19	5.05	1.22	.12
	One month delayed posttest of PST		5.00	1.80	
Female	Immediate posttest of the PST	10	4.00	1.41	-.51
	One month delayed posttest of the PST		4.20	1.32	

Table 21 indicates that there is no difference in the transferred problem solving ability between the immediate posttest and the one month delayed posttest as measured by the Problem-Solving Test for the two age groups.

Table 22 indicates that there is no difference in the transferred problem solving ability between the immediate posttest and the one month delayed posttest of the PLOT for each major group.

From the research data in Table 18, we know that the hypothetic-deductive scientific reasoning capability transferred in solving isomorphic problems. This result tell us



about the students' hypothetic-deductive scientific reasoning capability to generalize from the tasks concerning controlling variables to other problem tasks similar in nature. Further, the retention data assured somewhat the usefulness of the hypothetic-deductive scientific reasoning capability under all circumstances in terms of sex, age, and major.

Table 21. Comparison of means and SDs between the two age groups on the immediate posttest and the one month delayed posttest of the Problem-Solving Test (PST)

Mean age	Measures	N	Mean	SD	Paired t
19.14	Immediate posttest of the PST	14	4.44	1.41	-.38
	One month delayed of the PST		4.56	1.50	
21.42	Immediate posttest of the PST	13	5.00	1.29	.14
	One month delayed posttest of the PST		4.92	1.89	

It is interesting to find out that the one month delayed posttest mean score was higher than the immediate posttest of the PST for the engineering major and the business administration major in Table 22. However, there was not significant difference between the two tests statistically.

Table 22. Comparison of means and SDs between the immediate posttest and the one month delayed posttest of the Problem-Solving Test (PST) for each major group

Major	Measures	N	Mean	SD	Paired t
Engineering	Immediate Posttest of the PST	8	5.00	1.51	-.31
	One month delayed Posttest of the PST		5.25	2.12	
Natural sciences	Immediate Posttest of the PST	8	4.75	1.04	.31
	One month delayed Posttest of the PST		4.63	1.19	
Social studies	Immediate Posttest of the PST	5	4.60	1.67	.00
	One month delayed Posttest of the PST		4.60	1.34	
Business administration	Immediate Posttest of the PST	6	4.17	1.60	-.81
	One month delayed Posttest of the PST		4.67	1.51	
Architecture & Interior design	Immediate Posttest of the PST	2	5.00	1.41	1.00
	One month delayed Posttest of the PST		3.50	3.54	

Correlation between cognitive development and cognitive style

One of the research objectives of the present study was to identify the relationship between the cognitive growth of hypothetic-deductive scientific reasoning and field-dependent and field-independent cognitive style.

For this objective, the fourth hypothesis was established:

There is a positive correlation between the cognitive growth of hypothetic-deductive scientific reasoning and field-dependent and field-independent cognitive style.

The following null hypothesis was stated:

There is no positive correlation between the scores of the Piagetian Logical Operations Test and the Group Embedded Figures Test.

The null hypothesis was tested with the results on the Piagetian Logical Operations Test (PLOT) and the Group Embedded Figures Test (GEFT). Table 23 indicates that there is a positive correlation between cognitive growth of hypothetic-deductive scientific reasoning and field-dependent and field-independent cognitive style ( $r = .58, p < .01$ ).

The correlation coefficient of 0.58 between cognitive growth of hypothetic-deductive reasoning and field-dependence-independence cognitive style indicates that there is a type of directive linear relationship that exists between cognitive growth and cognitive style.

Table 23. Correlation matrix of the research variables

Variables	ACT	MSAT	GEFT	PLOT	PST
ACT	1.00	.85**	.22	-.04	.19
MSAT		1.00	.20	.06	.14
GEFT			1.00	.58**	.18
PLOT				1.00	.34
PST					1.00

\*\*  $p < .01$ .

Prediction of hypothetic-deductive scientific reasoning by field-dependent and field-independent cognitive style

One of the research objectives of the present study was to predict cognitive growth of hypothetic-deductive scientific reasoning by field-dependent and field-independent cognitive styles.

For this objective, the fifth hypothesis was established:

Performance on the Group Embedded Figures Test will predict hypothetic-deductive scientific reasoning on the Piagetian Logical Operations Test.

The following null hypothesis was stated:

Performance on the Group Embedded Figures Test will not predict hypothetic-deductive scientific reasoning on the Piagetian Logical Operations Test.

The null hypothesis was tested with the results on the Piagetian Logical Operations Test (PLOT) and the Group Embedded Figures Test (GEFT). Table 24 indicates that about 34 percent of the variation ( $R^2 = .3383$ ) in cognitive growth of hypothetic-deductive scientific reasoning is explained by linear regression on field-dependent and field-independent cognitive styles.

Table 24 indicates that  $A=10.5097$  and unstandardized  $B=+.2540$ . That is, the predicted score on hypothetic-deductive scientific reasoning is 10.5097 when the degree of cognitive styles = 0, and the predicted score increases by .2540 units on the hypothetic-deductive reasoning score in the PLOT. To obtain a predicted hypothetic-deductive reasoning score ( $Y'$ ) for any given score of cognitive styles as measured by the GEFT, the researcher would employ the A and B constants in the linear prediction equation  $Y' = 10.5097 + .2540X$ .

By varying the scores of cognitive styles as measured by the GEFT, the researcher could obtain a predicted hypothetic deductive scientific reasoning score for each level of field-dependent and field-independent cognitive styles.

All predicted scores will, of course, fall directly on the regression line and will not generally be equal to the actual observed hypothetic-deductive scientific reasoning scores.

Table 24. Bivariate regression of hypothetical-deductive scientific reasoning  
(Dependent) with field-dependent and field-independent cognitive style

		Analysis of variance	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Multiple R	.5816					
R <sup>2</sup>	.3383	Regression	1	44.98	44.98	14.83**
Adjusted R <sup>2</sup>	.3155	Residual	29	87.99	3.03	
Standard error	1.7418					

Variable	B	Beta	Standard error B	F
Cognitive style	.2540	.5816	.0659	14.83
Constant A	10.5097			

\*\* p < .01.

Training effects on hypothetic-deductive scientific reasoning capability by field-dependent and field-independent cognitive style

One of the research objectives of the present study was to identify the training effects on hypothetic-deductive scientific reasoning capability by field-dependent and field-independent cognitive style.

For this objective, the sixth hypothesis was established:

When hypothetic-deductive scientific reasoning is taught using the concrete-inquiry instruction model, field-dependent students will perform as well as field-independent students on the Piagetian Logical Operations Test.

The following null hypothesis was stated:

There is no difference between the mean scores of field-dependent student group and field-independent student group on the immediate posttest of the Piagetian Logical Operations Test.

The null hypothesis was tested with the results on the immediate posttest of the PLOT in the experimental group only. The results of the t-test for the PLOT and the GEFT are reported in Table 25.

Table 25 indicates that the field-independent students have more hypothetic-deductive scientific reasoning than the field-dependent students but the differences are not significant statistically. Therefore, the null hypothesis was sustained ( $t = -1.18$ ,  $p > .05$ ). The researcher interpreted that

the training with the concrete-inquiry instruction model improved students' hypothetic-deductive reasoning capability regardless of the students' cognitive styles.

Table 25. Comparison of means and SDs for t-test between the field-dependent students and the field-independent students on the PLOT in experimental group only

Cognitive styles	N	Mean	SD	t-value
Field-dependent	5	13.80	2.78	- 1.18
Field-independent	24	15.29	1.27	

Training effects on problem solving ability by field-dependent and field-independent cognitive style

One of the objectives of the present study was to identify the training effects on problem solving ability by field-dependent and field-independent cognitive style.

For this objective, the seventh hypothesis was established:

When hypothetic-deductive scientific reasoning is taught using the concrete-inquiry instruction model, the field-dependent students will perform as well as the field-independent students on the Problem-Solving Test.

The following null hypothesis was stated:

There is no difference between the mean scores of the field-dependent and the field-independent students on the immediate posttest of the Problem-Solving Test.



The null hypothesis was tested with the results on the immediate posttest of the Problem-Solving Test in the experimental group. The results of the t-test for the Problem-Solving Test and the Group Embedded Figures Test are reported in Table 26.

Table 26. Comparison of means and SDs for t-test between the field-dependent students and the field-independent students on the Problem-Solving Test in the experimental group only

Cognitive Styles	N	Mean	SD	t-value
Field-dependent	5	3.60	1.14	-2.07*
Field-independent	24	4.92	1.32	

\*  $p < .05$ .

Table 26 indicates that there were significant differences in problem solving ability between field-dependent students and field-independent students ( $t = -2.07$ ,  $p < .05$ ). Therefore, the null hypothesis was rejected. The researcher interpreted that the hypothetic-deductive reasoning training with the concrete-inquiry instruction model failed to improve problem solving ability of field-dependent students as much as that of field-independent students. It is clear that field-independent cognitive style is the important variable.

### Prediction of hypothetic-deductive scientific reasoning

One of the research objectives of the present study was to predict hypothetic-deductive reasoning by other research variables.

For this purpose of the study, the eighth hypothesis was established:

Performance on the Group Embedded Figures Test (cognitive styles), the Problem-Solving Test, American College Test, and the Minnesota Scholastic Aptitude Test will predict hypothetic-deductive reasoning capability on the Piagetian Logical Operations Test.

The following null hypothesis was stated:

Performance on the Group Embedded Figures Test (cognitive styles), the Problem-Solving Test, American College Test, and the Minnesota Scholastic Aptitude Test will not predict hypothetic-deductive reasoning capability on the Piagetian Logical Operations Test.

The null hypothesis was tested with the results on the PLOT, the GEFT, the PST, the ACT, and the MSAT. The F ratio and probability level obtained by multiple regression analysis are summarized in Table 27. Table 27 indicates that the relationship between hypothetic-deductive reasoning and the research variables was positive (Multiple R = .69, F = 5.81,  $p < .01$ ) and that forty-seven percent of the variation in hypothetic-deductive reasoning is explained by cognitive styles, problem solving ability, American College Test scores, and scholastic aptitude scores.

Table 27. Multiple regression analysis of hypothetical-deductive reasoning (Dependent) with cognitive styles (GEFT), problem solving ability (PST), the ACT, and the MSAT

Multiple R	.6870	Analysis of variance	DF	SS	MS	F
R <sup>2</sup>	.4720	Regression	4	62.76	15.69	5.81**
Adjusted R <sup>2</sup>	.3907	Residual	26	70.21	2.70	
Standard error	1.6433					

Independent variables	B	Beta	Standard error B	F
Cognitive style	.2510	.5738	.0645	15.09
Problem-solving ability	.3910	.2848	.2101	3.77
American College Test	-.2130	-.4975	.1158	3.38
Minnesota Scholastic Aptitude Test	.6240	.3289	.0508	1.51
(Constant A)	11.3113			

\*\* p < .01 .

The researcher was concerned with predicting hypothetical-deductive reasoning scores from the four independent variables. Therefore, the researcher employed the A and B values given in Table 27 to obtain the prediction equation.

$$Y' = A + B_1X_1 + B_2X_2 + \dots + B_kX_k$$

$$Y' = 11.3113 + .2510(\text{GEFT score}) + .3910(\text{PST score}) + (-.2130)(\text{ACT score}) + .6240(\text{MSAT score})$$

With this prediction equation, the researcher could compute a predicted hypothetical-deductive reasoning score for any given combination of cognitive styles, problem-solving ability, American College Test score, and the Minnesota Scholastic Aptitude Test score.

The researcher analyzed bivariate regression of the hypothetical-deductive reasoning capability with cognitive styles and problem solving ability. As summarized in Table 24, the cognitive growth of hypothetical-deductive reasoning and cognitive styles correlated at the .01 significant level ( $R=.58$ ,  $F=14.83$ ).

The correlation between cognitive growth of hypothetical-deductive reasoning and problem solving ability was analyzed by the bivariate regression as shown in Table 28. The multiple correlation was .34 and twelve percent of the variation in hypothetical-deductive reasoning is explained by the problem solving ability.

Table 28. Bivariate regression of hypothetical-deductive reasoning (Dependent) with problem solving ability as measured by the PST

Multiple R	.3413	Analysis of variance	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
R <sup>2</sup>	.1165	Regression	1	15.49	15.49	3.82
Adjusted R <sup>2</sup>	.0860	Residual	29	117.48	4.05	
Standard error	2.0127					
Independent variable B	Beta	Standard error B		F		
Problem solving ability	.4681	.3413	.2394	3.82		
(Constant A)	12.2053					

### Prediction of problem solving ability

One of the research objectives of the present study was to predict problem solving ability by other research variables.

For this purpose of the study, the ninth hypothesis was established:

Performance on the Piagetian Logical Operations Test, the Group Embedded Figures Test, American College Test, and the Minnesota Scholastic Aptitude Test will predict problem solving ability measured by the PST.

The following null hypothesis was stated:

Performance on the Piagetian Logical Operations Test, the Group Embedded Figures Test, American College Test, and the Minnesota Scholastic Aptitude Test will not predict problem solving ability measured by the PST.

The null hypothesis was tested with the results on the PST, the PLOT, ACT, MSAT, and the GEFT. The F ratio and probability level obtained by the multiple regression analysis are summarized in Table 29. Table 29 indicates that there was no significant correlation between the problem-solving ability and the other variables (Multiple R = .42, F = 1.38,  $p > .05$ ). The researcher failed to reject the null hypothesis. Only 17 percent of the variation in problem solving ability is explained by the cognitive growth of hypothetic-deductive reasoning, cognitive styles, American College Test scores, and Minnesota Scholastic Aptitude Test scores.

Table 29. Multiple regression analysis of problem solving ability (Dependent) with the PLOT, the ACT, the MSAT, and the GEFT

Multiple R	.4186	ANOVA	DF	SS	MS	F
R <sup>2</sup>	.1752	Regression	4	12.39	3.10	1.38
Adjusted R <sup>2</sup>	.0484	Residual	26	58.32	2.24	
Standard error	1.4977					

Independent variables	B	Beta	Standard error B	F
Hypothetic-deductive reasoning (PLOT)	.3244	.4449	.1670	3.77
American College Test (ACT)	.1254	.4018	.1095	1.31
Minnesota Scholastic Aptitude Test (MSAT)	-.2774	-.2004	.0473	.34
Cognitive Styles (GEFT)	-.4084	-.1283	.0735	.31
(Constant A)	-1.7840			

## CHAPTER V.

## SUMMARY, DISCUSSION AND CONCLUSIONS

## Summary

The purpose of the present study was to test a series of basic hypotheses concerning college students' hypothetic-deductive scientific reasoning of controlling variables as developed by a Piagetian experiment through the concrete-inquiry instruction model. In addition, the possible relationship between the level of cognitive development and the psychological trait of field-dependent and field-independent cognitive style of students was investigated.

To develop the college students' hypothetic-deductive scientific reasoning capability, the Piagetian tasks of pendulum task and bending rods task were selected for the study. These two Piagetian tasks were taught to the subjects of the experimental group by presenting and conducting an experiment with video tape cassette, in which the experimental tasks were contained in a sequence of procedures with the concrete-inquiry instruction model.

The concrete-inquiry instruction model was a highly specified and structured teaching sequence, which consisted of presenting a problem, making a hypothesis, conducting an



inquiry and making a design for solving the problem, conducting an experiment, processing feedback, and developing a summary and conclusion.

The Piagetian Logical Operations Test was used as a criterion measure to assess the treatment's effects and the Problem-Solving Test was also used to evaluate the transfer effects of the treatment for solving the problems in controlling variables in biology, chemistry, and electricity. In addition, the Group Embedded Figures Test was used for measuring students' field-dependent and field-independent cognitive style, which is an independent variable predicting hypothetic-deductive scientific reasoning.

