DOCUMENT RESUME

ED 191 715 SE 032 742

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TITLE Concrete and Formal Thinking Abilities in High School Biology Students as Measured by Three Separate Instruments. AESOP (Advancement of Education in Science-Oriented Programs) Paper.
INSTITUTION California Univ., Berkeley. Lawrence Hall of Science.
SPONS AGENCY National Science Foundation, Washington, D.C.
PUB DATE Nov 74
NOTE 13p.

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Biology; *Cognitive Ability; *Cognitive Measurement; Cognitive Processes; *Cognitive Tests; Course Content; Learning Theories; *Logical Thinking; Science Education; Secondary Education; *Secondary School Science
IDENTIFIERS *Piaget (Jean); Science Education Research

ABSTRACT

The purpose of this investigation was to classify a sample of high school biology students into concrete and formal operational levels using three separate instruments: (1) a battery of Piagetian tasks (the pendulum, bending rods, and the balance beam); (2) a written biology examination consisting of questions requiring concrete and formal operations; and (3) a subject-free examination also consisting of questions requiring concrete and formal reasoning. Using the obtained data, the authors' purpose was to determine if the logical operations under question were closely tied to specific content. Sixty-eight high school students (32 males and 36 females) enrolled in a biology course at Delphi High School in Delphi, Indiana served as subjects. The subjects did not perform more formally on the subject matter free Longeot examination and on the biology examination than on the Piagetian tasks. It was concluded that Piagetian tasks are relatively content free and can serve as realistic indicators of concrete and formal thinking abilities. (Author/DS)

CONCRETE AND FORMAL THINKING ABILITIES OF HIGH SCHOOL BIOLOGY STUDENTS AS MEASURED BY THREE SEPARATE INSTRUMENTS

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November 1974

*AESOP (Advancement of Education in Science-Oriented Programs) is supported by a grant from the National Science Foundation.

CONCRETE AND FORMAL THINKING ABILITIES IN HIGH SCHOOL BIOLOGY STUDENTS AS MEASURED BY THREE SEPARATE INSTRUMENTS

The use of Piagetian tasks such as the pendulum task and the balance beam task (Inhelder and Piaget, 1958) as measures of logical thinking ability has been criticized because the tasks appear to measure physics content and not the underlying cognitive operations which they purport to assess. For example, if a person fails to perform at the formal level on these tasks it may be because he simply has not been exposed to the specific physics content required by the tasks and not because he is a concrete thinker.

The purpose of this investigation was to classify a sample of high school biology students into concrete and formal operational levels using three separate instruments, (1) a battery of Piagetian tasks (the pendulum, bending rods, and the balance beam), (2) a written biology examination consisting of questions requiring concrete and formal operations, and (3) a subject matter free examination also consisting of questions requiring concrete and formal reasoning. Relationships among the classifications will be examined.

If the ability to perform the logical operations under question is closely tied to specific content, then it would be expected that subjects would perform more formally on the subject matter free examination and on the biology examination than on the Piagetian tasks. If on the other hand the Piagetian tasks are relatively content free, then subjects should perform at approximately equal levels on the Piagetian tasks and on the written examinations.

Method

Subjects

Sixty-eight high school students (32 males and 36 females) enrolled in a second semester biology course at Delphi High School in Delphi, Indiana served as subjects. The subjects ranged in age from 14 years-7 months to 17 years-10 months with a mean age of 15 years-5 months. Delphi High School is a modern school with over 800 students located in a rural section of North Central Indiana. The principal occupation of the residents is farming.

Instruments

The Piagetian Tasks. Three Piagetian tasks were administered in individual interviews. The tasks were (1) the pendulum (Inhelder and Piaget, 1958, pp. 67-79); (2) bending rods (Inhelder & Piaget, 1958, pp. 46-66); (3) equilibrium in the balance (Inhelder & Piaget, 1958, pp. 164-181). Since the tasks and scoring procedures have been described in detail elsewhere (Lawson, Nordland, and DeVito, 1974), only brief descriptions will be included here.

The Pendulum. Using a simple pendulum, this task tested the ability to control and exclude irrelevant variables. First E pointed out the independent and dependent variables. S was then given the problem of determining what variables affect the period. Since the only causal factor was the length of the string, the factors of weight of bob, angle of drop, and force or push must be excluded. This demonstration required understanding of the concept "all other things being equal."

Bending rods. This task tested the S's ability to identify and control variables. Given six flexible rods of varying length, diameter, shape, and material 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.

Equilibrium in the balance. Using a balance beam and hanging weights, this task tested the S's ability to balance various combinations of weights at various locations along the beam, e.g., given a 10 unit weight 7 units of length from the fulcrum, S was asked to predict the proper location of a 5 unit weight to achieve a balance. Successful completion of this task implied understanding of inverse proportion.

