DOCUMENT RESUME

ED 305 268 SE 050 482

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TITLE A Comparison of the Effect of a Systematic Modeling Approach and the Learning Cycle Approach on the Achievement of Integrated Science Process Skills of Urban Middle School Students.

PUB DATE 89

NOTE 32p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (62nd, San Francisco, CA, March 30-April 1, 1989).

PUB TYPE Reports - Descriptive (141) -- Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.

DESCRIPTORS Cognitive Processes; *Discovery Learning; Discovery Processes; Junior High Schools; Learning Activities; Learning Processes; *Learning Strategies; Learning Theories; *Middle Schools; *Modeling (Psychology); Models; Piagetian Theory; Process Education; Science Instruction; *Secondary School Science; *Urban Youth

IDENTIFIERS Science Education Research; *Systematic Modeling

ABSTRACT

Previous research has shown a relationship between formal reasoning ability and science process skill attainment. It has been hypothesized that an increased emphasis on teaching process skills might enhance the formal thinking abilities of students. A variety of strategies have been proposed to better accomplish this task, most notable, the learning cycle approach. There has been little research in science education on the use of modeling strategies for promoting process development and/or logical thinking. This paper deals with the overall relationship of Piagetian theory to science process development and with strategies for promoting more effective learning, teaching, and assessment of science process skills and/or logical thinking. The purpose of this study was to determine which of two teaching strategies would promote higher achievement of integrated process skills with urban middle school students. Furthermore, growth in the logical thinking of students was also measured. The two teaching strategies tried were a systematic modeling approach and the learning cycle approach. Students of both the modeling teachers and the learning cycle teachers outperformed those of a nonequivalent control group on integrated process skills. Modeling was found to be significantly superior to the learning cycle for promoting this achievement. (MVL)

A COMPARISON OF THE EFFECT OF A SYSTEMATIC MODELING APPROACH AND THE LEARNING CYCLE APPROACH ON THE ACHIEVEMENT OF INTEGRATED SCIENCE PROCESS SKILLS OF URBAN MIDDLE SCHOOL STUDENTS

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Introduction

The use of science process skills in problem solving is an important approach advocated by the National Science Teachers Association (1971). The scientific approach to problem solving is based on defining a problem, suggesting possible solutions to the problem and then testing to determine whether the solution suggested is correct. It is hoped that individuals proficient in these science process skills will not only make better scientists, but also better citizens, able to question the technological events of their world.

Certain basic and integrated science process skills have been agreed upon as essential goals in science education (Gagne', 1965; NSTA, 1983). The basic skills are observing, inferring, measuring, communicating, classifying and predicting. The integrated process skills include the ability to make hypotheses, identify and control variables, define operationally, interpret data and experiment (AAAS, 1967). Research has reported a strong relationship between these science process skills and an individual's formal reasoning ability (Tobin & Capie, 1982). It has not been determined whether or not this is a causal relationship.

Although many elementary and secondary science curricular materials place a strong emphasis on developing integrated science process skills, the majority of students in grades 6-8 are still unable to use these processes (Tobin & Capie, 1980). Many students also fail to demonstrate formal reasoning ability, even by the time they reach college age (Chiappetta, 1976).

This lack of success in promoting integrated science process skills and formal reasoning ability in students may be a function of how process skills have been presented and developed by teachers. Often, process skills are taught by presenting students with a series of probing questions designed to lead them successfully through a given process. This is really an interrogation approach to teaching, and perhaps an approach better suited for evaluation than for the development of new skills.

Educators have also used a discovery and/or inquiry approach to science education (Trowbridge and Bybee, 1986). These methods are used in an attempt to teach the processes of science by giving students the opportunity to perform activities requiring the use of process skills. Since many students do not have mastery of the skills required for discovery and inquiry, they may go through the motions of the activity without engaging in the desired mental tasks.

In this study it was assumed that a student lacking skills in science processes would not be able to respond successfully to activities or questions requiring the application of integrated science process skills. Before students are asked to practice process skills, and before questions are used for evaluation, students must be given the opportunity to develop these skills.