The sample of the present study consisted of 57 freshmen and sophomores at Iowa State University, Ames, Iowa. They were randomly assigned into two groups, 29 for the experimental group and 28 for the control group.

Research data from the posttest and one month delayed posttest of the Piagetian Logical Operations Test and the Problem-Solving Test, and the Group Embedded Figures Test scores were examined to test the nine hypotheses. In addition, the American College Test score and the Minnesota Scholastic Aptitude Test were analyzed to test the hypotheses.

Several types of statistical analyses were conducted to analyze the data. The t-test, the oneway analysis of

variance, and multiple classification analysis were used to test the treatment effect, the retention effect, and the transfer effect of the experiment. The bivariate regression analysis and the multiple regression analysis techniques were used to predict hypothetic-deductive scientific reasoning capability and the problem solving ability by the independent variables.

The findings are presented as follows:

Null hypothesis 1:

There is no difference between the Piagetian Logical Operations Test of the students instructed with the concrete-inquiry instruction model and the students not instructed with the concrete-inquiry instruction model: rejected ( $t=4.14$ ,  $p < .01$ ). The subjects of the experimental group exhibited greater cognitive growth of hypothetic-deductive scientific reasoning by the end of the experiment than the students not instructed with the concrete-inquiry instructional model.

Null hypothesis 2:

There is no difference between the scores of the immediate posttest and the one month delayed posttest of the Piagetian Logical Operations Test: failed to reject ( $t=.79$ ,  $p > .05$ ). The students instructed with a Piagetian experiment through the concrete-inquiry instruction model exhibited the same cognitive growth of

hypothetic-deductive scientific reasoning capability one month after the initial experiment.

Null hypothesis 3:

There is no difference between the Problem-Solving Test scores of the students instructed with the concrete-inquiry instruction model and the students not instructed with the concrete-inquiry instruction model: rejected ( $t=3.79$ ,  $p < .01$ ). The students instructed with a Piagetian experiment through the concrete-inquiry instruction model exhibited greater problem solving ability than the students not instructed.

Null hypothesis 4:

There is no positive correlation between the scores of the Piagetian Logical Operations Test and the Group Embedded Figures Test: rejected ( $R=.58$ ,  $p < .01$ ). There was a positive correlation between cognitive growth of hypothetic-deductive scientific reasoning and field-dependent and field-independent cognitive style.

Null hypothesis 5:

Performance on the Group Embedded Figures Test will not predict hypothetic-deductive scientific reasoning on the Piagetian Logical Operations Test: rejected ( $R^2=.34$ ,  $F=14.83$ ,  $p < .01$ ). Thirty-four percent of the variation in cognitive growth of hypothetic-deductive scientific

reasoning is explained by linear regression on field-dependent and field-independent cognitive style. The students' cognitive style predicted students' cognitive growth of hypothetic-deductive scientific reasoning capability at a statistically significant level of .01.

Null hypothesis 6:

There is no difference between the mean scores of field-dependent and field-independent students on the Piagetian Logical Operations Test: failed to reject ( $t = -1.08$ ,  $p > .05$ ). After hypothetic-deductive scientific reasoning was taught using the concrete-inquiry instruction model, field-dependent students performed as well as field-independent students on the Piagetian Logical Operations Test.

Null hypothesis 7:

There is no difference between the mean scores of field-dependent and field-independent students on the immediate posttest of the Problem-Solving Test: rejected ( $t = -2.07$ ,  $p < .05$ ). After hypothetic-deductive scientific reasoning was taught, field-independent students performed better than field-dependent students on the Problem-Solving Test.

Null hypothesis 8:

Performances on the Group Embedded Figures Test, the Problem-Solving Test, the American College Test, and

the Minnesota Scholastic Aptitude Test will not predict hypothetical-deductive scientific reasoning capability on the Piagetian Logical Operations Test: rejected ( $R = .69$ ,  $R^2 = .47$ ,  $F = 5.81$ ,  $p < .01$ ). Forty-seven percent of the variation in cognitive growth of hypothetical-deductive scientific reasoning is explained by linear regression on cognitive style, problem solving ability, the American College Test scores, and the Minnesota Scholastic Aptitude Test scores. These research variables predicted students' cognitive growth of hypothetical-deductive scientific reasoning capability.

Null hypothesis 9:

Performance on the Piagetian Logical Operations Test, the Group Embedded Figures Test, American College Test, and Minnesota Scholastic Aptitude Test will not predict problem solving ability on the Problem-Solving Test: rejected ( $R = .42$ ,  $R^2 = .18$ ,  $F = 1.38$ ,  $p < .05$ ). Students' hypothetical-deductive scientific reasoning capability, cognitive style, the American College Test scores, and the Minnesota Scholastic Aptitude Test scores did not predict the students' problem solving ability on the Problem-Solving Test.

## Discussions

Cognitive developmental level of the subjects

The results of the present study indicated that 71 percent of the subjects were at the fully developed formal operational level, while 29 percent were not. This result is close to the finding of Barnes (1977), who found that 74 percent of college students were at the formal operational level. Lawson (1973) also found that 78 percent of chemistry students and 64 percent of physics students were at the formal operational level.

But the results of the present study were not consistent with those of the following studies: Ross et al. (1976) found that 48 percent of the college students were at the formal operational level and Juraschek (1974) reported that 48 percent of the prospective elementary school teachers were at the formal operational level. Arons (1976), reporting on students in an introductory physical science course, found "no more than 25 percent have attained the level of formal operations; perhaps 25 percent are in transition between concrete and formal levels; and about 50 percent are essentially concrete operational" (p. 834). Renner (1976) cited research showing that "50 percent of Oklahoma's entering college freshmen and 60 percent of its high school seniors still occupy the concrete operational stage of intellectual development" (p. 219).

It is suspected that these discrepancies are due to the different types of the measurement instruments for testing cognitive development. The present study employed the measuring instrument which was developed by following thoroughly the techniques that Piaget had used, while the other studies employed the Piagetian type tasks, for examples, "Island Puzzle," "Mealworm puzzle," "Mystery object puzzle," "Circuit puzzle," "Bacteria puzzle," etc. It is suspected that these puzzle problems require somewhat more than hypothetic-deductive scientific reasoning capability.

#### Effects of a Piagetian experiment through the concrete-inquiry instruction model

It is obvious that the subjects of the experimental group of the present study profited from the use of the concrete-inquiry instruction model to improve hypothetic-deductive scientific reasoning capability of controlling variables.

The positive results with the experimental group indicated that the instructional sequences and materials of the present study can be effective in enhancing formal operational thought. This conclusion supports Schneider and Renner's (1980) research results, which indicated that greater gains were made in intellectual development by the concrete inquiry instruction group over the formal exposi-

tion group during the experimental procedure. Sheehan (1970) also found that the concrete instruction was of benefit to both concrete and formal operational students.

However, the increment scores of the experimental group were not very high compared with the scores of the control group. It is suspected that because of the ceiling effect on the pendulum task and the bending rods task, the magnitude of the training effects for the tasks could not be high. The underlying evidence was that the 71 percent of the subjects were already at the advanced formal operational level. But this conclusion is opposed to Lawson's (1980b), who found that the concrete operational college students enhanced nearly twice as much as their seventh grade counterparts.

The retention data of hypothetic-deductive scientific reasoning and problem solving ability in the present study expanded somewhat the usefulness of the training effects. This result was different from that of Bredderman (1973), who found that there was no retention of skill in controlling variables when he retested students one month later.

In addition, transfer effects of hypothetic-deductive reasoning on problem solving ability founded in the present study tell us something about the students' hypothetic-deductive reasoning capability to generalize from the tasks learned to others similar in nature. This conclusion was



different from that of Lawson, Blake, and Nordland (1975), who found that students were unable to transfer the skill of controlling variables from one task to another. However, the conclusion of the present study was consistent with Lawson and Wollman's (1977), who found that there was some transfer of the skill to novel situations with seventh grade students.

#### Functional aspects of cognitive development and cognitive style

The research data of the present study imply that there was a positive correlation between the cognitive growth of hypothetic-deductive reasoning capability and field-dependent and field-independent cognitive style. This conclusion is consistent with Ghuman's (1977), who found that there are significant correlations between Witkin's dimension and the cognitive variables, including factor B of the Children's Personality Questionnaire (CPQ).

These results supported Lawson and Wollman's (1977), which generated the conclusion that there are high correlations between the Group Embedded Figures Test and the bending rods and the balance beam tasks. These results also support Pascual-Leone's research (1969), which found that success on many of Piaget's concrete operational tasks was significantly restricted by field-dependence. Even adult

field-dependent subjects did poorly on concrete conservation and class inclusion tasks.

However, research data of the present study suggest that field-dependent subjects' restriction in cognitive processes can be eliminated by the training of hypothetic-deductive scientific reasoning. The research data of the present study indicated that after training, field-dependent students performed as well as field-independent students on the hypothetic-deductive scientific reasoning problems.

One of the important findings in the present study was that 34 percent of the variation in cognitive growth of hypothetic-deductive scientific reasoning capability is explained by linear regression on field-dependent and field-independent cognitive style.

This conclusion is interpreted that there is a positive correlation between field-dependence-independence cognitive style and the student's hypothetic-deductive scientific reasoning. And the 34 percent indicates that the proportion of variance in the variable of hypothetic-deductive scientific reasoning is "explained" by the variable of field-dependence-independence cognitive style.

### Conclusions

The major conclusions fo the present study are summarized as followings:

1. There were not many college students who have not fully developed formal operational thought. Seventy-one percent of the subjects were already at the advanced formal operational level, while twenty-nine percent of the subjects were at the preformal operational thought level.
2. Cognitive growth of hypothetic-deductive scientific reasoning can be enhanced by a Piagetian experiment through the concrete-inquiry instruction model.
3. The improved hypothetic-deductive scientific reasoning capability had a retention effect one month after the initial experiment.
4. There was some transfer of hypothetic-deductive scientific reasoning capability to novel problem solving situations with college students.
5. There was a positive correlation between the cognitive growth of hypothetic-deductive scientific reasoning and field-dependence-independence cognitive style.
6. Field-dependence-independence cognitive style is one of the important factors predicting performance on hypothetic-deductive scientific reasoning capability.

### Implications for Curriculum and Instruction

The implications of these findings for curriculum and instruction are challenging. Piaget has consistently maintained that the order in which a person moves through the stages in his intellectual development model should be constant, and in order to move from stage to stage the individual must be confronted only with those activities and situations which can be understood by him in this present stage. Thus a concrete operational thinker does not become formal operational by constantly being confronted with formal operational tasks and concepts; he must meet situations which are at the concrete level but which also will add to and challenge his thinking ability to promote progress to higher levels.

A significant amount of the subject matter of science requires formal operational thought. Understanding of hypothetic-deductive proportional reasoning, for instance, is needed in numerous physical and biological concepts and principles such as gravitational acceleration, air pressure, the chemical law of definite composition, and diffusion.

Hypothetic-deductive combinational reasoning is required for comprehension of Mendelian genetics and for an understanding of the nature of probability. Hypothetic-deductive correlational reasoning represents the cornerstone of much

of the descriptive investigative work or the biologist and psychologist (e.g., is there a relationship between smoking and lung cancer, intelligence and students' academic achievements, or between CO<sub>2</sub> concentration and phytoplankton?). Hypothetic-deductive reasoning of controlling variables is required for conducting various experiments in biology, chemistry, psychology, and physics.

The research reported in the present study indicates that the acquisition and transfer of hypothetic-deductive scientific reasoning can be facilitated through the concrete-inquiry instruction model. These results suggest that cognitive development of hypothetic-deductive scientific reasoning can be changed and improved through a highly specified instructional sequence. And the enhanced hypothetic-deductive scientific reasoning facilitates not only the comprehension of concepts that incorporate some scientific reasoning and logic, but also the solution of the problems that required some scientific reasoning capability and logical thinking presented in the classroom learning setting.

These results indicate that the acquisition and transfer of Piaget's formal operational thought can be facilitated through the concrete-inquiry instructional sequence. The instruction model of the study can develop the strategies for improving students' academic achievements as well as formal operational thought.

This conclusion implies that classroom learning situations should provide a variety of increasingly complex experiences that allow students to question, explore, attempt to make hypothesis, and attempt to discover and inquire about meaningful concepts involved in those experiences.

Furthermore, the research data indicate that the concrete-inquiry instruction model may help foster field-dependent students to understand scientific concepts as well as field-independent students.

This conclusion suggests that classroom situations that allow students to confront problems, share experiences and views, examine alternatives, and search for resolutions would help students avoid being dominated by the immediate content of those problems and would do much to enhance both cognitive development of formal operational thought and cognitive style of field-dependence-independence.

Finally, transfer effect of training on problem solving provides evidence that the initial hypothesis of the present study is true, that is, that if educational programs are overtly designed to foster cognitive development of formal operational thought, the understanding of the learning material from any discipline that "must" be taught will be the concomitant outcome.

### Suggestions for Further Research

Based on the findings from the present study, the following recommendations for further study are made:

1. Replication of this study involving the concrete operational student group and the formal operational group simultaneously may substantiate the findings here and provide a broader base for generalizations.
2. To identify the training effects on subject matter, a study can be conducted using the concrete-inquiry instruction model focusing on school achievement, particularly science education.
3. A similar study can be done comparing junior high school (8th grade), senior high school (11th grade), and college students to provide a broader base for generalizations about cognitive developmental level.
4. Attempts can be made to develop other skills of formal reasoning, such as syllogistic reasoning, propositional thinking, and reflexive thinking etc., using the concrete-inquiry instruction model to provide a broader base for generalizations about different types of formal operational tasks.
5. A similar study can be conducted comparing the concrete-inquiry instruction model with the other instructional sequences to compare the effects of the instructional sequences.

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APPENDIX A: INFORMED CONSENT FORM FOR EXPERIMENTAL GROUP

INFORMED CONSENT FORM

Purpose of the experiment: To identify learning abilities between the experimental group and the control group

Procedure: Each student will view two video tape cassettes about controlling variables of pendulum task and bending rods task. These tapes will direct the student to do several simple pendulum and bending rods experiments. Each student also will take the Piagetian Logical Operations Test (PLOT) for testing scientific reasoning, the Problem-Solving Test (PST) for testing problem solving abilities, and the Group Embedded Figures Test (GEFT) for testing cognitive style. Total time is approximately two hours.

Risks: There are no risks in this experiment. If one feels uncomfortable participating in the experiment situation, she/he can choose not to volunteer.

I, \_\_\_\_\_ have read and understand the points listed above. I understand that any questions I have regarding this experiment will be answered by the experimenter. I also understand that I can choose not to participate in this experiment at any time. I understand that all data will be confidential and that the assignment of a random subject ID number will help the researcher analyze the data. These numbers will then be destroyed.

If you agree to participate in the study, please sign and data blank spaces on this consent form.

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Signature

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Month / Date / Year

APPENDIX B: INFORMED CONSENT FORM FOR CONTROL GROUP

INFORMED CONSENT FORM

Purpose of the experiment: To identify learning abilities between the experimental group and the control group

Procedure: Each student will take two paper and pencil tests; the Piagetian Logical Operations Test (PLOT) for testing scientific reasoning, and the Problem-Solving Test (PST) for testing problem solving abilities.

Risks: There are no risks in these tests. If one feels uncomfortable participating in the test situation, she/he can choose not to volunteer.

