DOCUMENT RESUME

ED 038 320 SE 008 323

AUTHOR Butts, David P.; Howe, Ann C.
TITLE The Effect of Instruction on the Acquisition of Conservation of Volume.
INSTITUTION Southwest Educational Development Lab., Austin, Tex.; Texas Univ., Austin. Science Education Center.
PUB DATE [70]
NOTE 11p.

EDRS PRICE EDRS Price MF-$0.25 HC-$0.65
DESCRIPTORS Cognitive Development, *Concept Formation, *Conservation (Concept), *Elementary School Science, *Instruction, Intellectual Development, *Learning
IDENTIFIERS Piaget

ABSTRACT

Tested was the hypothesis that science instruction based on task analysis will lead to the acquisition of the ability to perform certain Piaget volume tasks which have been characterized as requiring formal operations for their solutions. A Test on Formal Operations and a Learning Hierarchies Test were given to fourth- and sixth-grade students in a school which had used "Science - A Process Approach" and to fourth- and sixth-grade students in another school which had not used "Science - A Process Approach". After pretesting, students at each grade level at each school were divided by random assignment into experimental and control groups. The experimental groups received instruction based on learning hierarchies which incorporated ideas of Gagne; the control groups received instruction not related to hierarchies. All children were posttested with instruments used as the pretest. It was found that ability to perform the volume tasks at fourth-grade level may be related to experience in "Science - A Process Approach". A similar relationship with sixth-grade students was not found. A positive correlation was found between mental age and performance on the Test on Formal Operations. The results seem to support Piaget's theory of equilibration. (BR)

THE EFFECT OF INSTRUCTION ON THE ACQUISITION OF CONSERVATION OF VOLUME

Ann C. Howe
Southwest Educational Development Laboratory
Austin, Texas

David P. Butts
Science Education Center
University of Texas
Austin, Texas

The extent to which intellectual development may be promoted by classroom science experiences and the conditions under which such development may be maximized are subjects of continuing interest. Piaget's cognitive-developmental theory stresses the role of processes which are internal to the learner and not dependent on instruction or other outside events. Children are believed to move through stages which represent a progressive organization and reorganization of experience to form mental structures capable of accommodating and assimilating new material. The essential difference between one stage and another is a difference in the child's mode of thinking. In spite of the large amount of research which has been undertaken to confirm and extend Piaget's theory, there is still little agreement as to how or whether instruction can affect this developmental sequence (1, 2).

Another approach to the problems of classroom learning has been taken by Gagné (13). He has proposed a cumulative learning theory which does not postulate developmental stages and focuses on task performance. He believes that a task can be performed if subordinate competencies are identified, described in behavioral terms, and taught in sequence. Readiness depends upon previously acquired behaviors or

capabilities rather than upon a mental structure which can assimilate the new material. When this theory is translated into classroom practice, children are taught to perform tasks in a sequence which is partly determined by logical analysis and partly by trial-and-error. Science - A Process Approach is an elementary school science program which is based in part on the work of Gagné. The program is composed of learning sequences which are believed to "represent a progression of intellectual development of the individual" (4).

Intellectual development is assessed by Piaget through the use of tasks which children are asked to perform. A child's stage of development is indicated by the successful performance of certain tasks and the inability to perform others. The growth of the concept of volume has been studied by the use of tasks related to displacement volume and volume as occupied space. Piaget used the term "conservation of volume" to refer to an abstract conception of volume which is not usually formed before the age of 11 or 12.* Successful performance of these volume tasks is taken as an indication that a child is able to use formal operational reasoning processes which are not accessible to children in an earlier concrete operational stage.

The work reported here was undertaken with fourth and sixth grade children. Its purpose was to assess the effect on acquisition of conservation of volume of (a) experience in a science program based on Science - A Process Approach, (b) experience in an instructional program based on task analyses of the conservation-of-volume tasks.

*Conservation of volume should not be confused with conservation of continuous quantity which is sometimes referred to as "conservation of liquid."

The Sample

The subjects of the study were 189 fourth and sixth grade students from eight classrooms of two public schools in middle-class neighborhoods in Austin, Texas. There were 48 fourth and 48 sixth grade students who had had instruction in Science - A Process Approach for at least 15 months prior to testing. There were 43 fourth and 50 sixth grade students who had never had such instruction. The mean ages were 10.2 years for fourth grade and 12.2 years for sixth grade. Scores on the California Test of Mental Maturity (CTMM) were used as an indication of mental ability.