Modeling strategies have been used in various content areas to promote this type of process skill development. In modeling, one focuses attention on the process being taught, and in this manner the learner is provided with concrete sets of observable operations tied to abstract principles. Educators specializing in staff development, such as Madeline Hunter (1984), promote modeling as an integral part of all lesson design.

The use of modeling originated with the work of Bandura (1969). He defined modeling as a process of learning through observing and imitating others. His theory focused on methods of modifying social behaviors based on cognitive processes. Modeling was used to provide rules that observers could use to guide their own performance.

For example, a modeling teaching strategy has been used to teach inference skills to students who demonstrate poor reading comprehension (Gordon, 1985). Inference is a process that is considered very important in reading comprehension as well as in science problem solving. Using this strategy, the teacher first defines the inference process for students. Then the teacher answers inferential questions about a segment of text while providing reasons for these answers. In the next phase of the procedure the teacher again answers inferential questions about a segment of text but this time asking the students to provide reasons to support the teacher s answers. Finally, the students are asked to make their own inferences and supply their reasons aloud. Only after the inference making skill is in place are students asked to practice this skill on their own by answering the questions provided by the reading curriculum .

Modeling of arithmetic skills has also been found to be more effective than didactic instruction (Schunk, 1981). In addition, the writing process has been taught using modeled instruction.

Teachers are encouraged to think aloud about their own writing efforts and then to model the processes they used in their own writing in order to improve student writing (Harris, 1983).

Since many of the process skills being addressed in reading, math and writing are related to science process skills, one would expect modeling strategies to be effective in science instruction as well. However, very little research has been done on the use of modeling to promote science process skill achievement. Sumners (1979) reported the successful use of a science fiction novelette to model science process skills. Allison and Shigley (1986) have shown that the percentage of operational questions asked by students was increased by teacher modeling followed by student practice. No studies have been found which have attempted to increase integrated science process skills in students through systematic teacher modeling.

The systematic modeling teaching strategy examined in this study was based on a strategy developed by Cramer (1977) and studied by Spencer (1986). This strategy was developed to promote the inference forming skills necessary for reading comprehension. It consists of four steps: Analogy, Modeling, Applying and Practice. Through these steps, the teacher, by thinking aloud, leads the student gradually through the cognitive processes required for successful inference formation.

Since a relationship between formal reasoning abilities and science process skill achievement has been demonstrated (Tobin & Capie, 1982; Padilla, Okey & Dillashaw, 1983), it has been proposed that teaching process skills may enhance formal thinking abilities. In a study using college students, Jones (1983) found that teaching basic and integrated process skills did result in an increase in logical reasoning abilities. Many process oriented science curricula are based on the assumption that this causal relationship is also true with middle school and high school science students. If teacher modeling can increase student process skill achievement, formal reasoning abilities may also demonstrate a corresponding increase.

Purpose

The purpose of this study was to determine if a systematic modeling instructional approach affects the achievement of integrated science process skills and/or formal reasoning ability of middle school science students. Specifically, the following four research questions were addressed:

1. Do students who have received modeled instruction of integrated science process skills demonstrate any significant difference in their achievement of these process skills when compared with students in control groups?

2. Do students' cognitive developmental levels affect integrated process skill achievement?

3. Will students who are at a concrete developmental level manifest different achievement of science process skills with modeled instruction than will students who are at a formal operational level of cognitive development?

4. Do students who have received modeled instruction of integrated science process skills demonstrate significant

differences in their logical reasoning abilities when compared with students in control groups?

Sample

The sample in this study consisted of 327 sixth through ninth grade students in a large urban school system whose teachers were enrolled in a university inservice education course which emphasized the teaching of science process skills. Students in this study can be characterized as having a low socio-economic status (SES) and also exhibit lower than average basic skill abilities.

Although these students were grouped into pre-existing sections, the sections and teachers were randomly assigned to treatment groups.