I, \_\_\_\_\_ have read and understand the points listed above. I understand that any questions I have regarding these tests will be answered by the tester. I also understand I can choose not to participate in these tests at any time. I understand that all data will be confidential and that the assignment of a random subject ID number will help the researcher analyze the data. These numbers will then be destroyed.

If you agree to participate in the study, please sign and date blank spaces this consent form.

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Signature

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Month / Date / Year

APPENDIX C: SCRIPT FOR PENDULUM TASK

A PIAGETIAN EXPERIMENT WITH THE CONCRETE-INQUIRY INSTRUCTION MODEL

1. Major skill to be taught:

Hypothetic-deductive reasoning capability of controlling variables

2. Instructional objective:

Given a relative complex problem situation, the student will be able to conduct an individual experiment of controlling variables by making a hypothesis, a valid comparison, a fair test, and the empirical verifications for solving the problem.

3. Learning tasks to be taught: Pendulum task and bending rods task

4. Teaching method to be used:

Individual experiment with the concrete-inquiry instruction model using video tape cassette presentations

5. Instructional procedures of the concrete-inquiry instruction model

- (1) Presenting problem
- (2) Forming hypothesis
- (3) Designing and experimenting
- (4) Feedback
- (5) Summary and conclusion

SCRIPT FOR PENDULUM TASK

VIDEO

AUDIO

Title:

" A piagetian experiment through  
the concrete-inquiry instruction  
model"

Subtitle:

" Controlling variables"

Instructor

A pendulum apparatus

A string of the pendulum

A pendulum bob

Music

Music

Today, I would like to introduce you to the way  
scientists think. Scientists, like many other  
people, use logical thinking. Studying logical  
thinking is of considerable importance to stu-  
dents who want to do scientific or other work  
that requires manipulation of variables

Now, I am going to begin with this appara-  
tus. Do you know what this is called? This is  
called a pendulum. Compare yours with this one.

As you can see the pendulum consists of a  
string from this stand and the pendulum bob that  
can be hooked on the end of the string. This is  
called the string end of the pendulum and this is  
called a pendulum bob. Notice that yours is



The 20cm long string with  
the 20g weighted pendulum  
bob.

The stopwatch

The pendulum bob is swinging

" FREQUENCIES "

PUSH THE PAUSE BUTTON  
AND  
BEGIN YOUR OWN EXPERIMENT

similar to this one. This pendulum bob swings like the pendulum bob of the wall clock. If you push it like this, the pendulum bob swings back and forth.

Now, I will show you how many times this pendulum bob swings for a certain length of time. Let's count the number of swings of the pendulum bob for 5 seconds. The length of string is 20cm long and the weight of the pendulum bob is 20g. I will release the bob at this point of height. Let's count the number of the swings for just 5 seconds with this stopwatch. You can use the stopwatch provided for you. Set the stopwatch to begin and push the pendulum bob like this. One, two, three, four, five. This time, the pendulum bob swings 5 times for 5 seconds. This number of the swings is called the frequency.

From now on, I am going to ask you to do a series of experiments with your pendulum. I will demonstrate the way you are to do the experiments. Then I will show you this card which contains the following directions: push the pause button and begin your own experiment when I want you to begin when you see this sign push the pause

The worksheet

The pause button on VTR deck

"WHAT ARE THE POSSIBLE FACTORS WHICH MIGHT AFFECT THE FREQUENCIES OF THE PENDULUM BOB? "

button on your VTR deck and begin your own experiment as the sign indicated. Observe your experiment and measure the results of the experiment. Record your data from the experiment on the worksheet that has been provided for you. When you have completed your experiment, push the pause button on the VTR deck again and we will go on to the next steps.

From the previous demonstration I performed for you, you have seen that the 20 cm long string with the 20 g pendulum bob swings 5 times in 5 seconds. Now, I would like to ask you a question. What affects the number of times the pendulum will swing back and forth in a 5 seconds period of time? Can you guess the possible factors which might affect the frequencies of the pendulum bob?

Push the pause button on VTR deck and begin the experiment, and answer question number one on your worksheet.

With a series of the experiments, you can test the following variables to determine the effect each has on the number of the swings of the pendulum. Compare your own results of the experiment. Take a look at the following variables.

1. THE LENGTH OF THE STRING
2. THE WEIGHT OF THE PENDULUM BOB
3. THE HEIGHT AT WHICH THE PENDULUM BOB IS RELEASED, AND
4. THE FORCE USED TO IMPEL THE PENDULUM BOB

- (1) The length of the string
- (2) The weight of the pendulum bob
- (3) The height at which the pendulum bob is released, and
- (4) The force used to impel the pendulum bob.

These four variables might affect the frequency of the pendulum bob. So, they are called the independent variables. And the frequency of the pendulum is affected by these four variables. So, the frequency of the pendulum is called a dependent variable. We can summarize the relationship between the independent variables and the dependent variable like this.

THE INDEPENDENT VARIABLE	THE DEPENDENT VARIABLE
l	
w	..... F
h	
f	

l denotes the length of the string, w denotes the weight of the pendulum bob, h denotes the height at which the pendulum bob is released, f denotes the force used to impel the pendulum bob, and the dependent variable, which is used the capital letter F denotes the frequency of the pendulum bob in a certain amount of time.

Now, can you suppose which variable really affects the frequency of the pendulum? If you think one of the four variables will affect the frequency of the pendulum, how can you test it?

If X, then Y.

If we vary the independent variable X, then the dependent variable Y will vary.

If X, then Y.

If we vary the force used to impel the pendulum bob, then the frequency of the pendulum bob will vary.

Before testing the assumption, you should devise a hypothesis about the assumption. You can establish the hypothesis by using "If X, then Y." formula. For example, "If we vary the independent variables X, then the dependent variable Y will vary."

Now, let's suppose that the force used to impel the pendulum bob affects the frequency of the pendulum bob. Can you devise a hypothesis about this assumption? Establish your own hypothesis by using "If X, then Y." formula. Push the pause button on the VTR deck and write your hypothesis on the line of question two on your worksheet.

Okay, good. As you write down your hypothesis on the worksheet, we can establish the hypothesis like this, "If we vary the force used to impel the pendulum bob, then the frequency of

the pendulum bob will vary." Compare your hypothesis on the worksheet with this one.

If you made your own hypothesis like this one, test whether our hypothesis is true or not. You can test your hypothesis by counting the frequency of the pendulum bob in a certain amount of time. Use your pendulum with a 20cm long string and a 20g weighted pendulum bob, those are provided for you. Count the frequencies of the pendulum bob for just 5 seconds by using the stopwatch. After testing your hypothesis, answer question 3, 4, and 5 on your worksheet. Push the pause button on the VTR deck and begin your experiment when I show you this card.

The 20cm long string with  
the 20g pendulum bob

Push the pause button.

The 20cm long string with  
the 20g pendulum bob

Now, let's review the process of testing the hypothesis on your experiment. First, tie the 20cm long string on the pendulum stand and hook the 20g weighted bob like this. I am going to release the bob at this height. The first time I

Push the bob slightly.

The pendulum bob swings 5 times in 5 seconds.

All the variables except the force to impel the bob must be controlled as constant.

Push the bob harder than the first time.

will push the bob slightly like this and count the frequency for just 5 seconds. Set the stopwatch to begin and get ready, go. One, two, three, four, five, stop counting. The pendulum bob swings 5 times in 5 seconds. Now, I'll push the bob harder than the first time. Be sure that all the variables except the force to impel the bob are to be controlled. The other variables, except pushing the bob, must be held constant. So, the length of the string, the weight of the pendulum bob, and the height at which the pendulum bob is released are the same as the time before. However, the second push is different from the first push. Let's push the bob harder than the first push and count the frequency of the first push. Set the stopwatch to begin and get ready, go. One, two, three,

The pendulum bob swings 5 times in 5 seconds.

The different forces used to impel the pendulum bob did not affect the frequency of the pendulum bob.

<u>The independent Variables</u>	<u>The dependent Variable</u>
l,	
w,	
h,	
f, $\bar{f}_1$ , $\bar{f}_2$ , .....	$\rightarrow$ F (Frequency is not changed)

four, five. This time the pendulum bob swings 5 times in 5 seconds. The results are the same as that of the first push. So, we can say that the different forces used to impel the pendulum bob do not affect the frequency of the pendulum bob.

From our experiment, we can summarize the results of the experiment like this.

l, w, h, and f denote the original length, weight, height, and force respectively. But  $\bar{f}_1$  and  $\bar{f}_2$  denote the first (push slightly) and the second (push more strongly) push of the pendulum bob. From the results of the experiment we can conclude that the different kinds of forces used to impel the pendulum bob do not affect the frequency of the pendulum bob. How do these results compare to the ones you recorded on your worksheet? Push the

The different heights might vary the frequency of the pendulum bob.

If we vary the height at which the pendulum bob is released, then the frequency will vary.

pause button and compare those items.

Next, suppose that the different height at which the pendulum bob is released will vary the frequency of the pendulum bob. Now, to make this point more clear, it is best to make a hypothesis concerning this point of view. Establish your own hypothesis and write it down on the line of question number 6 on your worksheet. Push the pause button and do that.

After you write your hypothesis on the worksheet, we can establish a hypothesis this way: "If we vary the height at which the pendulum bob is released, then the frequency will vary." Compare your hypothesis with this one.

Now, can you test whether this hypothesis is true or not? Do test your own hypothesis with the equipment provided for



Be sure that all the independent variables except the height are controlled as constant.

you. You can test your hypothesis by counting the frequency of the pendulum bob in 5 seconds. Be sure that the independent variable which you have to manipulate is the height at which you release the pendulum bob. You can also use the stopwatch provided for you to count the complete swings of the pendulum bob exactly. After the experiment, write your data on question numbers 7 and 8, and make your conclusion on the line of question number 9. Push the pause button and do your experiment with the pendulum again.

Now, let's review the process of testing the hypothesis on your experiment. Here, we have a pendulum with the 20cm long string and the 20g weighted bob like this. This time we have to manipulate the independent variable of the height at

The length of the string,  
the weight of the pendulum bob, and  
the force used to impel the pen-  
dulum bob must be the same as  
the time before.

Release the pendulum bob at  
the half height.

The pendulum bob swings 5 times  
in 5 seconds.

Release the pendulum bob at  
the full height.

The pendulum bob swings 5 times  
in 5 seconds.

which we release the pendulum bob while  
controlling the other independent varia-  
bles. In other words, the length of the  
string, the weight of the pendulum bob,  
and the forces used to impel the pendulum  
bob are all the same as in the former ex-  
periment. First, we can count the frequen-  
cy of the bob in 5 seconds when we release  
the pendulum bob at half height like this.  
Now, are you with me? Set the stopwatch  
and get ready, go. One, two, three, four,  
and five. The pendulum bob swings 5 times  
in 5 seconds. This time, however, I'll  
release the pendulum bob at the full height  
like this. Set the stopwatch again and  
get ready, go. One, two, three, four, and  
five. This time the pendulum bob swings  
5 times in 5 seconds again. We've got the  
same results for the experiment we had the

<u>The independent variables</u>	<u>The dependent variable</u>
l,	
w,	
h, h <sub>1</sub> , h <sub>2</sub> , .....	F
f,	(Frequency is not changed)

Different weights might vary the frequency of the pendulum bob.

time before.

From our experiment, we can summarize the results like this.

From this summary of the experiment on the board, we can conclude that the different heights at which the pendulum bob is released don't affect the frequency of the pendulum bob. So, the hypothesis "If we vary the height at which the pendulum bob is released, then the frequency of the pendulum bob will vary " has been proved to be a false hypothesis. Compare this one to your own result.

We can suppose that the different weights of the pendulum bob might vary the frequency of the pendulum bob. Can you make a hypothesis about this problem? Establish your own hypothesis on question number 10 of your worksheet. Push the pause

If we vary the weight of the pendulum bob, then the frequency of the pendulum bob will vary.

The 20g weighted pendulum bob

The 50g weighted pendulum bob

button on the VTR deck and write down your hypothesis.

We can establish the hypothesis like this: "if we vary the weight of the pendulum bob, then the frequency of the pendulum bob will vary." Compare this to your own hypothesis.

Now test whether your hypothesis is true or false. Be sure that the independent variable which you manipulate this time is the weight of the pendulum bob. You can use the 20g weighted pendulum bob and the 50g weighted pendulum bob respectively. You can also test our hypothesis by counting the frequency of the pendulum bob with the stopwatch. After the experiment, write down your data on question No. 11 and 12, and make your own conclusion

The 20cm long string with  
the 20g weighted pendulum bob.

The 20cm long string with  
the 50g weighted pendulum bob.

Be sure that all the independent  
variables except the weight of the  
pendulum bob are controlled.

on the line of question number 13 on  
your worksheet. Push the pause button  
and do your own experiment.

Now, let's review the process of test-  
ing the hypothesis of your experiment. As  
you know, to test the hypothesis we have  
to use two different weights for the  
pendulum bob. One is the 20g weighted bob  
and the other is the 50g weighted pendulum  
bob. Be sure that the other independent  
variables are held constant. In other words,  
the length of the string, the height at  
which the pendulum bob is released, and  
the forces used to impel the pendulum bob  
must be the same as before. First I'll  
hook the 20g weighted pendulum bob to the  
end of the 20cm long string like this and  
push the bob. Set the stopwatch to begin

The pendulum swings 5 times  
in 5 seconds.

The 20cm long string with  
the 50g weighted pendulum bob.

The pendulum bob swings 5 times  
in 5 seconds.

<u>The independent variables</u>	<u>The dependent variable</u>
l,	
w, $\bar{w}_1$ , $\bar{w}_2$ , .....	F
h,	(Frequency is not changed)
f,	

and get ready, go. One, two, three, four, and five. We have 5 swings of the pendulum bob in 5 seconds. Next, I'll replace the 20g bob with the 50g bob. Hook the 50g weighted pendulum bob to the end of the 20cm long string like this and push the pendulum bob. Set the stopwatch to begin and get ready, push. One, two, three, four, and five. Once again, we've got the same results as before. The pendulum bob swings 5 times in 5 seconds. There are no differences between the two experiments. So, from our experiment, we can summarize the results of the experiment like this.

From this, we can conclude that the different weights of the pendulum bob don't affect the frequency of the pendulum bob. So, the hypothesis we made has been proved to be a false hypothesis. Did you

The different length of the string might vary the frequency of the pendulum bob.

If we vary the length of the pendulum string, then the frequency of the pendulum bob will vary.

get the same data and the same conclusion? Compare this to your own result of the experiment. So, push the pause button.

Last, we can suppose that the different length of the string might vary the frequency of the pendulum bob. Can you make a hypothesis about this problem? Establish your own hypothesis on question No. 14 of the worksheet. Push the pause button on the VTR deck and write down your hypothesis.

Did you make your hypothesis? We can establish the hypothesis like this; "if we vary the length of the pendulum string, then the frequency of the pendulum bob will vary." Compare this to your hypothesis.

Now, test your hypothesis. Be sure that the independent variable which you

this time manipulate is the length of the string. You can use two lengths of the string. You can also test your hypothesis by counting the frequency of the pendulum bob with the stopwatch. After the experiment, write down the data on question No. 15 and 16, and answer question No. 17 of the worksheet.

Now, let's review the process of testing the hypothesis of your experiment. As you know, to test the hypothesis we must use two lengths of string. One is the 10cm long string and the other one is the 30cm long string. Be sure that the other independent variables are held constant. In other words, the weight of the pendulum bob, the height at which the pendulum bob is released, and the forces used to impel the pendulum bob must be the same as before. So, first I'll tie the 10cm long string on the

The 10cm long string with  
the 20g pendulum bob.  
The 30cm long string with  
the 20g pendulum bob.