Level of performance on the three tasks was assessed on the basis of the quality of subjects' verbal responses and their ability to exhibit appropriate behaviors, i.e., to control variables on the exclusion, and separation of variables tasks, and to hang weights in correct locations on the equilibrium task. Task responses were categorized into the following four levels:

IIA.	Early concrete operational
IIB.	Fully concrete operational
IIIA.	Early formal operational
IIIB.	Fully formal operational

The biology examination.* A pencil and paper biology examination of 13 items was constructed by the authors and administered by the classroom instructor. Using biology content, the examination was designed to assess student's ability to use the concrete operations of conservation of weight, class inclusion, and serial ordering, and the formal operations of controlling variables, proportional reasoning, implication, combinatorial analysis, and lack of closure. Most questions required a multiple choice response plus an explanation. Some required essay type responses. Examples of the examination items follow.

Concrete item - serial ordering.

Four types of rats were bred for laboratory experiments. Type A rats were found to be more resistant to disease than type C rats. Type B rats were more disease resistant than Type C rats and Type D rats were more disease resistant than A rats. Which type of rats was least disease resistant?

A. type A rats
B. type B rats
C. type C rats
D. type D rats

Explain your choice.

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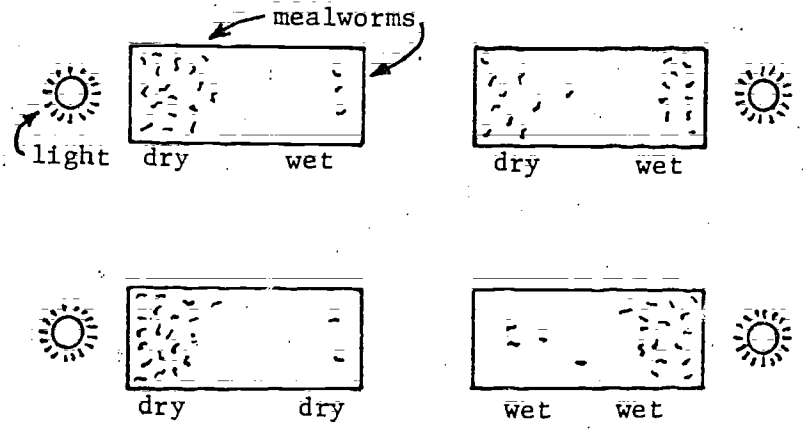
*Details of this examination may be obtained from the author (A.E.L.).

Formal item - controlling variables.

An experimenter wanted to test the response of mealworms to light and moisture. To do this he set up four boxes as shown in the diagram below. He used lamps for light sources and watered pieces of paper in the boxes for moisture. In the center of each box he placed 20 mealworms. One day later he returned to count the number of mealworms that had crawled to the different ends of the boxes.



The diagrams show that mealworms respond (respond means move to or move away from) to:

A. light but not moisture
B. moisture but not light
C. both light and moisture
D. neither light nor moisture

Explain your choice.

Scoring. Of the 13 examination items, 4 items required only concrete operations for successful completion, 8 items required formal thought and one item involved combinatorial analysis. Subject responses were classifed as follows:

IIA.	No concrete items correct and no formal items correct.
IIB.	At least one concrete item correct and no formal items correct.
IIIA.	At least one concrete and one formal item correct or one concrete item correct, no formal item correct, and the combinatorial problem correct.
IIIB.	At least one concrete and one formal item correct and the combinatorial problem correct.

For an item to be considered correct, S must select the correct response from among those given and provide a reasonable explanation for his selection.

The subject matter free examination. A pencil and paper examination developed by Longeot (Longeot 1962, Longeot 1965) was chosen as the subject matter free examination of concrete and formal thinking ability. This examination was administered to a groups of S's by the classroom instructor. The examination consisted of 19 items subdivided into four parts.* Part I included 4 concrete class inclusion and serial ordering questions. Part II consisted of proportionality problems of which two items required only concrete thought and 3 items required early formal thought (formal IIIA). Part III consisted of 6 problems called detective stories. Each problem involved propositional logic and was considered to require formal thought for successful completion. Part IV involved four combinatorial problems, two problems required concrete thought and two problems required formal thought.

Examples of the items are shown below:

Part I. Class inclusion - Concrete

Arthur is more agile than Bob
Bob is more agile than Donald

Conclusions:

A. Bob is the most agile of the three children
B. Arthur is the most agile of the three children
C. One cannot know

Part II. Proportionality - early formal.

