DOCUMENT RESUME

ED 207 820 SE 035 609

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TITLE Conservation Reasoning Ability and Performance on BSCS Blue Version Examinations.
INSTITUTION California Univ., Berkeley. Lawrence Hall of Science.
SPONS AGENCY National Science Foundation, Washington, D.C.
PUB DATE Feb 75
NOTE 14p.

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Biology; *Cognitive Ability; *Cognitive Development; Cognitive Tests; *Conservation (Concept); High School Students; Individual Testing; Interviews; Science Course Improvement Projects; Science Education; Secondary Education; Secondary School Science; *Student Characteristics
IDENTIFIERS Biological Sciences Curr Study Blue Version; *Piagetian Tasks; *Science Education Research

ABSTRACT

Twenty-three high school biology students were individually administered three conservation tasks (weight, volume, volume displacement). During one semester, they were examined over the course material using published Biological Sciences Curriculum Study (BSCS) Blue Version examination questions which were previously classified as requiring either concrete or formal reasoning for successful completion. Two predictions were made and partially confirmed: (1) a significant relationship exists between a student's ability to conserve and his level of success on the examination items; and (2) nonconserving students do not score above the level of chance success on formal examination items. (Author)

CONSERVATION REASONING ABILITY AND PERFORMANCE ON BSCS BLUE VERSION EXAMINATIONS

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February, 1975

Introduction

The ability to recognize that a given quantity remains invariant across transformations in size, shape, configuration, or context is termed conservation reasoning. According to Piaget, "Every notion, whether it be scientific or merely a matter of common sense, presupposes a set of principles of conservation . . . ."[1,p.3] Piaget's contention is that conservation reasoning is a necessary condition of all rational thought. The literature on conservation is extensive and will not be reviewed here.** In general, the ability for individuals to demonstrate conservation reasoning depends to a great extent upon the quantity under consideration. In fact, conservations can be divided into two distinct types of quantitative invariants, the so-called first-order quantitative invariants (e.g., number, length, area, weight) and the so-called second-order quantitative invariants (e.g., volume, density, momentum, rectilinear motion).[3] Piaget considers the first-order conservations indexes of concrete operational thought and the second-order conservations indexes of formal operational thought. This is so because the latter presumably necessitate the simultaneous and coordinated applications of two reversibilities (reversal via reciprocity) to observed data while the former require only the successive applications of the two reversibilities (reversal via inversion-negation).[2] The simultaneous coordination of the two

* AESOP (Advancing Education Through Science Oriented Programs) is supported by a grant from the National Science Foundation.

** For a lengthy review of recent experiments on the development of conservation reasoning, see Brainerd and Allen.[2]

forms of reversibility is what constitutes the central acquisition at the stage of formal operations.

This discussion of conservation reasoning and its hypothesized role as a prerequisite for rational thought suggests that a strong relationship should exist between a student's ability to demonstrate conservation reasoning and his ability to profit from instruction in science.

The Problem

Lawson[4] found in samples of high school biology, chemistry and physics classes, students who were unable to demonstrate formal reasoning on a battery of classical Piagetian tasks, were also unable to demonstrate understanding of concepts previously designated as "formal operational." The examinations used to assess concept understanding were nonstandardized examinations constructed by Lawson. The aim of the present investigation is to examine, in a sample of high school biology students, the relationship between ability to conserve first and second-order quantitative invariants and ability to respond correctly to questions on published Biological Sciences Curriculum Study (BSCS) Blue Version examinations.[5] On the basis of Piagetian theory, it was predicted that students who demonstrated conservation reasoning would perform significantly better on the biology examinations than nonconserving students. Further, it was predicted that nonconservers would not demonstrate success above the level of chance on examination questions previously classified as "formal operational."

Method

Subjects. Twenty-three high school students (twenty males and three females), enrolled in an elective biology course which used the BSCS Blue Version as a textbook, served as subjects. The subjects ranged in age from 14.9 to 17.0 years; the mean age was 15.8 years. IQ data was not available; however, since the course was an elective and considered by the students to be relatively difficult, it attracted generally above average students. The high school is a modern and well equipped facility located near Kokomo, Indiana and enrolls approximately 900 students.