Be sure that all the independent variables except the pendulum string are held as constant.



The 10cm long string with the 20g weighted pendulum bob.

The 10cm long string swings 7 times in 5 seconds.

The 30cm long string with the 20g weighted pendulum bob.

The 30cm long string with the 20g weighted pendulum bob swings 4 times in 5 seconds.

stand and then I'll hook the 20g weighted pendulum bob on the end of the string like this. Now, count the frequency of the pendulum bob for 5 seconds. So, set the stopwatch to begin and ready, go. One, two, three, four, five, six, and seven. The pendulum bob swings 7 times in 5 seconds. Now, I want to replace the 10cm long string with the 30cm long string on the pendulum string and hook the 20g weighted bob on the end of the string. So, let's count the frequency of the pendulum bob for 5 seconds again. Set the stopwatch to begin and ready, go. One, two, three, four. This time, the pendulum bob swings just 4 times in 5 seconds. So, we can say that the different lengths of the string of the pendulum affect the frequency of the pendulum bob. Once again, the different length of the

<u>The independent variables</u>	<u>The dependent variable</u>
$l, l_1, l_2, \dots$	$F$
$w,$	(Frequency is changed)
$h,$	
$f,$	

pendulum string affects the frequency of the pendulum bob.

So, from our experiment, we can summarize the outcomes of the experiment like this.

From the summary of the experiment, we've noted that  $\bar{l}_1 \text{ -- } \bar{F}_1$  and  $\bar{l}_2 \text{ --- } \bar{F}_2$ . We can presume also that if we vary the length of the string like  $\bar{l}_3, \bar{l}_4$ , and so on, then the frequency will vary like  $\bar{F}_3, \bar{F}_4$ , and so on. Now, we are in a position to formulate the hypothesis that the frequency of the pendulum bob is related to the length of the string. Compare this result to your own result and complete the items. Push the pause button.

Thus far, we have manipulated the variables to see how the four independent variables affect the dependent variables.

The combination effects of two independent variables on the one dependent variable.

Choose two independent variables and make the possible hypothesis.

Now, let's think about the combination effects of two or three independent variables on the dependent variable. So far, we have made a hypothesis and an experiment concerning an effect of one independent variable on one dependent variable. However, we can suppose the concomitant variation of both the length of the string and the weight of the pendulum bob will affect the frequency of the pendulum bob. From time to time, we want to identify which independent variable affects the dependent variables in real life situations. For example, among the variables, which relevant variable affects the frequency of the pendulum bob?

For now, choose two independent variables among the four and establish the possible hypothesis. Devise an experiment for testing your hypothesis. You use all

of the string, the weights of the pendulum bobs, the heights at which the pendulum bob is released, and the forces used to impel the pendulum bob. The dependent variable is the frequency of the pendulum bob. Push the pause button on the VTR deck and conduct your own experiment. Write down the hypothesis, data, and conclusion on your worksheet.

Did you finish your experiment? Now, let's review the process of the experiment together. To review the process of the experiment including the concomitant variables on the dependent variable, I would like to choose two independent variables for our example: the length of the string and the weight of the pendulum bob.

First, we must establish a hypothesis

The concomitant effects of the length of the pendulum string and the weight of the pendulum bob.

If we vary both the length of the pendulum string and the weight of the pendulum bob simultaneously, then the frequency of the pendulum bob will vary.

The 30 cm long string with the 20 g weighted pendulum bob.

The pendulum bob swings 4 times in 5 seconds.

about these two independent variables, as follows: "If we vary both the length of the pendulum string and the weight of the pendulum bob simultaneously, then the frequency of the pendulum bob will vary." Push the pause button on the VTR deck and compare this to your own hypothesis.

Now, let's devise an experiment for testing your hypothesis. First, tie the 30 cm long string on the stand and the 20 g bob on the end of the string like this. Let's push the bob and count the number of swings of the bob. Set the stopwatch and get ready, go. One, two, three, and four. The pendulum bob swings four times in 5 seconds. Now, remember that. Now, this time, let's replace the 20 g bob with the 50 g weighted pendulum bob and hook it on

The 30cm long string with the  
50g weighted pendulum bob.

The pendulum bob swings 4 times  
in 5 seconds.

The 10cm long string with the  
20g weighted pendulum bob.

Be sure that all the independent  
variables except the manipulating  
variables must be held constant.

the end of this 30cm long string again.  
Push and count the frequency of the bob  
for 5 seconds. I'll release this bob at  
this half height the same as before. Set  
the stopwatch and ready, and go. One, two,  
three, and four. This time we obtain the  
same data. The pendulum bob swings 4 times  
in 5 seconds.

This time around, let's replace the  
30cm long string with the 10cm long string.  
Hook the 20g bob on the end of the string  
like this. I'll release the bob at this  
height using the same push as before. Be  
sure that the other variables except the  
manipulating variables are held constant.  
Watch the bob carefully and count the fre-  
quency for just 5 seconds. Are you ready,  
go. One, two, three, four, five, six,  
seven. The pendulum bob swings 7 times

The pendulum bob swings 7 times  
in 5 seconds.

The 10cm long string with the 50g  
weighted pendulum bob.

The pendulum bob swings 7 times  
in 5 seconds.

<u>The independent variables</u>	<u>The dependent variable</u>
$l, \bar{l}_1, \bar{l}_2, \dots$	$F, \bar{F}_1, \bar{F}_2$
$w, \bar{w}_1, \bar{w}_2, \dots$	
$h,$	
$f,$	

in 5 seconds. Now, let's replace the 20g weighted bob with the 50g weighted bob and hook it on the end of the 10cm long string the same as before. I'll release the bob at this height with the same push as before. Set the stopwatch and count the frequency for just 5 seconds. Are you ready, go. One, two, three, four, five, six, seven. This time the pendulum bob also swings 7 times in 5 seconds. We obtain the same data as before. From our data of the experiment, we can summarize the results of the experiment like this:

As you can see from the summary, the concomitant variation of both the length of the string and the weight of the pendulum bob have affected the frequency of the pendulum bob. Our hypothesis is proved to be true. However, we've shown

The length of the pendulum string affects the frequency of the pendulum bob.

The long string swings slowly and the short string swings fast.

The combination effects of two independent variables on the dependent variable.

that the relevant independent variable, the length of the string, is the only variable which can affect the dependent variable. So, in other words, the long string with the bob swings slowly and the short string with the bob swings fast. So, we are in a position to formulate the hypothesis that the frequency of the pendulum bob is related to the length of the string.

Now, let's conduct another experiment concerning the combination effects of two independent variables on the dependent variable. Choose another two independent variables among four again, and establish the possible hypothesis. After that, conduct the experiment for testing your hypothesis again. You can also use all the strings, the weight of the pendulum bobs, the height



at which the bob is released, and the forces used to impel the pendulum bob. Push the pause button on the VTR deck, write down the hypothesis, and conduct the experiment. After your experiment, write down the data and make your own conclusion of the experiment.

Now, let's review the process of the experiment again. To conduct another experiment, I'll choose two independent variables. One is the weight of the pendulum bob and the other one is the height at which the pendulum bob is released.

First, with these two independent variables I can make the hypothesis like this: "If we vary both the weight of the pendulum bob and the height at which the pendulum bob is released, then the frequency of the pendulum bob will vary."

The concomitant effects of the weight of the pendulum bob and the height at which the pendulum bob is released.

If we vary both the weight of the pendulum bob and the height at which the pendulum bob is released, then the frequency of the pendulum

will vary.

Be sure that all the variables except the weight of the pendulum bob and the height at which the pendulum bob is released are controlled as constant.

First, release the 20g bob at the half height.

The pendulum bob swings 5 times in 5 seconds.

Second, release the 20g bob at the full height.

The pendulum bob swings 5 times in 5 seconds.

Now, let's conduct an experiment for testing the hypothesis. Be sure that all variables except the weight of the pendulum bob and the height at which the pendulum bob is released are controlled. The other two independent variables must be held constant. So, I'll tie the 20cm long string on the stand like this, and first I will hook the 20 g weighted bob and, release the bob at the half height like this. Now, set the stopwatch to begin and ready, go. One, two, three, four, and five. The pendulum bob swings 5 times in 5 seconds. Now, this time I'll release the the 20g bob at the full height like this. Set the stopwatch again and count the number of swings in just 5 seconds. Get ready, go. One, two, three, four, and five. This time the pendulum bob also swings 5 times in 5

Replace the 20g bob with 50g bob.

First, release the 50g bob at the half height.

The pendulum bob swings 5 times in 5 seconds.

Second, release the 50g bob at the full height.

The pendulum bob swings 5 times in 5 seconds.

The independent variables

l,

w,  $\bar{w}_1$ ,  $\bar{w}_2$ , .....

h,  $\bar{h}_1$ ,  $\bar{h}_2$ , .....

f,

The dependent variable

F,  $\bar{F}_1$ ,  $\bar{F}_2$

seconds. We've got the same results from two experiments. Now, I would like to replace the 20g weighted pendulum bob with the 50g weighted one. And first I'll release the 50g bob at the half height like this. Now, get ready, and go. One, two, three, four, and five. This time also the pendulum bob swings 5 times in 5 seconds. Now, let's release the 50g weighted bob at the full height like this. Let's count the frequency for just 5 seconds again. Stopwatch, get ready, get set and go. One, two, three, four, and five. This time also the pendulum bob swings only 5 times in 5 seconds. We've got the same data all the time in this experiment. Therefore, we can summarize the results of the experiment in this way.

As you can see from the summary, the concomitant variation of both the weight

The concomitant variation of both the weight of the pendulum bob and the height at which the pendulum bob is released did not affect the frequency of the pendulum bob.

of the pendulum bob and the height at which the pendulum bob is released have not affected the frequency of the pendulum bob. So, our hypothesis is proved to be false. The concomitant variation of both the weight of the pendulum bob and the height at which the pendulum bob is released do not affect the frequency of the pendulum bob. From the results of the experiments we did, we have learned that the only relevant independent variable which can affect the dependent variable is the length of the pendulum string.

APPENDIX D: WORKSHEET I FOR PENDULUM TASK

WORKSHEET I  
FOR  
INDIVIDUAL EXPERIMENTATIONS USING VIDEO-TAPE PRESENTATION

(PENDULUM TASK)

ID NUMBER: \_\_\_\_\_

BIRTH DATE: \_\_\_\_\_

TODAY'S DATE: \_\_\_\_\_

SEX: MALE \_\_\_\_\_ FEMALE: \_\_\_\_\_

MAJOR: \_\_\_\_\_

INPUT TIME

Starting time: \_\_\_\_\_

Ending time: \_\_\_\_\_

PENDULUM TASK

1. What makes the frequency of the pendulum bob greater or less? Write four possible factors involving the pendulum task which might affect the number of swings of the pendulum bob.

- (1) \_\_\_\_\_  
(2) \_\_\_\_\_  
(3) \_\_\_\_\_  
(4) \_\_\_\_\_

- I. Experiment involving the forces used to impel the pendulum bob.

2. Write down your own hypothesis on the lines.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

3. Pendulum bob which was pushed slightly:

The number of complete swings of the 20g pendulum bob with a 20cm long string in 5 seconds is \_\_\_\_\_

4. Pendulum bob which was pushed harder than first time:

The number of complete swings of the 20g pendulum bob with a 20cm long string in 5 seconds is \_\_\_\_\_

5. Write down your conclusion from the experiment.

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II. Experiment involving the height at which the pendulum bob is released.

6. Write down your hypothesis in this case.

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7. Pendulum bob at the half height:

The number of complete swings on the 20g pendulum bob with a 20cm long string in 5 seconds is \_\_\_\_\_

8. Pendulum bob at the full height:

The number of complete swings on the 20g pendulum bob with a 20cm long string in 5 seconds is \_\_\_\_\_

9. Write down your conclusion from this experiment.

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III. Experiment involving the weight of the pendulum bob.

10. Write down your hypothesis in this case.

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11. The number of complete swings of the 20g pendulum bob with a 20cm long string in 5 seconds is \_\_\_\_\_.
12. The number of complete swings of the 50g pendulum bob with a 20cm long string in 5 seconds is \_\_\_\_\_.
13. Write down your conclusion from this experiment.

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IV. Experiment involving the length of the string.

14. Write down your hypothesis on this problem.

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15. The number of complete swings of the 20g pendulum bob with a 10cm long string in 5 seconds is \_\_\_\_\_.
16. The number of complete swings of the 20g pendulum bob with a 30cm long string in 5 seconds is \_\_\_\_\_.
17. Write down your conclusion from this experiment.

---

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V. Experiment involving the concomitant effects of both the length of the string and the weight of the pendulum bob.

18. Write down two independent variables that you have chosen

(1) \_\_\_\_\_

(2) \_\_\_\_\_

19. Write down your hypothesis on this problem.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

20. Write down your experimental design for testing the hypothesis.

21. Write down the data you've got in this experiment.

22. Write down your conclusion from this experiment.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

VI. Another experiment involving the concomitant effects of two independent variables.

23. Write down two independent variables that you have chosen for your experiment.

(1) \_\_\_\_\_

(2) \_\_\_\_\_

24. Write down your hypothesis on this problem.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

25. Write down your experimental design for testing the hypothesis.

26. Write down the data that you've got in this experiment.

27. Write down your conclusion from this experiment.

\_\_\_\_\_  
\_\_\_\_\_

APPENDIX E: SCRIPT FOR BENDING RODS TASK

SCRIPT FOR BENDING RODS

VIDEO

AUDIO

"Controlling variables"

Music

"Bending rods task"

Instructor with bending rods  
apparatus.

I would like to continue with an experiment involving controlling variables with the bending rods task. The controlling variables experiment with different tasks facilities the student's problem solving ability which is needed to solve the problems in any kind of situation. So, I am going to conduct some experiments with the bending rods apparatus. This is called a bending rods apparatus. As you can see, this is a metal frame, and these are different sorts of aluminum and brass rods. The bending rods apparatus consists of a metal frame into which six different types of

The bending rods apparatus

aluminum and brass rods are inserted. These six rods are different in terms of the cross-sectional shape, the materials, the thickness, and the length of the rods.

Rod number one is a thick-round-aluminum rod, rod two is a thin-round-aluminum rod, rod three is a thick-round-brass rod, rod four is a thick-square-aluminum rod, rod five is a thick-round-aluminum rod that is short, and rod six is a thick-square-brass rod. The properties of the rods can be seen with this illustration.

---

<u>Rod</u>	<u>Length</u>	<u>Material</u>	<u>Shape</u>	<u>Thickness</u>
1	long	aluminum	round	thick
2	long	aluminum	round	thin
3	long	brass	round	thick
4	long	aluminum	square	thick
5	short	aluminum	round	thick
6	long	brass	square	thick

---

We can use two different weights. One is a 300g weight, and the other one is a 600g weight. We can hang the weight on the end of the rod like this. I'll hook the 300g weight on the end of rod one and rod one bends like this. For our particular

Which rod bends the most?

Which rod bends the least?

The independent variables

The dependent variable

purpose, we want to see which rod bends the most and also the rod which bends the least.

At this point, I would like to ask you a question. How can we identify the rod which bends the most or the least? And what variables will affect the flexibility of the bending rod? Can you identify the variables that might affect the bending rod? Push the pause button and manipulate the rods and the weights, and then identify the possible variables that might affect the bending rod. After this, answer question No. 1 of bending rods task on your worksheet. Push the pause button.

From manipulating the bending rods apparatus, we've observed the independent variables that might affect the bending rods and the dependent variable as follows in this example.