Instruments

A test of Volume Concepts was developed by adapting for group presentation four items on displacement volume (Volume Task I) which were described by Piaget (5) and have been used by other investigators (6, 7), and three versions of an item described by Piaget (5) on volume as space occupied (Volume Task II). The tasks were presented by the examiner to a group of children; the children marked individual response sheets. Pass-fail criteria were established for each task. Data are reported as the number or percent of children who were able to perform each of the two tasks.

A hypothesized cumulative learning sequence or hierarchy was developed for each task. The terminal tasks were Volume Task I and Volume Task II. The learning hierarchies were developed by following a procedure outlined by Gagné (3) for the construction of a learning hierarchy for a conservation task. Suggestions made by Lunzer (6) for a learning sequence for displacement volume were also used.

The Learning Hierarchies Test (LHT) was composed of 18 items designed to test for each of the capabilities in the learning hierarchies. The administration of this test was similar to the administration of the Test of Volume Concepts. In each case the examiner demonstrated problems with objects. On the Learning Hierarchies Test the pretest and posttest scores of 96 control subjects gave a Pearson product moment correlation coefficient of 0.70.

Method

The study was designed to include two types of control groups, one for experience in Science - A Process Approach (S-APA) and one for experience in the instructional program based on the learning hierarchies. The control and experimental groups for Science - A Process Approach were previously assembled groups which were not constituted by random assignment, and there was no way to determine whether the two groups were equivalent before one of them had instruction in Science - A Process Approach. Therefore, the control was not a "true" control. The school which was chosen to supply this control group was as nearly equivalent to the school which used Science - A Process Approach as it was possible to obtain from the schools which were available. Campbell and Stanley (8) call this design the Static Group Comparison.

The control groups for the instructional program based on the hierarchies, on the other hand, were constituted by random assignment within each grade level at each school. This is the Pretest-Posttest Control Group Design of Campbell and Stanley (8). Since this design has a "true" control, any differences in the effect of

instruction found within one school may be accepted with more confidence than differences found between schools.

All children were pretested with the two instruments described above. The children from two classes at each grade level in each school were pooled and assigned at random to an instruction or a control group. There were a total of eight groups. Those assigned to an instruction group received instruction based on the learning hierarchies one period per day for five days; the control groups received instruction for the same length of time but the instruction was unrelated to the learning hierarchies. All instruction groups were taught by the same teacher. The children were provided with a variety of manipulable objects and were allowed freedom for the interchange of ideas. The program was conducted under classroom conditions. Nine days after the end of the instructional period (three weeks after pretest) all children were posttested on the two instruments.

Findings

An indication of the effect of experience in the S-APA program was sought by comparing performances on the pretest of the Test of Volume Concepts by computing chi square from 2 x 2 contingency tables. A statistically significant difference ($p < .01$) was found in performance on Volume Task I between the fourth grade children who had been in the S-APA program and those who had not. Because of a difference in mean CTMM scores, the data were reanalyzed by means of a multilinear regression model, using CTMM scores as a covariable. The difference between the groups remained statistically significant.

Since the fourth grade children who had been in the S-APA program performed better on Volume Task I than the other fourth grade children, it was expected that there would be a similar difference between the sixth grade groups, but such a difference was not found. There was no significant difference between the performance on Volume Task I of the fourth grade group which had had S-APA and the performances of the two sixth grade groups. This suggests that an understanding of displacement volume may, under certain conditions, be attained earlier by some children than others but that differences which are present at fourth grade have disappeared by sixth grade.

The overall proportion of children who were able to perform Volume Task II was lower than the proportion who were able to perform Volume Task I. Differences between groups in performance on Task II were not great enough to be statistically significant.

On the pretest of the Learning Hierarchies Test, a significant difference ($p < .01$) was found between the means of the two fourth grade groups and between the two sixth grade groups, with those who had been in the S-APA program having higher scores in each case.

All groups who received instruction based on the learning hierarchies had posttest scores on the Learning Hierarchies Test which were higher than the respective control-group posttest scores. The differences between the means were statistically significant ($p < .05$) in three cases. The greatest gain was made by the group with the lowest pretest score and the highest scores apparently approached a ceiling. (See Table II.)