Procedures

The treatment in this study consisted of two phases. During the first phase, a group of urban middle school teachers were instructed in the science process skills and taught to use a specific strategy when teaching these skills to their students. In the second phase, these inserviced teachers evaluated and taught basic and integrated science process skills to their students using their assigned strategy.

Thirteen middle school science teachers from the Detroit Public School system completed an inservice course at Wayne State University which consisted of ten, three hour sessions. These sessions were held between January and March, 1988 and were designed to train teachers in both basic and integrated science process skills. A series of process skill lessons (Norman, 1988) along with the book Learning Science Process Skills (Funk & Okey, 1979) were used for this training.

Half of these teachers were trained to use a systematic modeling strategy and the remaining teachers were trained to use a well established control methodology, the learning cycle. Three additional teachers, from the same Detroit schools, who had not received the university training, participated in this study.

The systematic modeling experimental treatment used in this study was adapted from the four level Inference Demonstration Procedure developed by Cramer (1977). This procedure was used to increase inferential reading comprehension (Spencer, 1986). This modeling technique consisted of the following parts:

Part 1: Concept and Process Skill Introduction

The instructor introduced the student activity and the necessary process skills. An effort was made to help students relate this activity and the required processes to previous student experiences. Examples from common everyday experiences were used to help make this transfer.

Part 2: Instructor Modeling

The teacher performed a demonstration which required the use of the science process skill being addressed. The teacher answered a series of questions about the demonstration while modeling the use of this process skill. Thinking aloud, the teacher presented reasons to support all answers given.

Part 3: Instructor Modeling and Student Response

The teacher repeated the procedure described in Part 2, using a second demonstration and questioning sequence. As the teacher was answering the suggested questions, he/she solicited reasons to support the answers from the students.

Part 4: Student Independent Practice

Students practiced the skill in question by performing the student activity and answering the questions provided. Students worked with partners and were encouraged to think aloud about the reasons for their answers. During this part of the procedure, the teacher moved around the room monitoring the student responses, adjusting instruction where necessary. After completing the activity, the students shared their answers and their reasons for supporting these answers with other members of the class.

The learning cycle strategy, used by the teachers who instructed the control treatment group of students, was a well established inductive approach (Karplus & Thier, 1967; Renner, Abraham & Birnie, 1983). This teaching strategy divided instruction into the following three phases:

1. Gathering Data Phase

Students performed an activity designed to introduce and develop a process skill.

2. Conceptual Invention Phase

Teacher and class discussed the activity students had completed and through this discussion further developed the process skill being addressed.

3. Concept Expansion Phase

Students performed additional activities to further develop the process skill.

In this learning cycle approach, the process skill being addressed was not modeled initially. The teacher merely announced the skill to be used and students then explored and experienced the science process in a problem solving context. After completing an independent activity, students, with teacher guidance, reflected on what had been done. The students then applied the skill to a new situation.

Teachers used their assigned strategies to teach their students a series of fifteen process skill lessons during a three month time interval. Students in both the modeling and learning cycle groups were introduced to the same science process skills. These processes were taught using student activities and discussion. Teachers were required to teach one lesson on each basic science process skill to their students. These were selected from activities presented in the university class and from ones developed by the teachers. In addition, each teacher taught ten integrated process skill lessons. Five of these lessons were adapted from the generic ones used in the university class and the other five, written by the teacher, had been evaluated and corrected during those class sessions.

Teachers administered an integrated process skill achievement test and a formal reasoning test to their students before and after process skill instruction.

A third, non-equivalent control group of three teachers was selected from the same Detroit middle schools. These teachers administered the pretest and posttest to one of their science classes. These teachers received no special training and taught their regular science curriculum.

Instrumentation

The two tests selected to evaluate students and teachers who participated in this study were the Middle Grades Integrated Process Skill Test (Cronin & Padilla, 1986) and the Group Assessment of Logical Thinking (Roadrangka, Yeany & Padilla, 1983). Both were used for pretesting and posttesting subjects.