Procedure. Subjects were administered three conservation tasks in individual interviews. The tasks were the conservation of weight, conservation of volume using clay, and volume displacement. The conservation of weight task is considered to be a first-order quantitative invariant and, therefore, indicates concrete reasoning. The volume using clay task and the volume displacement task are considered to be second-order quantitative invariants and, therefore, indicators of early formal reasoning. Subsequent to administration of the tasks, the subjects were taught the regular course of study for approximately one semester. During the semester, six chapter examinations were given by the classroom teacher, (Chapters six through twelve). Each examination consisted of approximately twenty to thirty questions taken directly from the BSCS examination item book. Prior to selecting items from the BSCS examination item book, all the items were judged to require either concrete or formal thought for successful completion. In most cases about one half of the items selected for inclusion on the chapter examinations were classified as "concrete questions" and about one half were classified as "formal questions."

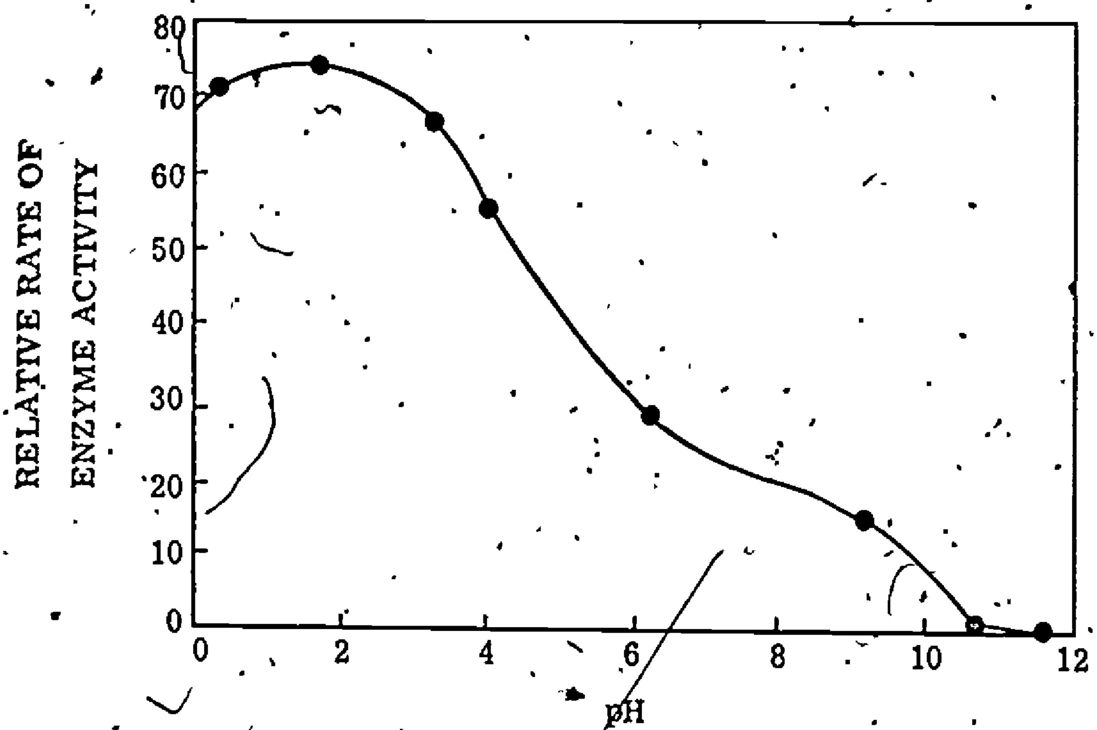
Questions were categorized as concrete if successful response required the student to:

