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ABSTRACT
The designs, results, and conclusions of several related research studies which examine the role of student preferences in problem-solving strategies are summarized. Emphasis is upon the relationship between an individual's stated preference and his or her ability to implement this preference and successfully solve a related science task. Students between the ages of 15 and 22 were given an 18-item abstract preference survey consisting of 18 written problem-solving tasks. The subjects were to state their preferences concerning method for arriving at a solution to each task and later were given the opportunity to solve three tasks taken from the survey. Results indicate that there was no significant difference between the abstract preference scores for formal and concrete operational students, although there were significant differences between the abstract ability scores for these students. (MN)

David Dunlop

THE ROLE OF STUDENT PREFERENCES IN PROBLEM - SOLVING STRATEGIES

by

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TABLE 12-- High School Student's Preferred Method of Problem Solving

ABSTRACT

Several related research studies which examine the role of student preferences in problem-solving strategies will be summarized with an emphasis upon the relationship between an individual's stated preference and his or her ability to implement this preference and successfully solve a related science task.

INTRODUCTION

Although problem solving activities are an integral part of a unified science curriculum, we have not thoroughly explained the role of the many different variables which may influence the student's behavior and/or learning in this type of activity. A review of the literature will indicate that several researchers are using a Piagetian-type model to study human learning in problem solving activities. Further, many of these studies focus on or are related to the student's level of performance. Sayre and Ball (1) indicate that formal operational students tend to have better science grades than non-formal students taking the same course. They also report no significant difference in the performance of males and females on identical tasks. This, they state, is in contradiction to studies by Bridgham (2) and Elkind (3).

One variable which may influence a student's performance is his/her acquisition of logical structures (cognitive level of development). Sayre and Ball (1) seem to support this point of view when they state that the lower grades received by non-formal operational students may be due, in part, to their cognitive developmental stages, over which they have little control.

Raven (4) also recognizes the importance of the acquisition of logical structures in helping to determine the level at which a student will perform; however, Raven indicates that the acquisition of these structures can be facilitated through instruction.

Another variable which influences the level of operations at which a student functions is that of individual preference. This paper summarizes several studies (5, 6, 7) which investigated the role of an individual's preference in helping to determine the level at which that student preferred to function and the subsequent success in problem solving settings.

OBJECTIVES

This paper will summarize the designs, results, and conclusions of a series of studies which investigated one or more of the following hypotheses:

1. There is no significant difference in the cognitive level of development for college science students who are science majors and college science students who are non-science majors.
2. There is no significant difference in the abstract preference scores for college science students who are science majors and college science students who are non-science majors.
3. There is no significant difference in the cognitive level of development of students in grades 8, 9, 12, 13 (college freshmen), and 16 (college seniors).
4. There is no significant difference in abstract preference scores of students in grades 8, 9, 12, 13, and 16.

5. There is no significant correlation between abstract preferences in selecting methods to solve a problem and cognitive levels of development.
6. There is no significant difference between the manner in which students state that they will attempt to solve a problem and the manner in which they actually do attempt to solve the problem.

Further, this paper will contain a discussion of the degree to which formal and non-formal students are successful in using their preferred method of problem solving.

DESIGN

Several (between 116 and 466 depending upon the specific study) science students between the ages of 15 and 22 were given an 18-item abstract preference survey. This survey consisted of 18 written problem solving tasks and required the subjects to state their preferences concerning methods for arriving at a solution to each task. The methods of solution for each task were ranked by a panel of educators according to the degree of abstraction represented, thus allowing an abstract preference score to be calculated. The test-retest reliability for 28 people was 0.84. The validity of the preference instrument was based upon the theoretical construct for concrete and formal as described by the Piagetian developmental theory (8).

Students with a high level of abstract reasoning ability were identified by scores from the Shipley Test of Abstract Reasoning (9). This test is part of a scale for measuring intellectual impairment, and it was specifically designed to separate children of different abstraction ages. It is composed of twenty items, may be administered in 10 minutes, and the reliability coefficient obtained for 322 individuals was 0.89. This particular test was used because earlier studies have provided some evidence that groups of students with high abstract reasoning abilities are similar to groups of students found to be in the formal stage of operations as defined by traditional Piagetian types of tests (10). Additional groups and sub-groups were formed using the students academic major, content emphasis within a major, grade level, and sex.