Middle Grades Integrated Process Skill Test (MIPT)

This test was designed to measure a student's ability to use integrated science process skills by using a paper and pencil, group testing format. The objectives addressed in this test include identifying researchable questions, formulating hypotheses, identifying variables, designing an experiment, recording data and interpreting data. Objectives and test items used in Dillashaw and Okey's Test of the Integrated Science Process Skills (1980) were selected and modified by Cronin and Padilla (1986) for middle school use. This revised test did not require specific content knowledge or well developed reading skills.

Content validity was established by Dillishaw and Okey (1980) for the items used in this test by giving a panel of experts in science education a copy of the test items and a list of the outcomes. The panel was asked to identify which test items corresponded to which outcomes. The panel also completed the items in order to verify the scoring key. Experts agreed with developers on the assignment of test items to objectives 95% of the time. They agreed with the scoring of the items 97% of the time. This concurrence was taken as evidence of test item validity.

The overall reliability was established by Cronin and Padilla (1986) with a Kuder-Richardson value of 0.89. The field test used consisted of 1152 seventh grade students.

Group Assessment of Logical Thinking (GALT)

This test was designed to measure concrete and formal operational reasoning. (Roadrangka et al., 1983) It evaluated the student's ability to use conservational thinking, proportional reasoning, probabalistic reasoning, correlational reasoning, combinatorial reasoning and to isolate and control variables. The determination of the developmental levels of learners using individually administered Piagetian Tasks requires a specially trained interviewer and is extremely time consuming. In order to evaluate the cognitive level of a large sample of students, before and after administration of the treatment, a pencil and paper group test was selected. The test contained pictorial representations of real objects. The questions were presented in multiple choice format. The students not only had to select an answer but also had to select the reason or justification for making their selection.

Convergent validity was established by Roadrangka and others by comparing the results of this group test with results obtained from the same individuals using Piagetian interview tasks. A correlation of 0.80 was obtained between the classification of an individual through the use of GALT and by using the interview results. Construct validity was argued for on the basis of a single factor solution of correlated sub-tests and the ability to predict process skill achievement on the Test of Integrated Process Skills (Dillashaw & Okey, 1980)

Reliability was established by Roadrangka and associates by calculating internal consistency values. An adequate Cronbach's alpha value of 0.85 was obtained.

Statistical Analysis

Data analysis was accomplished by employing a 3x2 factorial analysis of covariance on the student measure of integrated science process skills. The MIPT posttest results, adjusted for pretest scores, were evaluated with respect to both teaching strategy and initial student cognitive reasoning level. The systematic modeling strategy was compared to both the learning cycle control strategy and to a traditional control strategy. For the analysis, students were divided into 'concrete' and 'above concrete' reasoning levels, according to their GALT pretest scores.

In addition, the GALT posttest results, adjusted for initial cognitive reasoning ability, were compared for the three groups of students who experienced different teaching strategies. Once again, analysis of covariance was used.

Results

Class means and their corresponding standard deviations for the MIFT can be found in Table 1. Table 2 reports the means, standard deviations and adjusted means for the separate cells of the ANCOVA performed on the student MIPT results. The ANCOVA F value obtained (89.3) with 2 and 320 degrees of freedom for the first main effect, integrated process skill ability between strategy groups, was significant at the 0.05 level (see Table 3). Results obtained from the Bartlett-Box F test were not significant at the 0.05 level and thus supported the assumption of homogeneity of variance associated with this method of analysis.

In order to determine which groups accounted for the difference found in the ANCOVA, a posteriori comparisons were made. The Scheffe´ method of multiple comparisons was used to analyze paired contrasts (see Table 4). Once again, an alpha level of 0.05 was used to test for statistical significance. These comparisons showed a significant difference between the non-equivalent comparison group and both of the groups taught by teachers who were trained in the process skill inservice program. There is also a significant difference on the adjusted mean scores of the systematic modeling treatment group and the learning cycle, control group.

Upon examination of the adjusted means of each group (see Table 5), it can be noted that the means of both groups taught by inserviced teachers were higher than the mean of the non-equivalent comparison group. The systematic modeling group also produced a higher mean score on the MIPT than did the control group using the learning cycle strategy.