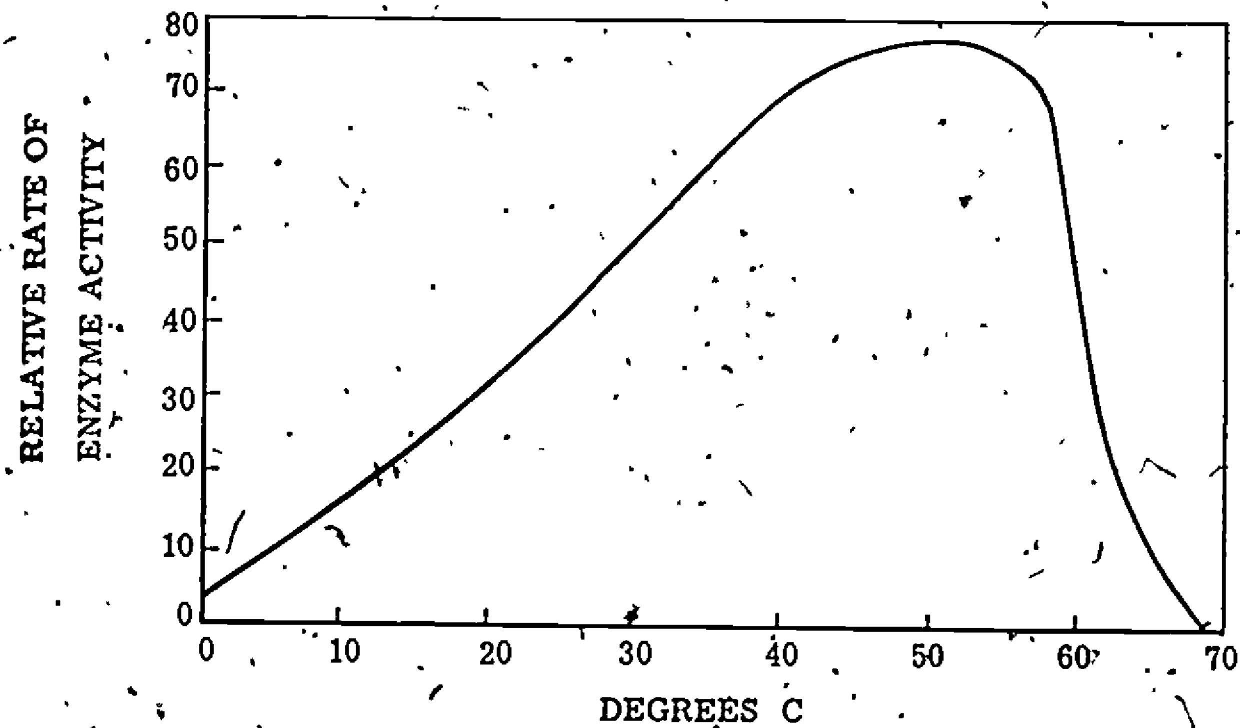
1. recall facts;
2. relate, make inferences, and draw conclusions from direct observation or from graphed data;
3. establish one-to-one correspondences between two sets of data;
4. apply a memorized algorithm;
5. understand concepts defined in terms of familiar objects and events.

Questions were categorized as formal if successful response required the student to:

1. reason hypothetically, i.e., with the form, if... then ... therefore;
2. use theories or idealized models to interpret data;
3. evaluate results of experiments and recognize ambiguous and unambiguous conditions, i.e., to understand the necessity for the control of variables and recognize hidden assumptions;
4. use proportional or probabilistic reasoning;
5. understand concepts defined in terms of other concepts or through abstract relationships.

<u>Example of concrete items</u> - Chapter Six [5], p. 35


RELATIVE RATE OF
ENZYME ACTIVITY
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
pH


RELATIVE RATE OF
ENZYME ACTIVITY
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
DEGREES C

The enzyme graphed will work best at a temperature of:

(a) 10°-20°C
(b) 20°-30°C
(c) 30°-40°C
(d) 40°-50°C

The enzyme graphed will work best in:

(a) an acid medium
(b) an alkaline medium
(c) a neutral medium
(d) a carbohydrate medium

These questions require a student to recall information such as the meaning of acid and alkaline in terms of pH and to draw direct conclusions from graphed data.

<u>Example formal item</u> -- Chapter Seven [5], p. 44

Fifty pieces of various parts of plants were placed in each of five sealed containers of equal volume. At the start of the experiment each jar contained 250cc of CO_2. The amount of CO_2 in each jar at the end of two days was as shown in the table.

Container	Plant	Plant part	Light Color	Temperature (°C)	CO_2 (cc)
1	myrtle	leaf	red	15	100
2	myrtle	leaf	red	27	50
3	myrtle	stem	blue	21	200
4	oak	root	blue	27	300
5	oak	leaf	orange	27	150

Assume that the experimental conditions not listed are identical in all five containers.

On the basis of the data in the table, you could properly compare the amount of CO_2 used per day at two different temperatures by comparing containers.

(a) 1 and 2
(b) 1 and 3
(c) 4 and 3
(d) 2 and 3

This question requires a student to recognize ambiguous and unambiguous experimental conditions, i.e., to understand the necessity for the control of variables.

The Conservation Tasks

Conservation of Weight.[6] Two balls of clay (50-g) were presented to the subject (S). After S agreed that they weighed the same, one ball was transformed into a pancake shape and S was asked: "Do the pieces of clay weigh the same? Does the pancake-shaped piece weigh more? Or does the ball weigh more? Why?" Responses were scored as correct if S answered that the pieces still weighed the same and justified his belief with one of the following arguments: (a) You did not add or subtract any clay. (b) They weighed the same before so they still weigh the same. (c) The "pancake" is flatter but it is also wider so it still weighs the same.