The independent variables

The weight (w)

The length (l)

The material (m) ..... Flexibility (F)

The cross sectional shape (s)

The thickness(t)

The weight of the metal chunk

If we vary the weight hung on the end of the rod, then the flexibility of the bending rod will vary.

The dependent variable

Flexibility (F)

Let's test to see which rod will bend the most and which one will bend the least. First, let's think about it by using the weight of the metal chunk. Let's test whether or not the weight of the chunk, the independent variable, will affect the frequency of the bending rod. Can you make a hypothesis and conduct the controlling variables experiment? Push the pause button and do this. You can use the bending rods apparatus and the weights provided for you. After the experiment, complete question No. 2, 3, 4, and 5.

Let's review the process of the experiment. First, we might make the hypothesis like this; "if we vary the weight hung on the end of the rod, then the flexibility of the bending rod will vary." For testing this hypothesis, we'll choose rod one and



Choose rod one and rod five.

Be sure that all the properties of the rods except the weight must be the same.

Hook the 300 g weight on rod one.  
Hook the 600 g weight on rod five.

Rod five bends more than rod one.

<u>The independent variables</u>	<u>The dependent variable</u>
$w, \bar{w}_1, \bar{w}_2 \dots\dots$	$F, \bar{F}_1, \bar{F}_2$
$l,$	
$m,$	
$s,$	
$t,$	

rod five. The reason why we choose rod one and rod five is that the independent variables concerning the two are all the same. Be sure that all the properties of the rods chosen to test the hypothesis are the same except for the property being tested. As you see, rod one and rod five are long-aluminum-round thick rods. Now, I'll hook the 300 g weight on the end of rod one and the 600 g weight on the end of rod five. As you can see rod five is bending more than rod one. So, we can summarize the results of the experiment like this.

$w$  denotes the weight of the chunk hung on the end of the rod,  $\bar{w}_1$  denotes the 300 g weight, and  $\bar{w}_2$  denotes the 600 g weight.  $\bar{F}_1$  and  $\bar{F}_2$  denote the degree of flexibility of the bending rods when the 300 g weight and the 600 g weight are hung on them.

The length of the rod

If we vary the length of the rod,  
then the flexibility of the rod  
will vary.

So, we can conclude that the varying weight of the metal chunks affects the flexibility of the bending rod. Compare this to your own results and complete the items.

Next, we'll conduct an experiment to see whether or not the length of the rod might affect the flexibility of the bending rod. How do you make the hypothesis for this problem? To test your hypothesis, which rods will you select for the experiment, and why? Push the pause button on the VTR deck and then conduct your experiment. And after this, answer questions 6, 7, 8, and 9.

Now, let's review the process of the experiment you did. First, we will construct the hypothesis like this: "If we vary the length of the rod, then the flexibility of the rod will vary." We will pick rod one and rod five for testing the hypothesis.

Rod one;

long, aluminum, round, and thick

Rod five;

short, aluminum, round, and thick

Be sure that all the independent variables of the rods are held constant except the one independent variable being tested.

<u>The independent variables</u>	<u>The dependent variable</u>
w,	
l, $\bar{l}_1, \bar{l}_2, \dots$	F, $\bar{F}_1, \bar{F}_2$
m,	
s,	
t,	

Notice that we have to insert rod five into the metal frame in order to make it shorter than rod one. Now, the lengths of rod one and rod five are different from each other. But the other properties of two rods are the same, that is, round-thick-aluminum rods. Be sure that all the independent variables of the rods are held constant except the one independent variable being tested. Now, let's hang the 300 g weight on the end of rod one and rod 5 respectively. As you can see, the flexibility of the rods is different. Rod one, the long rod, bends more than rod five. So, our hypothesis is proved to be true. We can summarize the result of the experiment like this:

l denotes the length of the rod,  $\bar{l}_1$  denotes rod one, the long rod, and  $\bar{l}_2$  denotes rod five, the short rod.  $\bar{F}_1$  and  $\bar{F}_2$  denote

The long rod (rod one) bends more than the short rod (rod five).

The material of the rod

the flexibilities of the rods when the weights are hung on them. We can conclude that the weight affects the flexibility of the rod. In other words, if we vary the length of the rod, then the flexibility of the rod will vary.

Next, we will conduct an experiment concerning the material of the rod. Our assumption is that the material of the rod might affect the flexibility of the rod. There are two kinds of material. One is aluminum, the other is brass. Can you make a hypothesis about this and conduct an experiment for testing your hypothesis? Please do your own experiment again and answer questions 10, 11, 12, and 13 on your worksheet.

Let's review the process of your experiment. First, we'll make a hypothesis

If we change the material, then the flexibility of the rod will vary.

Rod one;

long, aluminum, round, and thick

Rod three;

long, brass, round, and thick

Be sure that all the variables except the material must be controlled as constant.

<u>The independent variables</u>	<u>The dependent variable</u>
----------------------------------	-------------------------------

w,

l,

m,  $\bar{m}_1$ ,  $\bar{m}_2$ , ..... F,  $\bar{F}_1$ ,  $\bar{F}_2$ ,

about the problem like this.

To test this hypothesis, we will choose rod one and rod three. The reason we choose these two rods is that all the properties of the two are held constant except the property being tested, the materials. As you can see, rod one and rod three are long and thick, but the material of each rod is different. One is aluminum and the other one is brass. Let's hang the 300 g weight on the end of each rod. As you can see, rod one, the aluminum rod, bends more than rod three, the brass rod. So, our hypothesis is true.

We can summarize the results of the experiment like this:

m denotes the material of the rod, and  $\bar{m}_1$  and  $\bar{m}_2$  denote rod one, one aluminum rod and rod three, a brass rod.  $\bar{F}_1$  and  $\bar{F}_2$

s,

t,

---

The aluminum rod (rod one) bends more than the brass rod (rod three).

The cross sectional shape

The round rod and the square rod

denote the flexibility of the rods when the 300 g weight is hung on the end of each of them. We can conclude from this result that the material of the rod will affect the flexibility of the rod.

Next, we'll conduct an experiment concerning the cross sectional shape of the rod. We'll assume that the different kinds of cross sectional shapes will affect the flexibility of the rod. You will manipulate two kinds of cross sectional shapes. One is the round rod, and the other is the square rod. Do your own experiment with the bending rods apparatus provided you and answer questions 14, 15, 16, and 17 on your worksheet. Push the pause button on the VTR deck and begin.

Let's review the process of your experiment. First, we'll state the hypothesis

If we vary the cross sectional shape of the rod, then the flexibility of the rod will vary.

Rod one;

long, aluminum, round, and thick

Rod four;

long, aluminum, square, and thick

The round rod (rod one) bends more than the square rod (rod four).

like this: "If we vary the cross sectional shape of the rod, then the flexibility of the rod will vary." We'll assume that the round rod will bend more than the square one. To test this hypothesis, we'll choose rod one and rod four. The reason why we choose these rods is that all the properties of the rods chosen must be equal except for the property being tested. Rod one and rod four are long, aluminum and thick. But the cross sectional shape of each is different. Rod one is round and rod four is square. Let's hang the 300 g weight on the end of each rod again. As you can see rod one bends more than rod four. The round one bends more than the square one. We can summarize the result of the experiment like this;

$s$  denotes the cross sectional shape of the rod, and  $\bar{s}_1$  and  $\bar{s}_2$  denote rod one,

<u>The independent variables</u>	<u>The dependent variable</u>
w,	
l,	
m,	
s, $\bar{s}_1, \bar{s}_2, \dots, F, \bar{F}_1, \bar{F}_2,$	
t,	

The tickness of the rod  
The thick rod and the thin rod

the round rod, and rod four, the square rod, respectively.  $\bar{F}_1$  and  $\bar{F}_2$  denote the flexibility of the rods when the 300 g weight is hung on the end of each. We can conclude that the cross sectional shape will affect the flexibility of the rod.

Finally, we'll consider whether or not the thickness of the rod will affect the flexibility of the bending rod. We may obviously assume that the thin rod will bend more than the thick one. Can you make a hypothesis and conduct an experiment to solve this problem? Push the pause button and begin your experiment. After that, answer questions 18, 19, 20, and 21 on your worksheet.

Now, let's review the process of the experiment you did. First, we might establish the hypothesis like this: "If we vary



If we vary the thickness of the rod, then the flexibility of the rod will vary.

Rod one;

long, aluminum, round, and thick

Rod two;

long, aluminum, round, and thin

Be sure that all the variables except the thickness of the rod must be held constant.

The thin rod (rod two) bends more than the thick rod (rod one).

the thickness of the rod, then the flexibility of the rod will vary." To test our hypothesis in this case, we'll choose rod one and rod two. The reason why we choose rod one and rod two is that all the properties of the rods are the same except for the property being tested. Both rod one and rod two are long aluminum and round. But the thickness of the rods is different from each other. Rod one is thick while rod two is thin. All the variables except the variable being tested must be held constant. Now, let's hang the 300 g weight on the end of each rod. As you can see rod two, the thin rod, bends more than rod one, the thick rod. We have proved that the hypothesis is correct. So, we can summarize the result of experiment like this.

$t$  denotes the thickness of the rod,

<u>The independent variables</u>	<u>The dependent variable</u>
w,	
l,	
m,	
s,	
t, $\bar{t}_1, \bar{t}_2, \dots, F, \bar{F}_1, \bar{F}_2,$	

1. The weight of the chunk
2. The length of the rod
3. The material of the rod
4. The cross sectional shape
5. The thickness of the rod

and  $\bar{t}_1$  and  $\bar{t}_2$  denote the flexibilities of the rods when the 300 g weight is hung on the end of each rod. From the results of this experiment, we can conclude that the different thickness of the rods affects the flexibility of the rods

From the series of the experiments we have made so far, we are in a position to formulate the hypothesis that the flexibility of the rod is related to the following variables: (1) the weight hung on the end of the rod, (2) the length of the rod, (3) the material of the rod, (4) the cross sectional shape of the rod, and (5) the thickness of the rod.

The most important thing we have learned in this series of the experiments is how we manipulate the controlled variables in various kinds of problem solving situations.

Controlling variables

We can use the techniques we have learned in this experiment in solving various problems in physics, chemistry, biology, and in all endeavors where hypotheses and evidence are to be evaluated.

The End

Music

APPENDIX F: WORKSHEET II FOR BENDING RODS TASK

WORKSHEET II

FOR

INDIVIDUAL EXPERIMENTATIONS USING VIDEO-TAPE PRESENTATION

(BENDING RODS TASK)

ID NUMBER: \_\_\_\_\_

BIRTH DATE: \_\_\_\_\_

TODAY'S DATE: \_\_\_\_\_

SEX: MALE \_\_\_\_\_ FEMALE \_\_\_\_\_

MAJOR: \_\_\_\_\_

INPUT TIME

Starting time: \_\_\_\_\_

Ending time: \_\_\_\_\_

BENDING RODS TASK

1. Write down five possible variables involving the bending rods task which might affect the flexibility of the rod.

- (1) \_\_\_\_\_  
(2) \_\_\_\_\_  
(3) \_\_\_\_\_  
(4) \_\_\_\_\_  
(5) \_\_\_\_\_

- I. Experiments involving the weight used to hang on the end of the rod.

2. Establish your own hypothesis on this problem.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

3. Which rods would you like to choose to test your hypothesis? \_\_\_\_\_

4. Write down the reason for your answer to question number 3.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

5. Write down your conclusion from this experiment.

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II. Experiments involving the length of the rod:

6. Establish your hypothesis on this problem.

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7. Which rods would you like to choose to test your hypothesis? \_\_\_\_\_

8. Write down the best reason for your answer to question number 7.

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9. Write down your conclusion from this experiment.

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III. Experiments involving the material of the rod:

10. Establish your own hypothesis on this problem.

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11. Which rods would you like to choose to test your hypothesis? \_\_\_\_\_

12. Write down the best reason for your answer to question number 11.

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13. Write down your conclusion from this experiment.

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IV. Experiments involving the cross section shape of the rod:

14. Establish your hypothesis on this problem.

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15. which rods would you like to choose to test your hypothesis? \_\_\_\_\_

16. Write down the best reason for your answer to question number 15.

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17. Write down your conclusion from this experiment.

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V. Experiments involving the thickness of the rod:

18. Establish your hypothesis on this problem.

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19. Which rods would you like to choose to test your hypothesis? \_\_\_\_\_

20. Write down the best reason for your answer to question number 19.

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21. Write down your conclusion from this experiment.

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APPENDIX G: PIAGETIAN LOGICAL OPERATIONS TEST

PIAGETIAN LOGICAL OPERATIONS TEST

ID NUMBER : \_\_\_\_\_

SEX: MALE \_\_\_\_\_ FEMALE \_\_\_\_\_

MAJOR: \_\_\_\_\_

YEAR: \_\_\_\_\_

BIRTH DATE: \_\_\_\_\_

TODAY'S DATE: \_\_\_\_\_

General directions

This is a test of certain understanding, skills, and abilities that you have gradually developed. The total number of correct answers that you mark will be your score. Wrong answers will not be counted against your score. Try to answer all the questions. If a question seems too hard, make the best guess you can.

Use a pencil to mark your answers on the test sheet. Each question has only one best answer. Mark only one answer for each question. To change an answer, erase four first mark completely.

Directions

First, carefully read the problem situation.

Then read each question carefully and decide which one of the four possible answers is the correct or best one.

Example

A closed figure having all four sides equal is a

- A. Triangle
- B. Rectangle
- C. Square
- D. Parallelogram

The correct answer to this question is lettered C, so you should mark on the choice C if this question were on the test.

GO ON TO THE NEXT PAGE.

READ THE FOLLOWING PROBLEM SITUATION CAREFULLY AND ANSWER QUESTION NUMBERS 1 AND 2.

PROBLEM SITUATION

Here is a pendulum. Three strings numbered 1, 2, and 3 suspended from a single support as illustrated in figure 1. String # 1 and # 3 are of equal length, and string # 2 is longer. Two 5 g weights are hung at the end of string # 2 and # 3. One 10 g weight is hung at the end of string # 1.

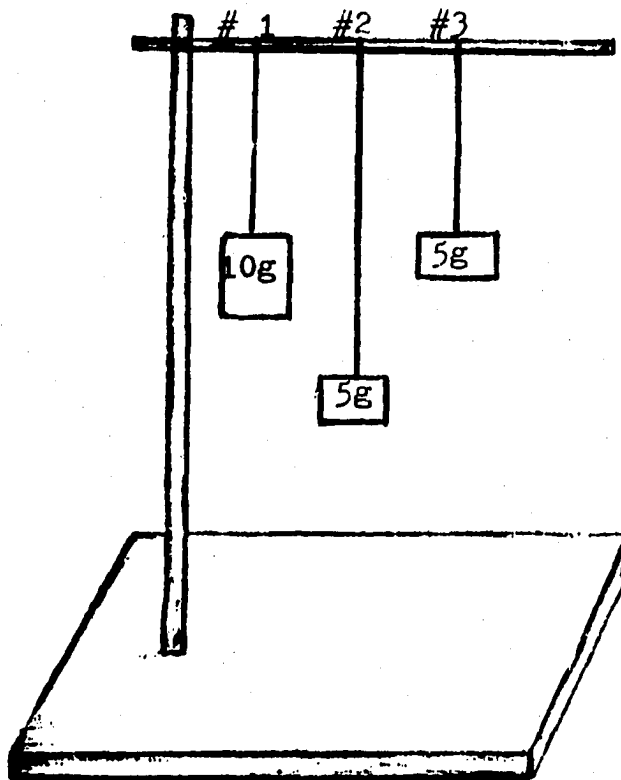


Figure 1. Pendulum apparatus

GO ON TO THE NEXT PAGE.