These results suggest that the systematic modeling teaching strategy was significantly superior to both the learning cycle control strategy and the traditional control strategy with regard to integrated science process skill achievement. The results also indicate that students whose teachers had received special university inservice training demonstrated significantly higher integrated process skill achievement than did students whose teachers had not received special process skill and strategy training.

An F value of 84.1 was obtained for the second main effect, integrated process skill ability with respect to cognitive levels, and was found also be significant at the 0.05 level. The adjusted mean obtained for the 'above concrete' group was higher than that obtained for the concrete group (see Table 6). These results imply that concrete operational students were less able to achieve integrated science process skills than were students at a higher cognitive reasoning level.

The F value obtained for the interaction term of the ANCOVA, which tests the effects of teaching strategy and cognitive level on integrated process skill ability, (see Table 3) was not significant at the 0.05 level. This suggests that students at a concrete operational level did not appear to benefit more from the systematic modeling teaching strategy than did students at a higher cognitive level.

Class means and their corresponding standard deviations for the The Group Assessment of Logical Thinking (Roadrangka, et al.,

1983) are found in Table 7. Table 8 presents the ANCOVA analysis of these results with respect to the three strategy treatment groups. Cell size, means, standard deviations and adjusted means are reported in Table 9. The means on this instrument were extremely low, and as a result, small actual raw score differences resulted in large standard deviations.

The ANCOVA F value obtained (77.9) with 2 and 323 degrees of freedom, when comparing formal reasoning ability between strategy groups, was significant at the 0.05 level. In order to determine which groups account for this difference, a posteriori comparisons were made. The Scheffe' method of multiple comparisons was used to analyze paired contrasts (see Table 10). Once again, an alpha level of 0.05 was used to test for statistical significance. These contrasts showed a significant difference between the treatment group and the learning cycle control group. There was also a significant difference between the learning cycle, control group and the non-equivalent, control group. No significant difference was obtained between the systematic modeling treatment group and the non-equivalent control group. The learning cycle control group had the highest adjusted mean of the three groups for the formal reasoning measure. The other two groups recorded the same adjusted mean values (see Table 9).

It should be noted that results obtained from the Bartlett-Box F test were significant at the 0.05 level and, therefore, the assumption of homogeneity of variance was violated. There are varied opinions on how failure to meet this assumption would effect the robustness of this analysis (Glass, 1972).

Results obtained through this analysis of student formal reasoning ability with respect to teaching strategy suggests that students who received systematic modeled instruction of integrated science process skills did not demonstrate greater growth in cognitive reasoning ability than did students who had received the control treatments.

Discussion and Implications

The results obtained in this study largely support the Cramer paradigm (1977) on the importance of teacher modeling during process skill instruction. Students who experienced the systematic modeling teaching methodology demonstrated greater integrated science process skill achievement than those who experienced the control teaching strategies, learning cycle or traditional. This would imply that students can better develop process skills when given the opportunity to observe and imitate a person who has mastery of the skill, practice the skill with the expert's guidance and finally practice the skill independently.

The learning cycle control treatment also resulted in integrated process skill achievement superior to that of the non-equivalent comparison group. This would indicate that teachers who have received science process skill instruction, regardless of the strategy used, are better able to promote process skill achievement in their students. Both groups, whose teachers participated in the university science process skill inservice, demonstrated greater achievement than those students whose teachers had not received special training. These results are consistent with prior studies which found that preservice teachers who had participated in classes which emphasized science process skills could better promote these skills in their students (Jaus, 1975; Campbell & Okey, 1977; Bluhm, 1979). This would imply that mastery of science process skills is important for successful instruction, regardless of whether this mastery is used to model the skills for students or to guide their independent discoveries toward concept formation. A teacher who can perform a science process skill can better help students achieve process skill mastery. This mastery cannot be assumed and must be a goal of inservice as well as preservice teacher education.