The first garage holds 24 vehicles; there are 4 trucks and 20 cars there now. The second garage holds 54 vehicles; it now has 9 trucks and 45 cars in it. The third garage holds 36 vehicles, with 6 trucks and 30 cars in it now. Unknown to the drivers, each garage has a "Lucky Parking Spot." In which garage is it most likely that a truck is parked in the lucky spot?

Conclusions:

A. In the third garage for it contains more trucks than the first garage and fewer cars than the second garage.
B. In the second garage for this one contains the most trucks.
C. In the first garage for this one contains the fewest cars.
D. In any of the garages, for they all have the same number of trucks in relation to the total number of their vehicles.

Part III. Propositional logic - formal

If you are going to go swimming then it is nice weather.
If you are going boating, then it is nice weather.
Finally, you are going boating.

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*The original Longeot examination consisted of 28 problems. A few problems from each section of the original were omitted to shorten the examination to allow its administration during one class period.

Conclusions:

A. It is nice weather.
B. It is not nice weather.
C. You are going swimming.
D. You are not going swimming.
E. One cannot know whether you are going swimming.

Part IV. Combinatorial Analysis - formal:

How many numbers of two figures are there when the numbers are made with the figures 1, 2, 3, 4, 5? Write the total amount of numbers on the answer sheet. (Do all the figuring in your head.)

Scoring. According to procedures described by Longeot, Ss were categorized into the Piagetian levels on each part of the examination as follows: Part I, 0-2 items correct placed S into level IIA; 3-4 items correct placed S into level IIB. Part II, 0-1 IIA; 2-3 IIB; 4-5 IIIA. Part III, 0 IIB; 1-3 IIIA; 4-6 IIIB*. Part IV, 0 IIA; 1-2 IIB; 3 IIIA; 4 IIIB.

Subjects were also classified in substages using a procedure adopted by Sheehan (Sheehan, 1970). The procedure combines responses on all four parts of the examination to obtain an overall classification of thinking ability for each S. Again since only 19 of the original 28 questions of the Longeot test were used, the scoring procedures were slightly modified as follows. Subjects with 0-5 of the concrete items correct and no formal items correct were classified into level IIA. Subjects with 6-8 of the concrete items and 0-4 of the formal items correct were classified into level IIB. Subjects with 7-8 concrete items correct and 4-6 of formal items correct were classified into level IIIA. Subjects with 7-8 of the concrete items correct and 7-11 of the formal items correct were classified into level IIIB.

Results and Discussion

Percentages of subjects classified into each Piagetian substage on the basis of the Piagetian interview tasks and the written examinations are shown in Table 1.

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*Since the Longeot examination uses a multiple choice format, some correct responses could be obtained by chance alone. Because of the scoring procedures used in Part III these correct responses would be reflected in increased levels of thinking ability. This error was avoided by adjusting the scores as follows. Ss who got no items correct were classified as IIB thinkers. Ss who got one of the 6 items correct were classified as formal IIIA thinkers. However, since the probability of getting each problem correct by chance was .1 and since there were 6 problems, the probability of scoring one of 6 correct by chance alone and being misclassified at level IIIA was $6(.1 \times .9^5) = .35$. For this reason, .35 of the Ss who scored 1 item correct were reclassified into the IIB level.

Table 1

Percentages of Students Classified into Concrete and Formal Levels on the Basis of Piagetian Tasks, the Biology Examination and the Longeot Examination*

Level	Piagetian Tasks (N=65)				Biology (N=67)	Longeot (N=63)				
	Pend.	Bending Rods	Balance	Combined Tasks		CI-SO	Prop.	Logic	Combina-Torial	Composite Score
IIA	12	3	3	2	23	11	8		2	15
IIB	40	40	35	45	42	89	41	49	20	42
IIA	43	54	56	50	27		51	49	22	35
IIIB	5	3	5	3	8			2	56	8

*Blanks indicate that the examination items did not allow classification of subjects into these levels. Not all 68 subjects were administered all measures due to absence during the testing.

An overall level of performance was also obtained for the three Piagetian tasks taken together. If a subject scored at level IIB on the one task and at level IIIA on the other two tasks he was placed into level IIIA. If a subject scored at level IIB on two tasks and level IIIA on the third task he was placed into level IIB, etc. These percentages are shown in the fourth column of Table 1. The last column of this table shows percentages of subjects classified into the substages using the Sheehan classification method. A comparison of overall results from the three separate measures shows similar percentages of subjects at the concrete and formal levels. Using the Piagetian tasks 46% of the Ss were classified as concrete thinkers. On the basis of the biology examination 65% were classified at the concrete level, while on the Longeot examination 57% of the Ss were classified at the concrete level.