1. Suppose you wanted to do an experiment to find out if changing the length of a pendulum changed the amount of time it takes to swing back and forth. Which pendulum or pendulums would you use for the experiment?

- \_\_\_\_\_ A. 1 and 2  
\_\_\_\_\_ B. 1 and 3  
\_\_\_\_\_ C. 2 and 3  
\_\_\_\_\_ D. 1, 2, and 3

Please explain your choice.

---

2. Suppose you wanted to do an experiment to find out if changing the weight on the end of the string changed the amount of time the pendulum takes to swing back and forth. Which pendulum or pendulums would you use for the experiment?

- \_\_\_\_\_ A. 1 and 2  
\_\_\_\_\_ B. 1 and 3  
\_\_\_\_\_ C. 2 and 3  
\_\_\_\_\_ D. 1, 2, and 3

Please explain your choice.

---

GO ON TO THE NEXT PAGE.

READ THE FOLLOWING PROBLEM SITUATION CAREFULLY AND ANSWER THE QUESTIONS

PROBLEM SITUATION

Here is a bending rods apparatus. This apparatus consists of a frame into which six sorts of different rods are inserted. Here are also two 300 g weights and one 600 g weight. You can hang the weights on the end of the rods. If you hang the weight on the end of the rods, the rod will bend. However, we don't know yet which rod will bend the most and which rod will bend the least.

Examine carefully the bending rods apparatus illustrated in figure 2 and answer the questions.

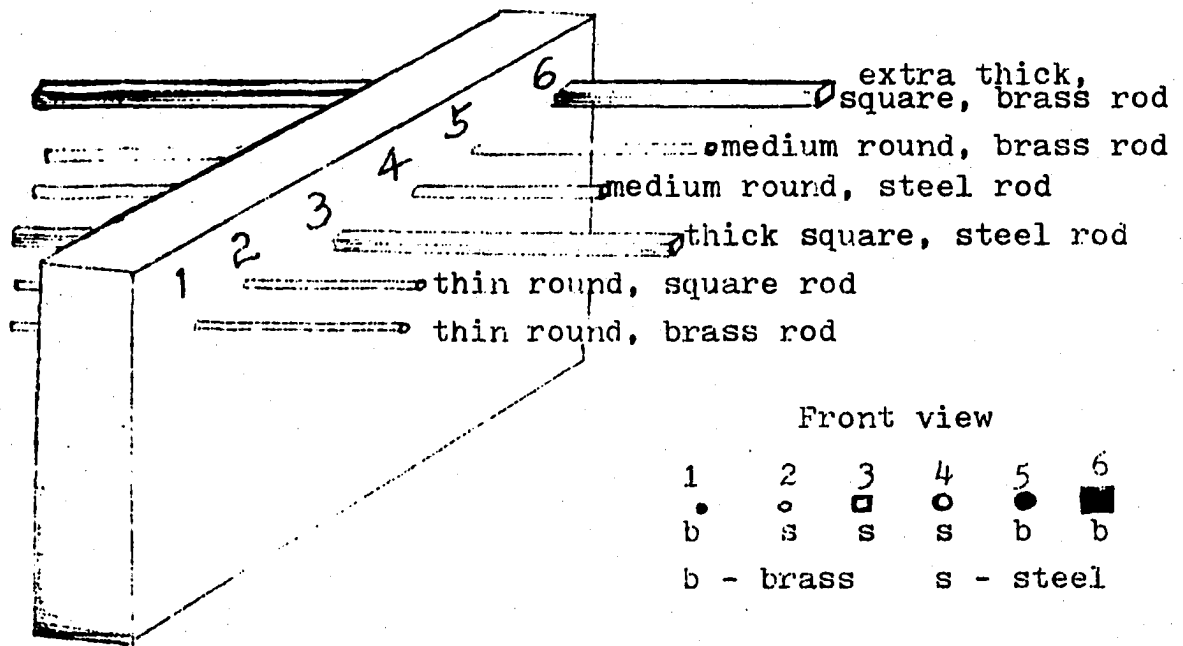
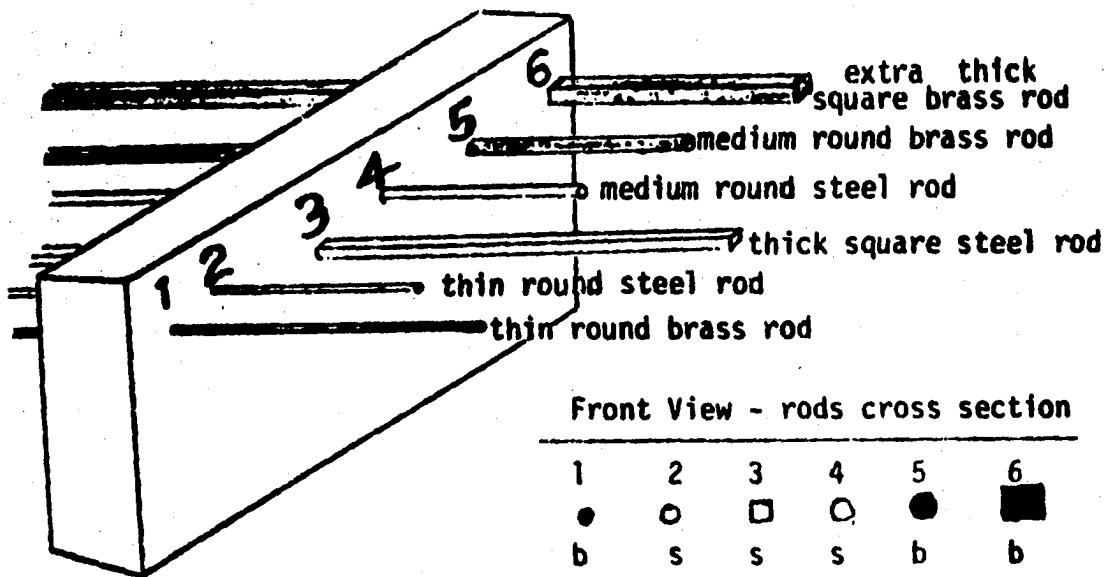


Figure 2. Bending rods apparatus

GO ON TO THE NEXT PAGE



Front View - rods cross section

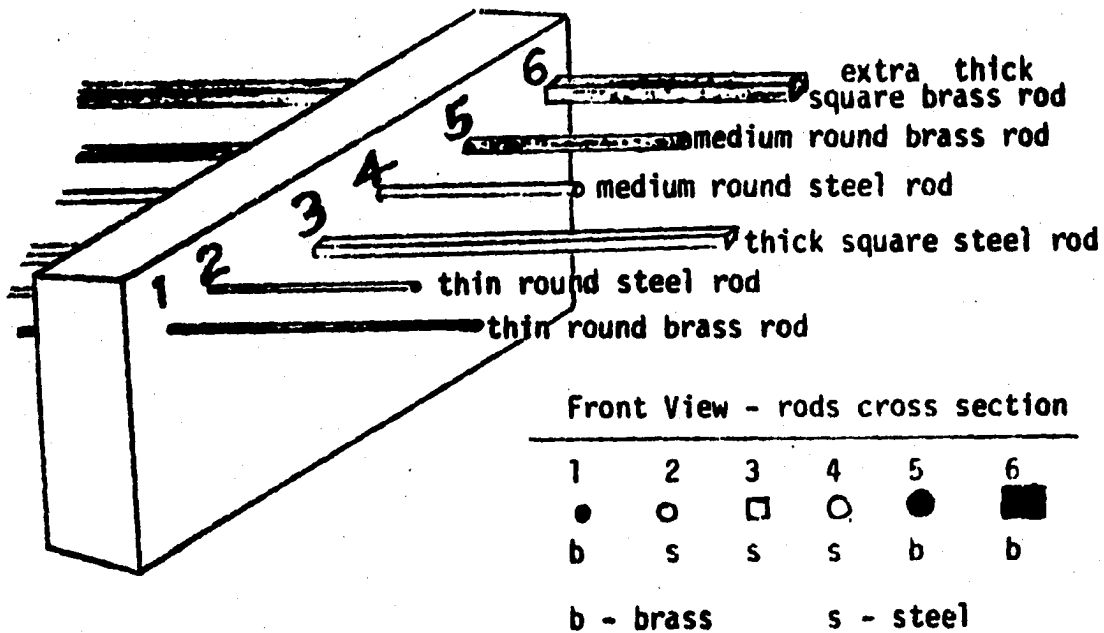
1	2	3	4	5	6
●	○	□	○	●	■
b	s	s	s	b	b

b - brass      s - steel

3. How many different thickness do the rods have?
- \_\_\_\_\_ A. all rods have the same thickness
- \_\_\_\_\_ B. 2
- \_\_\_\_\_ C. 3
- \_\_\_\_\_ D. 4
4. How many different cross sectional shapes do the rods have?
- \_\_\_\_\_ A. 4
- \_\_\_\_\_ B. 3
- \_\_\_\_\_ C. 2
- \_\_\_\_\_ D. All rods have the same cross sectional shape
5. How many different materials make up the rods?
- \_\_\_\_\_ A. all rods are made of the same material
- \_\_\_\_\_ B. 2
- \_\_\_\_\_ C. 3
- \_\_\_\_\_ D. 4

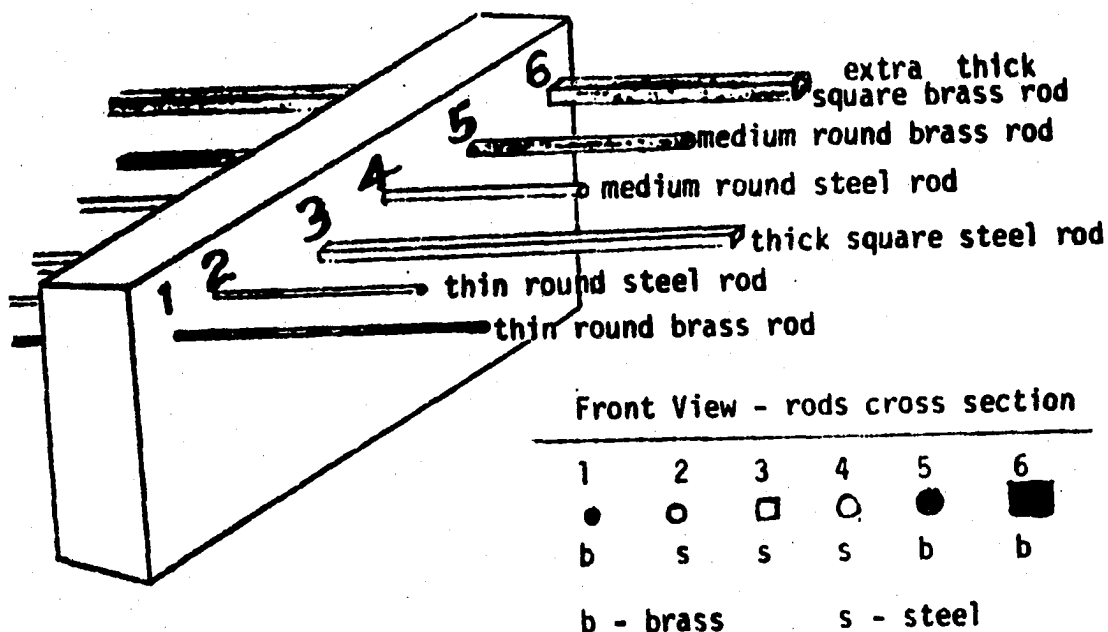
GO ON TO THE NEXT PAGE





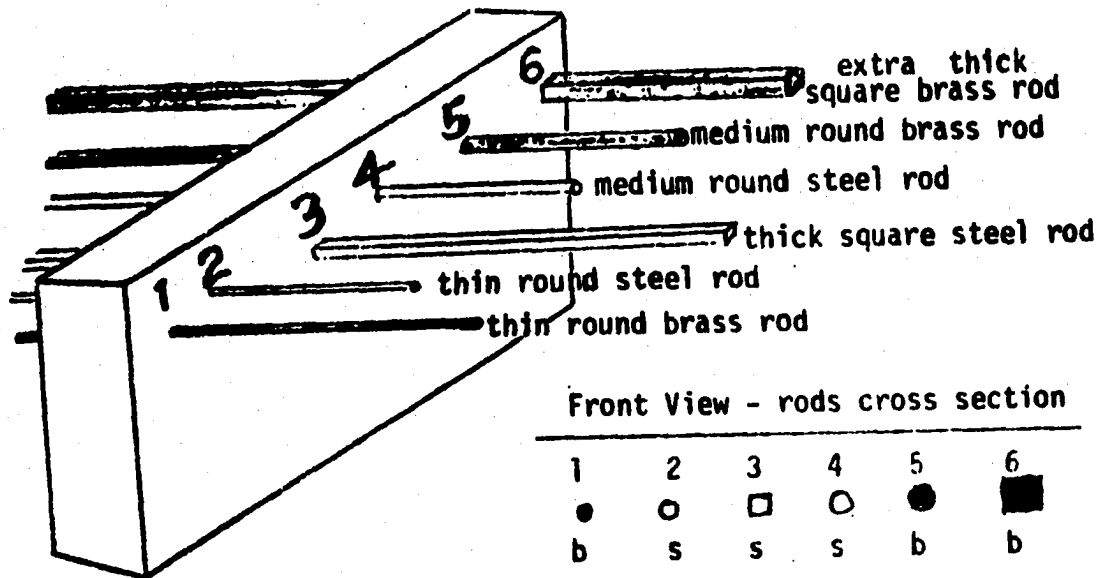
6. Where may weight be placed on the rods?
- \_\_\_\_\_ A. at the end  
 \_\_\_\_\_ B. at the end and one other place  
 \_\_\_\_\_ C. at three places  
 \_\_\_\_\_ D. at any point along the length
7. Which aspects of the rods might affect the bending rods?
- \_\_\_\_\_ A. length at which weight is placed  
 \_\_\_\_\_ B. thickness and material  
 \_\_\_\_\_ C. cross sectional shape and amount of weight placed  
 \_\_\_\_\_ D. all of the above
8. The material may affect the bending of the rods. Which rods could be used to show this?
- \_\_\_\_\_ A. rods 1 and 2  
 \_\_\_\_\_ B. rods 2 and 4  
 \_\_\_\_\_ C. rods 3 and 4  
 \_\_\_\_\_ D. rods 3 and 5

GO ON TO THE NEXT PAGE



9. Which choice best explains the reason for your answer to question 8?
- \_\_\_\_\_ A. both rods should be made of steel
- \_\_\_\_\_ B. one rod should be steel, the other brass, one thick, the other thin
- \_\_\_\_\_ C. one rod should be brass, the other steel
- \_\_\_\_\_ D. not sure and guessed
10. Rods 4 and 6 could be used to show bending due to:
- \_\_\_\_\_ A. the combined effects of material and thickness
- \_\_\_\_\_ B. the effect of cross sectional shape
- \_\_\_\_\_ C. the effect of length
- \_\_\_\_\_ D. none of the above
11. Which choice best matches the reason for your answer to question 10?
- \_\_\_\_\_ A. Rods 4 and 6 differed in more than two ways.
- \_\_\_\_\_ B. Rods 4 and 6 differed in more than two ways.