Several days after the completion of the paper and pencil tests mentioned above, each student was individually interviewed and given the opportunity to solve three different tasks. These tasks were taken from the 18-item preference survey and included a fossil identification task, a balance problem, and an electrical circuit problem.

Records were kept which allowed comparisons to be made concerning the actual manner in which a student attempted to solve a problem and the manner which the student previously indicated as a preferred method of solution. The McNemar test for the significance of changes as described in Siegel (11) was used to examine the related null hypothesis.

RESULTS

Tables 1-9 focus on the abstract ability and the abstract preferences of several different groups of science students. Table 1 shows that there is no significant difference between the abstract preference scores for formal and concrete operational students. When sub-divided by sex, the same result is found.

Predictably however, there are very significant differences between the abstract ability scores for formal and concrete operational students.

Also predictable are the significant differences among five different grade levels; however, it is interesting to note the lack of significant difference among the preference scores for these five grade levels (Tables 2 and 3).

Table 4 includes the sub-groups of science and non-science majors with respect to their abstract ability and preference scores. Although a significant difference exists between these two sub-groups for their abstract preference scores, no such difference is evident for their abstract ability scores.

Tables 5-9 show the product moment correlations for several different groups of students using abstract preference scores and abstract ability scores as the two variables. Although there are a few significant correlations between these two variables, it is generally true that the correlations are relatively low.

The results of the McNemar test for the significance of changes are found in Tables 10-15. Several points may be made concerning the degree to which students change their preferences after actually being asked to solve a problem. (It should be noted that for Tables 10-15, task number one is the fossil identification problem, task number two is the electric circuit problem, and task number three is the balance problem.)

First, when considering all three tasks, there is a similarity of performance between males and females. That is, both groups of students generally have a significant change in their preference after being asked to solve the tasks. In tasks one and two this shift of preference is from the concrete mode to the abstract mode, while in task three the shift is in the opposite direction.

Second, the similarity that existed between the males and females is not evident when examining high school students in comparison with college students. In this situation we can see that the college students are less likely to shift their preferences than are the high school students. The high school students show significant changes in their preferences in tasks one and three; however, the direction of their shift is toward the abstract preference in task one but toward the concrete preference in task three.

When comparing the high abstract group (formal operational) with the low abstract group (concrete operational), we find that in tasks one and two the formal operational students are similar to the concrete operational students in the degree to which they changed their preferences. For both groups the shift in task one was toward the abstract mode and the shift in task two was not significant. In task three the high ability group made a significant shift toward the concrete mode, but the low ability group made no significant change in their preference.

The data from Tables 10-15 indicate that students made significant changes in their preference approximately 83% of the time in task one, 16% of the time in task two, and 66% of the time in task three.

Table 16 summarizes the percentages of concrete and formal operational students which attempted and successfully completed the task as they indicated on the preference survey. Although several concrete students preferred to solve problems in an abstract manner, they were unsuccessful in their efforts. However, the success rate for those who preferred to use the concrete approach was very similar for the formal and concrete operational students.

TABLE 1 - A Comparison Between Formal and Concrete Operational Children With Respect to Abstract Preference Scores and Abstract Ability Scores.

Group	n	$\overline{X}$	s	t
		Abstract Preferences (Males)		
Formal Operational	15	8.60	2.23	0.23
Concrete Operational	6	8.83	1.60	
		Abstract Preferences (Females)		
Formal Operational	36	8.58	1.71	1.35
Concrete Operational	17	7.88	1.87	
		Abstract Preferences (Combined)		
Formal Operational	51	8.59	1.86	0.99
Concrete Operational	23	8.13	1.82	
		Abstract Ability (Males)		
Formal Operational	15	18.73	0.88	7.36*
Concrete Operational	6	15.00	1.41	
		Abstract Ability (Females)		
Formal Operational	36	18.72	0.78	11.00*
Concrete Operational	17	15.47	1.37	
		Abstract Ability (Combined)		
Formal Operational	51	18.73	0.80	13.32*
Concrete Operational	23	15.35	1.37	

$*p < .001$

TABLE 2-- A one way Analysis of Variance of Abstract Ability Scores for Five Different Grade Levels.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Between Groups	4	313.67	78.5	14.51 *
Within Groups	288	1557.51	5.41	
Total	292	1871.18		

*p $<$ .01

TABLE 3-- A one way Analysis of Variance of Abstract Preference Scores for Five Different Grade Levels.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Between Groups	4	15.22	3.80	1.15
Within Groups	288	1004.78	3.49	
Total	292	1020.00		

TABLE 4-- A Comparison Between Science and Non-Science Majors at the College Freshman Level With Respect to Abstract Ability and Abstract Preferences Scores.