TABLE I

Comparison of Groups on Pretest of Volume Concepts Test

Grade	Program	Frequencies Neg.	Pos.	Chi Square
		TASK I		
4	S-APA	30	18	14.3[a]
	No S-APA	41	2	
6	S-APA	28	20	0.19
	No S-APA	27	23	
		TASK II		
4	S-APA	40	8	1.19
	No S-APA	38	5	
6	S-APA	43	5	3.96
	No S-APA	37	13	

a:sig. at .01

TABLE II

Comparison of Groups on Learning Hierarchy Test Score Changes

Grade	Program		Means Pre	Post	Gain	Diff. in Gain	S_D^2	t
4	S-APA	Instr.	12.6	14.8	2.2	1.7	7.7	2.12[b]
		Control	11.6	12.1	0.5			
	No S-APA	Instr.	8.1	12.9	4.8	4.1	12.3	3.83[b]
		Control	7.0	7.7	0.7			
6	S-APA	Instr.	14.6	15.9	1.3	0.7	5.7	1.0
		Control	14.5	15.1	0.6			
	No S-APA	Instr.	12.8	14.2	1.4	1.5	5.6	2.20[b]
		Control	13.0	12.9	-0.1			

b: sig. at .05

There was no group which showed a statistically significant improvement in performance on either Volume Task I or II. The instructional program brought about a higher level of performance on the tasks of the Learning Hierarchies but did not bring about a statistically significant increase in the proportion of children who could perform the criterion volume tasks.

The test of a learning hierarchy is whether successful performance of all the tasks of the hierarchy leads to successful performance of the criterion task. A positive correlative was found between score on the Learning Hierarchies Test and performance on Volume Tasks I and II, as shown in Figure 1. Biserial correlation coefficients of 0.53 and 0.31 for Task I and Task II were found. Figure 1 indicates that of those who scored 17 or 18 on the Learning Hierarchies Test, 60 percent were able to perform Task I and 40 percent were able to perform Task II. When these figures were broken down into grade levels it was found that more sixth graders than fourth graders with high scores on the Learning Hierarchies Test were successful on Volume Tasks I and II. Table III gives the percentages for those who scored 17 or 18 on the posttest of the Learning Hierarchies Test.

TABLE III

Percent Of Children With High LHT Score
Who Were Successful On Volume Tasks

Grade	Task I	Task II
4	46	23
6	64	43

Competence in the tasks of the hierarchy seems to be more useful to a sixth grader than to a fourth grader in performing the volume tasks. Something is apparently needed which is not represented in the hierarchies and, whatever it is, sixth graders have more of it than fourth graders.

The results show that ability to perform the volume tasks of this study is related to performance of the competencies of the learning hierarchies but no specific level of performance was found to be necessary or sufficient.

A question which is often of interest in studies using Piaget-type tasks is whether there is a positive correlation between age and performance of the tasks. Figure 2 shows the percent of students in each age range who were able to perform the tasks; Figure 3 is similar except that mental age, rather than chronological age, is used.

There were six students in the sample who were able to perform both Tasks I and II on pretest and posttest. These six may be said to have a stable and well-formed concept of volume. When data for each of these students were examined, it was found that the common factors were a mental age of at least 12.5 and a high score on both pretest and posttest of the Learning Hierarchies Test.

Discussion

The promotion of intellectual development is one of the goals of several of the recently developed elementary science programs. If this goal is being met, it might be expected that children who had

been in such a program would perform Piaget tasks at an earlier age, or in greater proportion, than children who had not been in such a program. In the present study the fourth grade children who had been in such a program outperformed those who had not, on one of the tasks; there were no other cases in which those who had been in the program performed better. If the children who have been in such a program have experienced greater intellectual development but do not have necessary information to perform the tasks, then the provision of necessary information should lead to a higher level of task performance. This work was, in part, an attempt to determine by task analysis what information and skills were necessary for performance of the criterion tasks, and to provide the necessary information and experiences through an instructional program. The data indicate that the volume concepts necessary for performance of the criterion tasks were not developed under the conditions of this experiment, regardless of the age, mental ability, or previous science experience of the students.

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