GO ON TO THE NEXT PAGE



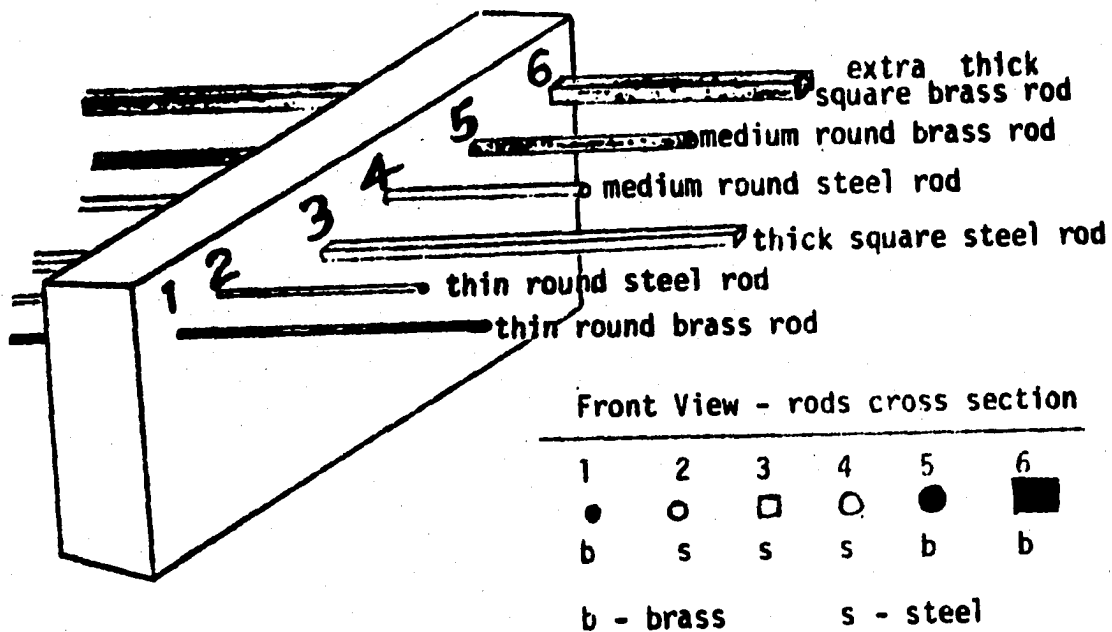
Front View - rods cross section

1	2	3	4	5	6
●	○	□	○	●	■
b	s	s	s	b	b

b - brass      s - steel

- Only the difference in one way is important.
- \_\_\_\_\_ C. Rods 4 and 6 differed in more than two ways.  
Only difference in two ways is important.
- \_\_\_\_\_ D. I was not sure. I guessed.
12. The thickness of the rods may affect the bending of the rods. How would you use the apparatus to show this?
- \_\_\_\_\_ A. Pick two rods made of the same material, thickness, and cross sectional shape. Adjust the rods to be the same length. Hang equal weights at the same length on each rod.
- \_\_\_\_\_ B. Pick two rods made of different material and thickness, and cross sectional shape. Adjust the rods to be the same length. Hang equal weights at a different length on each rod.
- \_\_\_\_\_ C. Pick two rods made of the same material and cross sectional shape, but different thickness. Adjust the rods to be the same length.

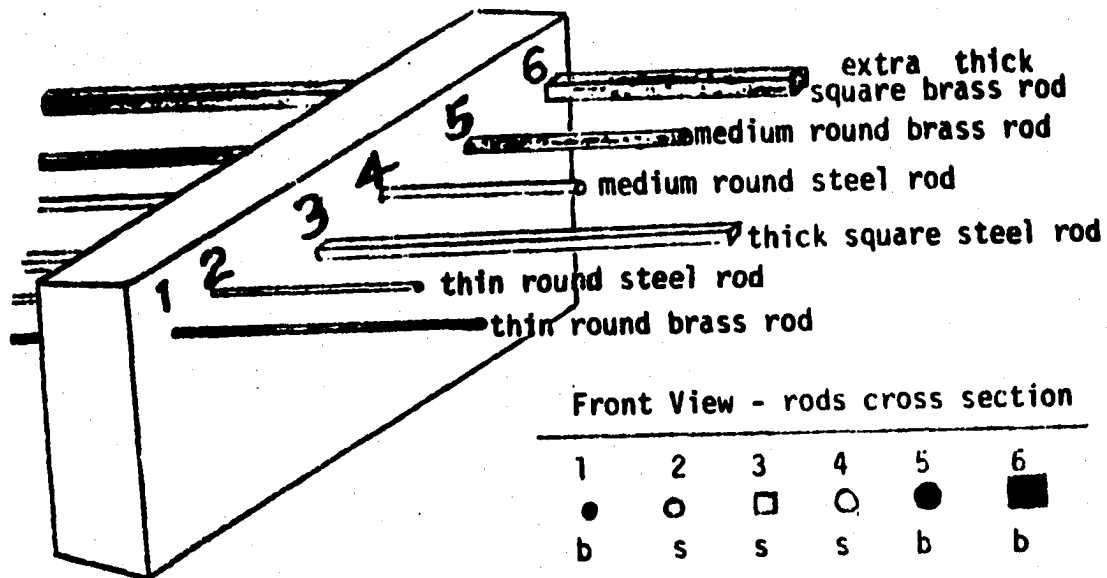
GO ON TO THE NEXT PAGE



Hang equal weights at the same length on each rod.

- \_\_\_\_\_ D. None of the above
13. Which statement best matches the reason for your answer to question 12?
- \_\_\_\_\_ A. All properties of the rods chosen must be equal except for the property being tested.
- \_\_\_\_\_ B. At least two properties of the rods should be different to test one of the properties
- \_\_\_\_\_ C. The property being tested should be the same in both rods. One other property should be different.
- \_\_\_\_\_ D. None of the above.
14. The amount of weight placed may affect the amount of bending. How could you show this?
- \_\_\_\_\_ A. Pick two rods made of the same material,

GO ON TO THE NEXT PAGE



Front View - rods cross section

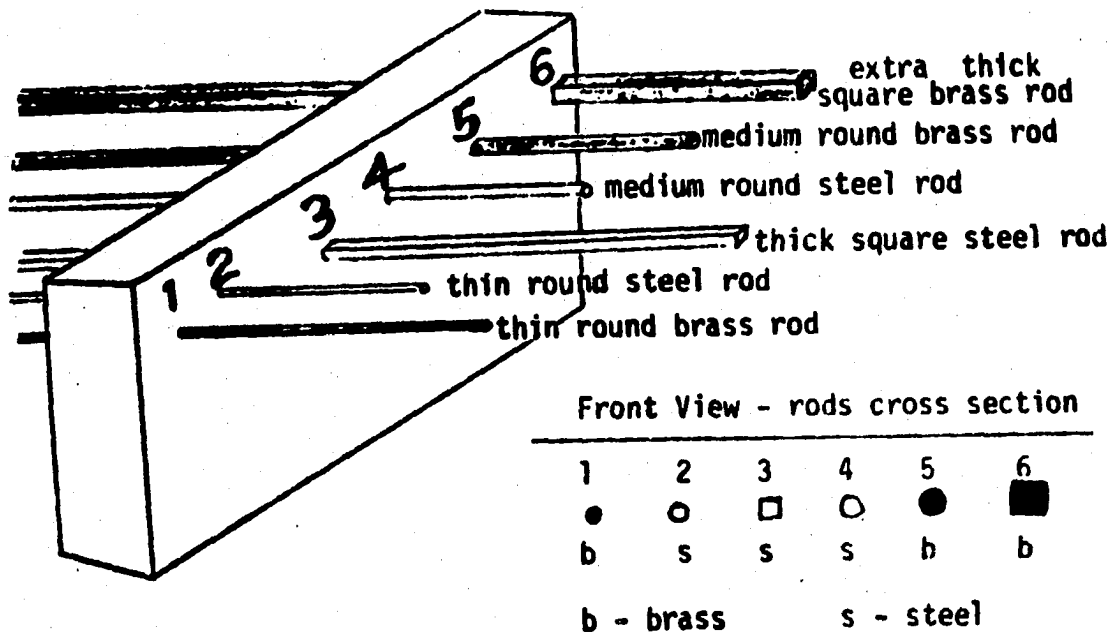
1	2	3	4	5	6
●	○	□	○	●	■
b	s	s	s	b	b

b - brass      s - steel

thickness, and cross sectional shape. Adjust the rods to be the same length. Hang a different amount of weight at a different length on each rod.

- \_\_\_\_\_ B. Pick two rods made of the same material, thickness, and cross sectional shape. Adjust the rods to be the same length. Hang an equal amount of weight at the same length on each rod.
- \_\_\_\_\_ C. Pick two rods made of the same material, thickness, and cross sectional shape. Adjust the rods to be different in length. Hang an equal amount of weight at a different length on each rod.
- \_\_\_\_\_ D. Pick one rod and hang a weight at a certain length. Remove the weight. Hang a different amount of weight at the same length.

GO NO TO THE NEXT PAGE



15. Which statement best matches the reason for your answer to the question 14?
- \_\_\_\_\_ A. At least two properties of the rods should be different.
- \_\_\_\_\_ B. Only the amount of weight used on the two rods can be different.
- \_\_\_\_\_ C. Equal weights at different lengths on the two rods must be used
- \_\_\_\_\_ D. None of the above.

STOP, THANK YOU.

APPENDIX H: KEY AND CRITERIA FOR SCORING THE PIAGETIAN  
LOGICAL OPERATIONS TEST

KEY AND CRITERIA FOR SCORING  
THE PIAGETIAN LOGICAL OPERATIONS TEST

KEY:

1. C: Everything is the same except the length. So, you can tell if length makes a difference.
2. B: Everything is the same except weight. So, you can tell if weight makes a difference
3. D, 4. C, 5. B, 6. D, 7. D, 8. A, 9. C, 10. D, 11. A, 12. C, 13. A, 14. D, 15. D.

CRITERIA FOR SCORING ITEM 1 AND ITEM 2

Item 1:

- A. Correct explanation in writing how the subjects arrived at the answer indicates that he controlled all variables but one variable being tested at the time to determine the answer. In other words, they may keep the weight, the height from which it is released, and the force used to impel the weight the same, but change the length of the string. Some examples are:

1. All variables of "pendulum 2" and "pendulum 3" are the same except the length of the string.
2. Because all other variables must be controlled as constant, while one variable (length of the



string) is tested.

3. All the same but the different length of the string.

B. Incorrect explanations were those in which the statement itself is not incorrect but it did not indicate any evidence that the subject controlled all variables but the length of the string at the time to determine the answer. Some examples are:

1. Because the shorter the string the smaller the time is to swing.
2. You compare the 1st situation and the 2nd situation.
3. Because the longer the string or the heavier the weight.

Item 2:

A. Correct explanations were those that indicate that all variables must be the same except the weight.

Some examples are:

1. Because all variables must be the same except the weight of the pendulum bob.
2. All variables held constant except weight of the the pendulum bob.
3. All the same but different weight of the pendulum bob.

B. Incorrect explanations were those in which the statement did not include the statement that all variables except the weight of the pendulum bob must be controlled. Some examples are:

1. Different weight, different height.
2. Because the short string and more weight will make the pendulum swing longer.
3. One could compare the situation 10 g, 5 g, 5 g, with 10 g, 10 g, and 10 g.

APPENDIX I: PROBLEM-SOLVING TEST

PROBLEM-SOLVING TEST

ID NUMBER: \_\_\_\_\_

SEX: MALE \_\_\_\_\_ FEMALE: \_\_\_\_\_

MAJOR: \_\_\_\_\_

YEAR: \_\_\_\_\_

BIRTH DATE: \_\_\_\_\_

TODAY'S DATE: \_\_\_\_\_

General Direction

This is a test of certain understanding, skills and abilities that you have gradually developed. The total number of correct responses that you make will be your score. Wrong answers will not be counted against your score. Try to answer all the questions. If a question seems too hard, make the best guess you can.

Use a pencil to mark your answers on the test sheet. Each question has only one best answer. Mark only one answer for each question and explain carefully how you arrived at your answer. To change an answer, erase your first mark completely.

Directions

First, carefully read the problem situation.

Then read each question carefully and decide which one of the four possible answers is the correct or best one.

GO ON TO THE NEXT PAGE.

READ THE FOLLOWING PROBLEM SITUATIONS CAREFULLY AND ANSWER QUESTIONS PROVIDED

1. TREE EXPERIMENT

Fifty pieces of various parts of plants were placed in each of five sealed containers of equal size. At the start of the experiment each jar contained 250 units of  $\text{CO}_2$ . The amount of  $\text{CO}_2$  in each jar at the end of two days is as shown in the table.

Container	Plant	Plant part	Light color	Temperature( $^{\circ}\text{C}$ )	$\text{CO}_2$ Remaining
A	Willow	leaf	blue	10	200
B	Maple	leaf	purple	23	50
C	Willow	root	red	18	300
D	Maple	stem	red	23	400
E	Willow	leaf	blue	23	150

QUESTION:

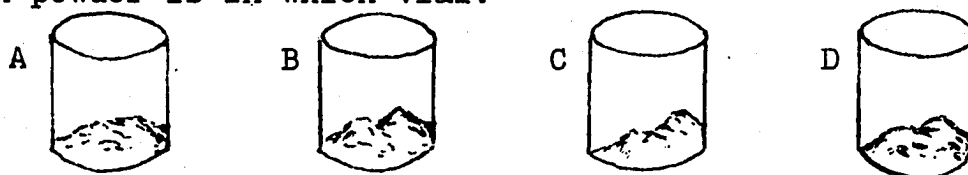
On the basis of the data in the table, a fair test of the amount of  $\text{CO}_2$  used per day at two different temperatures could be made by comparing which jars? \_\_\_\_\_

Please explain why you chose those jars: \_\_\_\_\_

GO ON TO THE NEXT PAGE

## 2. MISTERY MIXTURE PUZZLE

A chemistry student is given four labeled vials each containing a white powder. The student is told that one of the vials contains baking soda, one contains cornstarch, one contains epsom salts, and one of the vials contains a mixture of two of the other powders, but the student doesn't know which powder is in which vial.



The student does know that anything containing baking soda bubbles vigorously when a vinegar solution is added; neither cornstarch nor epsom salts reacts with vinegar. The student also knows that anything containing cornstarch turns black when an iodine solution is added; neither baking soda nor epsom salts reacts with iodine. The student divided the powder from each vial into two portions, adding a vinegar solution to the first portion and an iodine solution to the second portion. The results of these tests are shown in the table below.

<u>Powder in vial</u>	<u>Vinegar added</u>	<u>Iodine added</u>
A	no change	turns black
B	bubbles	no change
C	no change	turns black
D	no change	no change

**QUESTION:**

Is baking soda one of the powders in the vial containing the mixture of two powders?

Yes \_\_\_\_\_ No \_\_\_\_\_ Can't tell from the tests \_\_\_\_\_

Please explain carefully how you arrived at your answer.

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**3. CIRCUIT PUZZLE**

A science student, experimented with the circuit puzzle shown below. The circuit puzzle consisted of a folded piece of cardboard with four aluminum foil "terminals" A, B, C, and D, showing through holes in the top layer of cardboard. Ms. Electro knew that a terminal could be an isolated piece of foil, or two or more terminals could be connected by aluminum foil. However, the circuit puzzle was taped all around, so she could not open the puzzle to see which terminals were connected by aluminum foil.



GO ON TO THE NEXT PAGE



The student did know that when a battery and bulb combination is connected between two terminals, the bulb lights if there is any kind of aluminum foil path between the terminals; if the two terminals are not connected by foil, the bulb does not light. She performed two tests to find out which terminals are connected by foil.

TEST 1: When a battery and bulb were connected between terminals B and C, the bulb lit.