Group	n	$\bar{X}$	s	t
		Abstract Ability		
Science	200	17.66	1.62	0.85
Non-Science	266	17.80	1.94	
		Abstract Preference		
Science	200	8.18	1.90	3.83*
Non-Science	266	7.49	1.95	

*p < .001

TABLE 5-- Product-Moment Correlation Coefficients Between Abstract Ability and Abstract Preference Scores for Six Groups of College Freshmen.

Group	n	r	Level of Significance
Science	200	.05	n.s.
Non-Science	266	-.13	n.s.
Chemistry	24	.41	.05
Biology	121	-.02	n.s.
Natural Science	54	.08	n.s.
Total	466	-.07	n.s.

TABLE 6 - Product Moment Correlation Coefficients Between Abstract Ability and Abstract Preference Scores for Five Different Sub-Groups of High School Students.

Sub-Group	n	r	Level of Significance
Males	23	-.02	n.s.
Females	59	.13	n.s.
Formal	51	.08	n.s.
Concrete	23	.09	n.s.
Total Group	80	.09	n.s.

TABLE 7-- Product-Moment Correlation Coefficients Between Abstract Ability and Abstract Preference Scores for Five Different Grade Levels.

Grade Level	n	r	Level of Significance
8th	63	-.00	n.s.
9th	37	.01	n.s.
12th	102	-.26	.01
College Freshmen	95	.20	.10
College Seniors	27	.01	n.s.

TABLE 8-- Product-Moment Correlation Coefficients Between Abstract Ability and Abstract Preference Scores for Five Different Sub-groups of 8th Grade Science Students.

Sub-Group	n	r	Level of Significance
Males	29	-.21	n.s.
Females	34	.17	n.s.
High Abstract	3	.00	n.s.
Transitional	22	-.15	n.s.
Low Abstract	38	.26	n.s.

TABLE 9 -- Product-Moment Correlation Coefficients Between Abstract Ability and Abstract Preference Scores for Five Different Sub-Groups of College Freshmen.

Sub-Group	n	r	Level of Significance
Males	27	.39	.05
Females	68	.13	n.s.
High Abstract	61	.30	.02
Transitional	28	-.11	n.s.
Low Abstract	6	.82	.05

TABLE 10-- Female Student's Preferred Method of Problem Solving Before and After Being Asked to Solve the Actual Problem Solving Tasks.

TASK 1

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	7	11
	Concrete Method	42	23

$\chi^2 = 7.5^a$

TASK 2

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	12	28
	Concrete Method	21	22

$\chi^2 = 6.62^a$

TASK 3

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	17	10
	Concrete Method	50	6

$\chi^2 = 4.35^a$

[a] For 1 d.f. chi-square (.01) = 6.64, chi-square (.05) = 3.84

TABLE 11-- Male Student's Preferred Method of Problem Solving Before and After Being Asked to Solve the Actual Problem Solving Tasks.

TASK 1

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	2	2
	Concrete Method	15	14

$\chi^2 = 7.56^a$

TASK 2

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	7	3
	Concrete Method	15	8

$\chi^2 = 0^a$

TASK 3

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	15	4
	Concrete Method	11	3

$\chi^2 = 6.72^a$

[a] For 1 d.f. chi-square (.01) = 6.64, chi-square (.05) = 3.84.

TABLE 12-- High School Student's Preferred Method of Problem Solving Before and After Being Asked to Solve the Actual Problem Solving Tasks.