Table 2 shows contingency matrices which compare the number of Ss classified into each Piagetian substage on each measure. Table 2a compares classification of subjects on the Piagetian tasks with their classification on the Longeot examination. A chi square analysis of these data yielded at significant relationship between the classfications ($\chi^2 = 17.95$, df = 9, $p<.02$). Table 2b compares classifications of subjects on the Piagetian tasks and the biology examination. A chi-square analysis of these data yielded a significant relationship between the classifications ($\chi^2 = 20.70$, df = 9, $p<.02$). Table 2c compares classifications of subjects on the Longeot examination and the biology examination. A chi-square analysis of these data also yielded a significant relationship ($\chi^2 = 19.73$, df = 9, $p<.02$). In general these matricies show relatively consistant classifications of subjects across the three measures. Minor discrepancies were possibly due to measurement errors. The reliabilities of the Longeot examination and the biology examination were substantial (KR-20 = .85 and .98 respectively) however, the reliability coefficient of the Piagetian tasks was only moderate. (Spearman-Brown = .67).

In reference once again to Table 1, notice that only the combinatorial problems of the Longeot examination showed a substantial percentage of students classified at the formal IIIB level. Fifty-six percent of Ss were categorized as fully formal IIIB thinkers with respect to combinatorial ability. A possible explanation for the much larger percentage of IIIB responses on these questions than any other measure may be that the combinatorial items (such as the one given as an example above) which were designed to require formal IIIB thinking for successful completion did in fact only require formal IIIA thinking. If this was the case then subjects who obtained correct responses on these items were incorrectly categorized at the IIIB level. According to Longeot, the example combinatorial item mentioned earlier requires formal IIIB thinking only if the problem is solved without the use of pencil and paper. Notice that the problem tells Ss to do all the figuring in their heads. Marks on some examination booklets, however, indicated that a number of Ss did in fact not follow this directive. Further evidence to support the contention that the Longeot combinatorial items did not require formal IIIB thinking was the fact that only 14% of the Ss correctly solved the formal IIIB level combinatorial item which appeared on the biology examination. A further possible explanation for this large percentage is that the students may indeed be at the formal IIIB level with respect to combinatorial ability while at the same time they may be at the concrete or formal IIIA level with respect to the other abilities. This explanation suggests the possibility that the combinatorial operations may develop prior to, or be a prerequisite for, the development of proportional reasoning, propositional logic, and the ability to control variables.

Table 2

Contingency Tables Comparing Level of Subject Classification on the Combined Piagetian Tasks, Biology Examination and Longeot Examination

a.

		Longeot Examination Level			
		IIA	IIB	IIIA	IIIB
Piagetian Tasks Level	IIA	1	0	0	0
	IIB	6	13	5	2
	IIIA	2	11	14	2
	IIIB	0	1	2	1

b.

		Biology Examination Level			
		IIA	IIB	IIIA	IIIB
Piagetian Tasks Level	IIA	1	0	0	0
	IIB	10	14	4	1
	IIIA	2	15	11	3
	IIIB	0	0	3	1

c.

		Longeot Examination Level			
		IIA	IIB	IIIA	IIIB
Biology Examination Level	IIA	3	8	0	0
	IIB	5	14	8	1
	IIIA	1	4	10	3
	IIIB	0	1	3	1

Conclusions

Since subjects did not perform more formally on the subject matter free Longeot examination and on the biology examination than on the Piagetian tasks, the hypothesis that students perform poorly on the Piagetian tasks because of their specific physics content has not been supported. The conclusion which seems to be required is that the Piagetian tasks are relatively content free and can serve as realistic indicators of concrete and formal thinking abilitities. The increasing number of investigations (e.g., Keasey 1970, Elkind 1961, Karplus and Peterson 1970, Karplus and Karplus 1970; Kohlberg and Gilligan 1971, Higgens-Trenk and Gaite 1971, Lawson and Renner 1974, Lawson, Blake and Nordland 1974) which show large percentages of adolescents and adults operating at the concrete level on Piagetian styled tasks represents a much more serious educational issue than would be the case if the tasks were as content biased as some educators believe. Clearly more research should be initiated to determine not only the extent to which this apparent lack of formal thinking ability affects ability to deal with hypothetical situations and abstract concepts in the classroom but also to determine the extent to which it affects an individual's ability to function as an effective problem solver in everyday experience.

Acknowledgement

The authors wish to express sincere appreciation to Professor Floyd H. Nordland of Purdue University, Mr. David Hanna, and Mr. Robert Feldman of Delphi High School for their cooperation and assistance in conducting this investigation. Both authors were funded by a National Science Foundation grant to Purdue University during the time in which this investigation was initiated. For that support we are deeply grateful.

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