TEST 2: When a battery and bulb were connected between terminals B and D, the bulb did not light.

QUESTION:

Are the terminals C and D connected by aluminum foil?

Yes \_\_\_\_\_ No \_\_\_\_\_ Can't tell from the two tests \_\_\_\_\_

Please explain carefully how you arrived at your answer.

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STOP, THANK YOU.

APPENDIX J: KEY AND CRITERIA FOR SCORING THE PROBLEM-  
SOLVING TEST

KEY AND CRITERIA FOR SCORING  
THE PROBLEM-SOLVING TEST

Item 1: A and E

- A. The correct answer must indicate that an accurate test of the amount of  $\text{CO}_2$  used per day at two different temperatures could be made by comparing only containers A and E. All conditions of containers A and E are the same except temperature. Some examples are:
1. All variables of container A and E must be the same except the temperature.
  2. All things except temperature are the same.
  3. All conditions must be the same except the condition being tested.
- B. The incorrect responses were those that did not indicate that all variables except the temperature must be the same to make an accurate test of the amount of  $\text{CO}_2$  used per day at two different temperatures. Some examples are:
1. Both had the same temperatures (Containers D & E)
  2. Different temperatures (Containers A & C)
  3. Because  $\text{CO}_2$  is used up in these 2 jars significantly (Container B & E).

Item 2: No.

- A. The correct responses must indicate the justifications which do not require a prediction of what each vial contains. For example, "No: If baking soda were in the mixture, then two powders would bubble with vinegar (the baking soda by itself and the mixture). Since only one powder bubbles, the baking soda can't be in the mixture."

The correct responses also were those in which the data are used to correctly predict that the mixture is either in vial A or in vial C. An example is: "No: Baking soda is in vial B and epsom salts is in vial D. The mixture has to be either in vial A or in vial C, since both of these vials contain cornstarch. Since neither of them bubble with vinegar, baking soda cannot be one of the powders in the mixture."

- B. The incorrect responses were those in which explanations make no reference to the data. An example is: "Yes: Because the mixture has two powders so one must be baking soda."

The incorrect responses also were those having explanations which appeal directly to the data or merely repeat the information about how the powders react with the different solutions. Subcategories

are explanations which:

1. assume that the powder in the vial which bubbles with vinegar must be the mixture. "Yes: Because the powder in vial B reacts when vinegar is added but doesn't react with iodine, so baking soda must be one of the powders in the mixture."
2. ignore the boundary condition. "Can't tell: Since epsom salts does not react with iodine or vinegar, it doesn't affect the outcome of the tests. So the mixture could be in vial A, B, C, and it is impossible to tell if baking soda is in the mixture."
3. recognize the boundary condition, but ignore the crucial value of the negative data. "Can't tell: vial B must contain baking soda, since it bubbles with vinegar. However, it could be the mixture or the straight baking soda, you can't tell because neither epsom salts nor cornstarch react with vinegar."

Item 3: No.

- A. The correct responses must contain the explanations which provide valid logical justifications. "No: From test 1 we know that B and C are connected by aluminum foil. From test 2 we know that it is

terminal D that is an isolated piece of aluminum foil. If C and D were connected by aluminum foil, then B and D would be connected by aluminum foil through C, and the bulb would light between B and D. Since the bulb did not light, C and D cannot be connected."

B. The incorrect responses were those in which:

1. explanations make no reference to the test results and (or) introduce new information. "No: C and D cannot be connected because they are too far apart."
2. explanations which appeal directly to or merely repeat the test results. Subcategories are explanations which:
  - a) attempt to detach relational clues, assigning significance to individual terminals. "No: C and D are not connected because B and D didn't work, and D needs to be lit for C to work."
  - b) assume that a connection not explicitly denied by the test results must be possible. "Yes: Because C and D can be connected without B and D being connected."
  - c) fail to recognize the connection between the positive and negative test results. "Can't tell: Proving that C and B light and B and D do not

light has nothing to do with whether C and D light. More information is needed."

3. the test results are used to construct aluminum foil models of possible terminal connections, which are then used to make predictions about the C and D connection. Subcategories are explanations which:

- a) fail to recognize the crucial value of the negative test result. "Can't tell: Since the bulb lit between C and B, there are three possible connections: BAC, BC, or BDC. Since the bulb did not light between B and D, BDC is not a possible connection. However, this does not tell if C and D are connected, one would have to test."
- b) assume that the negative test result can occur only if one of the terminals is an isolated piece of aluminum foil. "No: From test 1 we know that B and C are connected by an aluminum foil. From test 2 we know that it must be D which is an isolated piece of foil. Therefore, C cannot be connected to D."

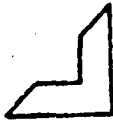
APPENDIX K: THE GROUP EMBEDDED FIGURES TEST



The following four simple/complex figures are taken from the practice section of the Group Embedded Figures Test.

Simple Figure

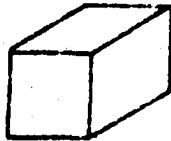
C



D



E



F



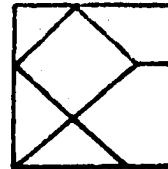
Complex Figure

5



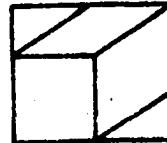
Find Simple Form "C"

3



Find Simple Form "D"

4



Find Simple Form "E"

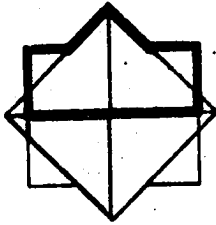
6



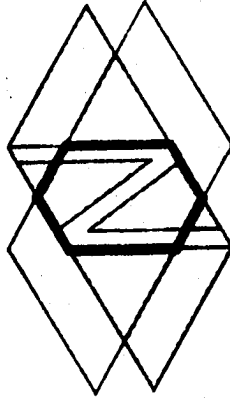
Find Simple Form "F"

GEFT-SCORING KEY

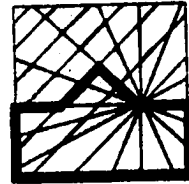
1  
(G)



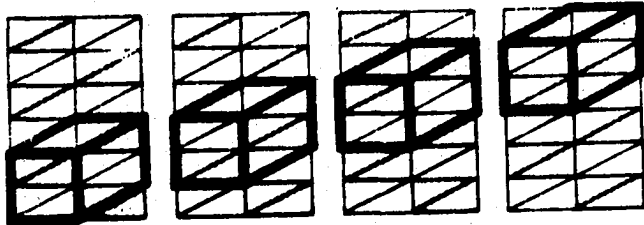
2  
(A)



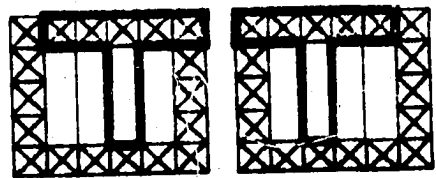
3  
(G)



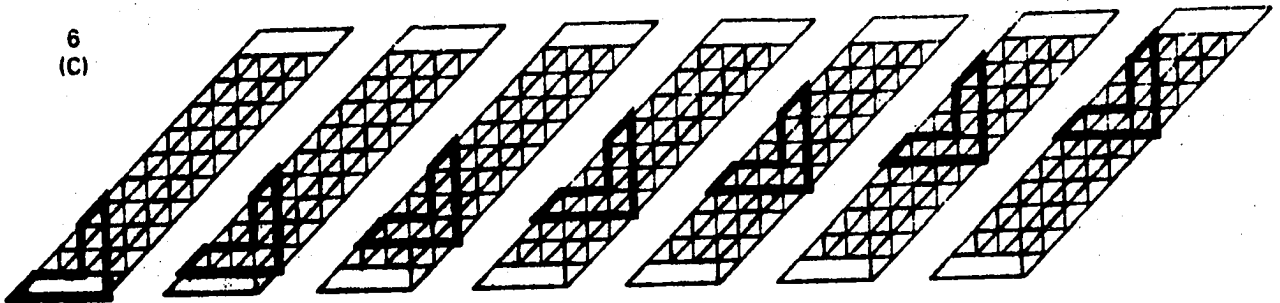
4  
(E)



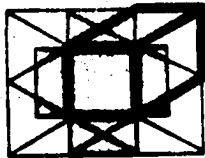
5  
(B)



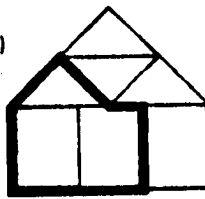
6  
(C)



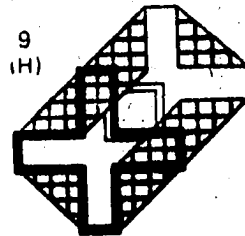
7  
(E)



8  
(D)

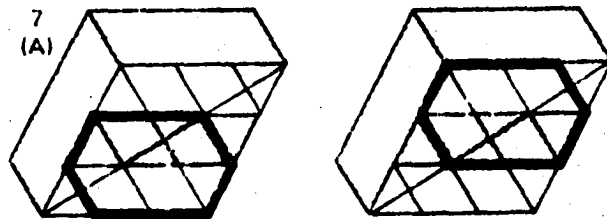
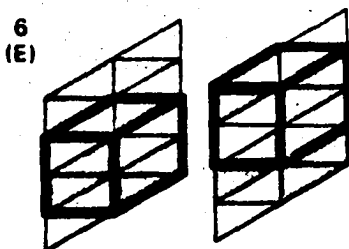
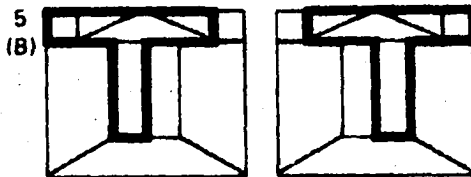
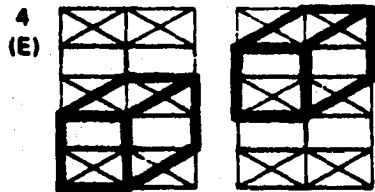
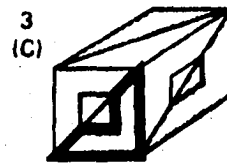
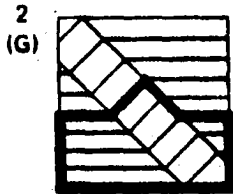
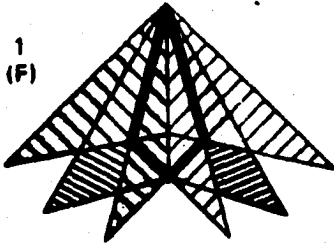


9  
(H)



## GEFT-SCORING KEY

## THIRD SECTION



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APPENDIX I: THE CODEBOOK FOR ANALYZING THE RESEARCH DATA

THE CODEBOOK FOR ANALYZING THE RESEARCH DATA

<u>Column</u>	<u>Variables</u>	<u>Variable name</u>	<u>Range of values</u>	<u>Value labels</u>
1	Card number	CD1	1	
2-3	Student ID #	ID1	01 - 99	
4	Group	GROUP	1 - 2	1= Experimental, 2= Control
5	Student sex	SEX	1 - 2	1= Male, 2= Female
6	Student grade	GRADE	1 - 3	1= Freshmen, 2= Sophomore 3= Junior
7-9	Student age	AGE	001 - 313	
10-11	Student major	MAJOR	01 - 29	(Engineering) 01 = Civil engineering 02 = Computer " 03 = Constructional " 04 = Electrical " 05 = Industrial " 06 = Mechanical "  (Natural sciences) 07 = Biology 08 = Computer science 09 = Food technition 10 = Physics 11 = Pre-medicine

<u>Column</u>	<u>Variables</u>	<u>Variable name</u>	<u>Range of values</u>	<u>Value labels</u>
				12= Pre-veterinarian
				13= Zoology
				(Social studies)
				14= Agricultural education
				15= Art education
				16= Bio-psychology
				17= Child development
				18= Economics
				19= Elementary education
				20= Journalism and economics
				21= Psychology
				22= Science and humanities
				(Business administration)
				23= Accounting
				24= Agricultural business
				25= Business
				26= Business administration
				27= Industrial administration
				(Architecture and Design)
				28= Architecture
				29= Interior design

<u>Column</u>	<u>Variables</u>	<u>Variable name</u>	<u>Range of values</u>	<u>Value labels</u>	<u>Key</u>
12-13	ACT	ACT	01 -34		
14-15	MSAT	MSAT	01 - 72		
16-17	GEFT	GEFT	01 - 18		
18	PLOT Item	PLT1	1 - 4	1=A, 2=B, 3=C, 4=D	3
19	"	PLT2	1 - 2	1=Correct, 2= Incorrect	
20	"	PLT3	1 - 4	1=A, 2=B, 3=C, 4=D	2
21	"	PLT4	1 - 2	1=Correct, 2= Incorrect	
22	"	PLT5	1 - 4	1=A, 2=B, 3=C, 4=D	4
23	"	PLT6	"	"	3
24	"	PLT7	"	"	2
25	"	PLT8	"	"	4
26	"	PLT9	"	"	4
27	"	PLT10	"	"	1
28	"	PLT11	"	"	3
29	"	PLT12	"	"	4
30	"	PLT13	"	"	1
31	"	PLT14	"	"	3
32	"	PLT15	"	"	1
33	"	PLT16	"	"	4
34	"	PLT17	"	"	4
35	PST Item	PST1	1 -	1= A & E (Correct) 2= A & B (Incorrect) 3= A & C ( " ) 4= B & E ( " )	

Column	Variables	Variable name	Range of values	Value labels	
36	PST Item	PST2	1 - 2	1= Correct, 2= Incorrect	1
37	"	PST3	1 - 3	1=Yes, 2= No, 3=Can't tell	2
38	"	PST4	1 - 2	1=Correct, 2=Incorrect	1
39	"	PST5	1 - 3	1=Yes, 2=No, 3=Can't tell	2
40	"	PST6	1 - 2	1=Correct, 2=Incorrect	1
41	Delayed PLOT	DPLT1	1 - 4	1=A, 2=B, 3=C, 4=D	3
42	"	DPLT2	1 - 2	1=Correct, 2=Incorrect	1
43	"	DPLT3	1 - 4	1=A, 2=B, 3=C, 4=D	2
44	"	DPLT4	1 - 2	1=Correct, 2=Incorrect	1
45	"	DPLT5	1 - 4	1=A, 2=B, 3=C, 4=D	4
46	"	DPLT6	"	"	3
47	"	DPLT7	"	"	2
48	"	DPLT8	"	"	4
49	"	DPLT9	"	"	4
50	"	DPLT10	"	"	1
51	"	DPLT11	"	"	3
52	"	DPLT12	"	"	4
53	"	DPLT13	"	"	1
54	"	DPLT14	"	"	3
55	"	DPLT15	"	"	1
56	"	DPLT16	"	"	4
57	"	DPLT17	"	"	4
58	Delayed PST	DPST1	1 - 4	1 = A & E (Correct) 2 = A & B (Incorrect)	1



<u>Column</u>	<u>Variables</u>	<u>Variable name</u>	<u>Range of values</u>	<u>Value labels</u>
				3 = A & C (Incorrect)
				4 = B & E ( " )
59	Delayed PST	DPST2	1 - 2	1= Correct, 2=Incorrect 1
60	"	DPST3	1 - 3	1=Yes, 2=No, 3=Can't tell 2
61	"	DPST4	1 - 2	1=Correct, 2=Incorrect 1
62	"	DPST5	1 - 3	1=Yes, 2=No, 3=Can't tell 2
63	"	DPST6	1 - 2	1=Correct, 2=Incorrect 1
64-66	Experiment time	EXT	001-200	(minutes)
67-68	Testing time	TT	01-80	(minutes)