TASK 1

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	6	10
	Concrete Method	24	32

$\chi^2 = 16.45$[a]

TASK 2

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	12	20
	Concrete Method	24	16

$\chi^2 = 0.32$[a]

TASK 3

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	20	4
	Concrete Method	43	5

$\chi^2 = 7.84$[a]

[a]For 1 d.f, chi-square (.01) = 6.64, chi-square (.05) = 3.84.

TABLE 13-- College Students' Preferred Method of Problem Solving Before and After Being Asked to Solve the Actual Problem Solving Tasks.

TASK 1

		Actual Selection	
		Concrete Method	Abstract Method
Written Preference	Abstract Method	4	3
	Concrete Method	30	8

$\chi^2 = 0.75^a$

TASK 2

		Actual Selection	
		Concrete Method	Abstract Method
Written Preference	Abstract Method	7	12
	Concrete Method	12	14

$\chi^2 = 1.71^a$

TASK 3

		Actual Selection	
		Concrete Method	Abstract Method
Written Preference	Abstract Method	12	10
	Concrete Method	18	5

$\chi^2 = 2.12^a$

[a]For 1 d.f. chi-square (.01) = 6.64, chi-square (.05) = 3.84.

TABLE 14-- High Abstract Ability (Formal) Student's Preferred Method of Problem Solving Before and After Being Asked to Solve the Actual Problem Solving Tasks.

TASK 1

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	5	7
	Concrete Method	29	16

$\chi^2 = 4.76^a$

TASK 2

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	10	18
	Concrete Method	14	15

$\chi^2 = 0.64^a$

TASK 3

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	15	9
	Concrete Method	30	3

$\chi^2 = 6.72^a$

[a]For 1 d.f. chi-square (.01) = 6.64, chi-s are (.05) = 3.84

TABLE 15-- Low Abstract Ability (Non-Formal) Student's Preferred Method of Problem Solving Before and After Being Asked to Solve the Actual Problem Solving Tasks.

TASK 1

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	1	3
	Concrete Method	12	9

$\chi^2 = 4.90^a$

TASK 2

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	3	6
	Concrete Method	8	8

$\chi^2 = 1.45^a$

TASK 3

		Actual Selection: Concrete Method	Actual Selection: Abstract Method
Written Preference	Abstract Method	4	1
	Concrete Method	16	4

$\chi^2 = 0.13^a$

[a]For 1 d.f. chi-square (.01) = 6.64, chi-square (.05) = 3.84

TABLE 16-- Percentages of students attempting and successfully solving three tasks in the manner that they previously stated to be their preference.

Group	% Attempting Abstract Solution	% Successful	% Attempting Concrete Solution	% Successful
		TASK ONE		
Concrete	50.0	00.0	36.8	21.1
Formal	62.5	37.5	52.4	26.2
		TASK TWO		
Concrete	28.6	00.0	50.0	6.3
Formal	76.2	23.8	65.5	37.9
		TASK THREE		
Concrete	0.0	0.0	85.0	65.0
Formal	5.9	0.0	96.9	87.5

SIGNIFICANCE AND DISCUSSION

One possible conclusion which can be drawn from these studies is that the possession of logical operations does not insure, or even suggest, the cognitive level of development at which a student will prefer to operate. Further, when presented with an actual problem solving situation, it is clear that many low ability children will attempt to solve the problem in a formal operational manner. When this occurs the chance for success is very slight. On the other hand many high ability children will recognize that the most efficient solution to the problem is through the use of a concrete strategy. In these cases the chances of success are very high.

When considering the manner in which students change their preference, one can see that the direction of change (from an abstract approach to a concrete approach or vice versa) is more consistent within a given task for several groups of students than it is among several tasks for one group of students. One possible interpretation is that, for many students, actual preferences are task dependent. If this is true, teachers could, when appropriate, encourage abstract thought and abstract performance by judicial selection of classroom activities. By the same process, of course, teachers may be able to prevent concrete operational students from creating an incongruity between their ability and their preferences. This should then increase the rate of success for concrete operational students when they are working on a problem solving task.

When examining a total grade level, one may see that the low ability students are not any more likely to select a concrete method of problem solving than are the high ability students. This was also the case for subgroups within the 8th grade; however, because some of the subgroups within the college freshman level indicated moderate correlations, it is possible that as age increases, the relationship between abstract ability and abstract preferences becomes more pronounced.