Conservation of Volume Using Clay.[6] The two balls of clay from the previous task were used. S agreed that two beakers (400-ml) contained the same amount of water and was asked: "When the pieces of clay are placed in the water, will the ball make the water level rise more? Will the "pancake" make the water level rise more? Or will they both make the water level rise the same? Why?" Responses were scored as correct if S answered that the pieces will make the water level rise the same and justified his belief by saying that it was because the pieces were equal in size, amount, or volume.

Volume Displacement.[7] Two metal cylinders of equal volume but different weight (18-g and 55-g) were handed S. The equal height and thickness of the metal cylinders were pointed out. The examiner then took the cylinders and lowered the lighter one into one of two test tubes (30-ml) which were partially filled with equal amounts of water. The rise in water level was noted and S was asked: "When the heavier cylinder is placed into the second test tube will the water level rise higher? Will the water level rise lower? Or will the water level rise the same as in the first test tube? Why? Responses were scored correct if the subject said that the water levels would rise the same and justified his belief by saying that it was because the metal cylinders were: (a) the same size, (b) the same height, (c) the same height and thickness, (d) took up the same space, or (e) were equal in volume.

On the basis of combined responses on the three tasks, students were placed into one of four groups as follows:

Group I - No conservation responses.

Group II - Conservation of weight only.

Group III - Conservation of weight and conservation of volume using clay or correct prediction and explanation on the volume displacement task.

Group IV - Conservation of weight, conservation of volume using clay, and correct prediction and explanation on the volume displacement task.

Results

Two of the twenty-three students showed no conservation reasoning and were placed into Group I. Four students conserved only weight and were placed into Group II. Three students conserved weight and volume using clay while seven students conserved weight and made correct predictions and explanations on the volume displacement task. These students were placed into Group III. Seven students demonstrated correct reasoning on all three tasks and were placed into Group IV. The reliability of the chapter examinations was calculated using the Spearman Brown split-half method.[8,p.457] The obtained reliability coefficient was .76 for the combined scores of all six examinations. The total number of examination items was 149.

Table I shows each group's percentage of correct responses on the concrete and formal examination items for the combined chapter examinations. For both concrete and formal examination items the percentage is larger for the group of students who demonstrated more conservation responses. Group differences for the concrete questions were significant at the .10 level ($F_{3,22} = 2.77$; $p = .07$). Group differences for the formal questions failed to reach significance at the .10 level ($F_{3,22} = 2.23$; $p = .12$).

TABLE I

Comparison of Group Mean Scores for Percentage of Correct Responses on the Concrete and Formal Examination Items

Variable		Group I (n=2)	Group II (n=4)	Group III (n=10)	Group IV (n=7)	F Ratio	Prob.
Concrete	$\bar{X}$	44.0	51.0	62.8	64.0	2.77	.07
Questions	sd	8.5	11.5	9.8	12.9		
Formal	$\bar{X}$	24.5	32.5	37.1	47.7	2.23	.12
Questions	sd	0.7	9.0	15.4	12.2		

Table II shows the percentage of correct responses on the concrete and formal examination items for each group of students after the percentages have been corrected for chance success.* Group differences for the concrete items after correction for chance success did not reach significance at the .10 level ($F_{3,22} = 1.59$; $p = .23$). Group differences for the formal items did reach significance ($F_{3,22} = 2.95$; $p = .06$). Of particular interest was the result that the nonconserving students (Group I) did not demonstrate success above the level of chance on the formal examination items.

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* This correction was performed using the following formula: $CP = \frac{KP-1}{K-1}$

Where CP = the corrected proportion of correct answers

P = the obtained proportion

K = the number of alternative answers to each item.[9]

TABLE II.

Comparison of Group Mean Scores for
Concrete and Formal Examination Items
After Correction for Chance Success

Variable		Group I (n=2)	II (n=4)	III (n=10)	IV (n=7)	F Ratio	Prob.
Concrete	$\bar{X}$	25.0	31.0	43.9	46.0	1.59	.23
Questions	sd	11.3	12.8	14.4	19.0		
Formal	$\bar{X}$	0.0	3.8	12.3	22.4	2.95	.06
Questions	sd	0.0	3.8	10.4	17.2		

Due to the fact that even the Group IV students responded correctly to such a small percentage of questions (46.0% of the concrete questions and 22.4% of the formal questions), it was decided to administer an additional Piagetian task which could assess higher levels of reasoning than those assessed by the conservation tasks. If the majority of students failed to demonstrate higher levels of reasoning, this could provide a possible explanation for the low percentage of success on the examinations. According to Piaget, the conservation of volume using clay task and the volume displacement task measure early formal reasoning. The task chosen to measure higher levels of reasoning was the bending rods task.* This task allows for categorization of responses into early concrete, late concrete, early formal and fully formal operational levels. On the basis of responses made on the bending rods task, one student (4.3%) was classified at the early concrete operational level, eleven students (47.8%) were classified at the fully concrete operational level, nine

* The bending rods task[10] tested the S's ability to identify and control variables. Given six flexible metal rods of varying length, diameter, shape, and materials which were fastened to a stationary block of wood, and hanging weights, S was asked to identify variables and demonstrate proof of the effect of each variable on the amount of bending of the rods. Piagetian level of performance on this task was assessed on the basis of the quality of S's verbal responses and their ability to exhibit the appropriate behavior. For a more detailed explanation of the task scoring procedures see Lawson, Nordland, and De Vito.[11]

students (39.1%) were classified at the early formal operational level, and two students (8.7%) were classified at the fully formal operational level. One of the two students classified at the fully formal operational level on this task was a Group III student, while the other was a Group IV student. Table III shows the correlations among the four Piagetian tasks and the concrete and formal examination questions. All correlations were positive and most reached significance ($p < .10$). The concrete conservation of weight task correlated more highly with the concrete examination items, while the formal bending rods task correlated more highly with the formal examination items.

TABLE III

Spearman Correlation Coefficients Among Piagetian Tasks and Concrete and Formal Examination Questions Before and After Correction for Chance Success

Task	Concrete Questions		Formal Questions	
	Before Correction	After Correction	Before Correction	After Correction
Conservation Weight	.52	.42	.39	.38
Conservation Volume	.28	.21	.42	.40
Volume Displacement	.33	.26	.31	.29
Bending Rods	.30	.21	.47	.47

rho = .30, $p < .10$; rho = .36, $p < .05$; rho = .49, $p < .01$.

Discussion

The finding that the majority of students in this sample performed below the fully formal operational level is similar to results of a number of previous studies.[12-17] The prediction that success on the conservation tasks is positively related to success on the content examinations was confirmed as was the prediction that students who were nonconservers of weight (early concrete thinkers) would not demonstrate success above the level of chance on examination questions previously classified as "formal operational." This result is supportive of Piaget's statement that conservation reasoning is a necessary precondition for abstract thought. It also is supportive of the hypothesis that a student who exhibits a lack of conservation reasoning ability is likely to encounter a great deal of difficulty in science courses which deal with abstract subject matter such as the BSCS Blue Version materials.

The fact that a student does demonstrate conservation reasoning however, in no way seems to insure his success in such a course. Even the best of conservers (Group IV) performed poorly on the examinations. One Group IV student, in fact, showed next to no success on the formal items (2% correct after correction for chance success). On the other hand, both Group I students scored above the level of chance on the formal items on the chapter six examination. One student scored 28% correct while the other scored 8% correct. Again on chapter eight, one Group I student scored 32% on the formal items. Both of these students scored 0% on formal items on other chapter examinations. This discrepancy, which is masked by simply looking at the total percentages in Tables I and II, suggests a number of possibilities: (1) perhaps these items were misclassified, (2) perhaps Piaget is not correct with regard to the importance of conservation reasoning and its general relation to concrete and formal thought, or (3) perhaps these students were able to obtain correct answers surreptitiously on these examinations. If number three were indeed the case and if Piaget were correct it would be hard to fault these students since it appears that they are being confronted with abstract subject matter presented on a verbal level and expected to understand it. According to Piaget, it is not possible for such students to develop understanding in this manner.

This research suggests that teachers would be well advised to obtain some information about their student's conservation abilities and use this information in making decisions about course content and method of presentation.

Synopsis

Twenty-three high school biology students were individually administered three conservation tasks (weight, volume, volume displacement). During one semester they were examined over the course material using published BSCS examination questions which were previously classified as requiring either concrete or formal reasoning for successful completion. Two predictions were made and were partially confirmed: (1) a significant relationship exists between a student's ability to conserve and his level of success on the examination items, (2) nonconserving students do not score above the level of chance success on formal examination items.

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