If you were unable to attend the verbal presentation which accompanied this summary, the references will be valuable in providing additional detail and discussion.

APPENDIX A

The Shipley Test of Abstract Reasoning

Complete the following. Each dash (__) calls for either a number or a letter to be filled in. Every line is a separate item. Take the items in order, but don't spend too much time on any one.

start here

(1) 1 2 3 4 5 __

(2) white black short long down __ __

(3) AB BC CD D __

(4) Z Y X W V U __

(5) 12321 23432 34543 456 __ __

(6) NE/SW SE/NW E/W N/__

(7) escape scape cape __ __ __

(8) oh ho rat tar mood __ __ __ __

(9) A Z B Y C X D __

(10) tot tot bard drab 537 __ __ __

(11) mist is wasp as pint in tone __ __

(12) 57326 73265 32657 26573 __ __ __ __ __

(13) knit in spud up both to stay __ __

(14) Scotland landscape scapegoat __ __ __ __ee

(15) surgeon 1234567 snore 17635 rogue __ __ __ __ __

(16) tam tan rib rid rat raw hip __ __ __

(17) tar pitch throw saloon bar rod fee tip end plank __ __ __ __ __ meals

(18) 3124 82 73 154 46 13 __

(19) lag leg pen pin big bog rob __ __ __

(20) two w four r one o three __

APPENDIX B

Abstract Preference Survey

This is NOT a test, but rather a preference survey. There are no right or wrong answers--only preferences. It consists of 18 problems each of which may be solved by more than one method. (Assume all methods could, if properly used, result in a correct solution.) As you read the items, select the method which YOU would prefer to use in arriving at the solution. You do not need to actually solve the problem at this time--just indicate which method you would prefer to use if someone asked you to solve the problem.

1. You are given three pieces of metal and are asked to identify them as to composition. Which would you more likely do first?

   A. Consult references such as handbooks, textbooks, and read about the theory and about the theory and properties of metals.
   B. Test the metals with acids, bases, and other liquids in the laboratory to determine their properties.

2. You have just found an interesting fossil but don't know what it is. Which of the following methods would you use to identify the fossil?

   A. Study the fossil through written descriptions.
   B. Compare it to pictures which you have of various named fossils.

3. If you wanted to understand how a certain piece of equipment operated, would you

   A. Read the instructions as you examined and used the equipment.
   B. Read the instructions thoroughly prior to examining or using the equipment.

4. When driving in an area which is new to you, which of the following do you prefer to do?

   A. Decide upon the proper direction by "instinct" and/or reason.
   B. Decide upon the proper direction by using a map.

5. Read the following sentence: "I am very glad I do not like onions, for if I liked them, I would always be eating them, and I hate eating unpleasant things." Which of the following comments would you prefer to make concerning that sentence?

   A. Onions are unpleasant for some people to eat.
   B. There is a contradiction between "if I liked them" and "onions are unpleasant".

6. You want to learn how the parts of an electric motor fit together. In addition, you want to learn this as quickly as possible.. Which of the following would you choose?

   A. Look at diagrams and read how the parts fit together.
   B. Take an actual electric motor apart and see how the parts fit.

7. On your last birthday you were given a small wooden puzzle. It has about 12 pieces and when properly assembled, it forms a solid cube. You are anxious to assemble this as easily as possible. Would you best like to

   A. Follow a diagram of how to put the pieces together.
   B. Follow the verbal instructions of a friend.

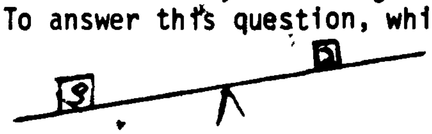
8. You are given a drycell battery, two light bulbs, some wires, and a switch. You are asked to hook up the materials in such a way as to make both lights burn at the same time. What would you more likely do first?

   A. Study about electric circuits, sketches, diagrams, and then draw some yourself.
   B. Take the given materials and actually manipulate them in order to get the system to work.

9. You have been given the task of determining a person's blood type. Which of the following best describes the method you would prefer to use in this determination?

   A. Using a sample of blood provided, you would test it in a laboratory to determine its type.
   B. Using an accurate family tree showing blood types of many blood relatives, (but not the type of the individual in question) you would determine the blood type of the individual by applying various principles of heredity and genetics which would be provided for you.

10. A 2 gram weight is placed exactly 6 centimeters to the right of a fulcrum. Another weight (3 grams) is placed 7 Cm to the left of the fulcrum. Where would the 3 gram weight need to be placed to have the system balanced? To answer this question, which of the following methods would you choose?



   A. A mathematical approach using formulas.
   B. Actual manipulation of the weights.

11. You have decided to play the role of a cook and wish to try making something you have never made before. Which of the following would you prefer to use as a source of instruction?

   A. Learn how to do it by watching a famous cook on T.V.
   B. Learn by reading one of the famous T.V. cook's book.

12. Given the same situation as above:

   A. Learn by having a neighbor explain it to you.
   B. Learn by watching a famous cook on T.V.

13. You have been given 2 chemicals in liquid form and asked what happens if they are mixed together. How would you prefer to find out?

   A. Using chemical principles, a probable solution could be deduced.
   B. Under controlled conditions the two chemicals would be mixed together and observations would be made.

14. You just bought a new game which is designed to illustrate the basic principles of genetics. How would you prefer to learn to play this game?

   A. Begin immediately and read the rules as you play.
   B. Read the rules until you understand how to play and then play.

15. You are about to build a picnic table for your own use in your backyard. Which of the following methods would you prefer to use in the building of the tables?

    A. Follow a set of plans (either your own or a set you purchased).
    B. Build the table "from your head" as you proceed.

16. You see a glass three-quarters full of water. When a stone is placed into the water, you notice the water level goes up. Which of the following would you prefer as a reason for your observation?

    A. The water will rise because the stone takes up space at the bottom.
    B. The stone is heavy; it will make the water rise.

17. If you were to visit a friend in another city for the first time, which of the following would you prefer to help you visualize the location of your fiends's home?

    A. A little map sketched out for you on a piece of paper.
    B. A verbal set of instructions given to you.

18. You have been given a square object of unknown composition. Its weight and size are known. You wonder if it will float if placed in various liquids such as alcohol, oil, water, and gasoline: How would you prefer to determine if this object would float in each liquid?

    A. By experimentation under controlled conditions, you would observe the results.
    B. Calculate the objects density and compare this to the density of the various liquids. Formulas which you needed would be provided.

REFERENCES

REFERENCES

1. Sayer, Steve and Daniel Ball, "Piagetian Cognitive Development and Achievement in Science," Journal of Research in Science Teaching, 12:165-174, April 1975.

2. Bridgham, R.G. "An Investigation of Piagetian Tests as Predictors of Student Understanding of Electrostatics," Doctor's Thesis, Harvard University, 1967.

3. Elkind, D. "Quantity Conceptions in Junior and Senior High Students," Child Development, 32:551-560, 1961.

4. Raven, Ronald, "Programming Piaget's Logical Operations for Science Inquiry and Concept Attainment," Journal of Research in Science Teaching, 11:251-261, 1974.

5. Dunlop, David L. and Frank Fazio, "A Study of Abstract Preferences in Problem Solving Tasks and Their Relationship to Abstract Ability and Formal Thought." Paper presented at the National Association for Research in Science Teaching Convention, Los Angeles, March 1975.

6. Dunlop, David L. and Frank Fazio, "Piagetian Theory and Abstract Preferences of College Science Students," Journal of College Science Teaching, 5:297-300, May 1976.

7. Dunlop, David L. and Frank Fazio, "Piagetian Theory and Abstract Preferences of Secondary Science Students," School Science and Mathematics, 77:21-26, January 1977.

8. Inhelder, Barbel and Jean Piaget, The Growth of Logical Thinking from Childhood to Adolescence, Basic Books, Inc., New York, 1958.

9. Shipley, Walter C. "A Self-Administering Scale for Measuring Intellectual Impairment and Deterioration," Journal of Psychology, 9:371-377, 1940.

10. Dunlop, David, "An Information Theoretic Analysis of Classification Sorting and Cognition by Ninth Grade Children Within a Piagetian Setting," Ph.D. Dissertation, University of Pittsburgh, 1973.

11. Siegel, Sidney, Nonparametric Statistics for the Behavioral Sciences, McGraw-Hill Book Company, New York, 1956.