This study supports previous research by reporting that students with higher cognitive reasoning ability can better achieve integrated science process skills (Tobin & Capie, 1982; Padilla, Okey & Dillashaw, 1983). This does not imply that concrete operational students cannot achieve these skills, but rather that they do not do so as well as students who are above the concrete operational cognitive level. This would lead one to believe that concrete operational students need more attention and guidance in order to master the higher level integrated science process skills.

Concrete operational students did not show a greater benefit in integrated science process skill achievement from the modeling strategy than did the students who were at a higher cognitive level. Students all seemed to benefit equally well from this methodology. The implication is that all types of students can improve their skills by observing the actions and listening to the reasoning of an expert. Formal operational students, however, can achieve these skills more easily than can concrete operational students, regardless of the strategy used.

This study failed to demonstrate that a systematic modeling teaching strategy can promote cognitive reasoning ability. The mean scores for students on the GALT were extremely low. The instrument used to evaluate cognitive reasoning ability may have been too difficult for the student sample in this study. Although the learning cycle group did demonstrate significantly greater ability at the end of the study, it should be noted that this group also had a higher mean score on the pretest. Even though the analysis adjusted for initial ability, a student at a higher cognitive level may be better prepared for cognitive growth than is a student with lower reasoning ability.

These results might also suggest that the learning cycle strategy is superior for promoting formal reasoning ability. Prior studies have reported that the learning cycle strategy can promote student intellectual growth (Schneider & Renner, 1980; Purser & Renner, 1983). This would be consistent with the fact that this strategy's original development was based on Piaget's theory of cognitive development (Karplus, 1977).

Before definite conclusions and implications can be drawn, a more sensitive instrument would have to be used as a measure of cognitive ability. An effort must also be made to insure more equality between the subject groups according to initial cognitive reasoning ability. The necessity of having to use intact classes of teachers who completed the university inservice, made it impossible to get a truly random group assignment.

Additional questions exist about the internal validity of this study which should be examined. There was a large teacher and student sample mortality, and one must question whether this affected the outcome of the study. It was also difficult to be certain that teachers used their assigned strategies during all of the lessons. The same problems, however, existed for both of the treatment groups and were not systematic in nature.

In summary, it appears that if science process skill achievement is to be supported as a major goal in science education, teachers must first be trained in the process skills. Then they should be trained to use an effective teaching strategy. The systematic modeling and learning cycle control treatments were more effective than the traditional methodologies used by the non-equivalent comparison teachers who had not participated in the university inservice. In order to improve student process skill achievement, however, teachers should be trained to think aloud or use metacognition while modeling integrated science process skills for their students during their science lessons. Students should be given the opportunity to participate in the reasoning process, by imitating their teachers metacognitive processes. Only when students have demonstrated mastery of the skill themselves, should they be encouraged to practice the skill independently or in small groups.

Students at a concrete operational level find these skills more difficult to master and, therefore, they may need longer periods of modeled instruction, followed by more opportunities for imitation, before they begin independent practice. Formal operational students, grouped with these concrete individuals, could also act as models and help guide their reasoning processes during science activities. This type of heterogeneous grouping might give concrete operational students the increased opportunities they need to watch and imitate exemplary modeling of integrated science process skills.

Suggestions for Further Research

The significant results obtained, along with the threats to the internal validity of this study, suggest that one could benefit from repeating this study with certain modifications. First of all, the instrument used to measure cognitive ability must be altered to better evaluate populations of students who have extremely low cognitive reasoning skills. In addition, teachers should spend more time practicing their assigned strategy. Teachers in this study found it difficult to consistently implement a new and different teaching methodology.

When repeating this study, one should attempt to increase the treatment time beyond the three months used in this study. A longer exposure to modeled instruction of integrated science process skills may result in the improved cognitive reasoning ability this study was unable to demonstrate.

The importance of mastery of basic science process skills for the successful achievement of integrated skills should also be investigated. Researchers might instruct teachers to attempt to achieve mastery of the basic skills through systematic modeling before attempting to model the more complex integrated skills.

Further research could also attempt to determine which process skill abilities respond best to modeled instruction. Certain skills, such as controlling variables, could be targeted for in depth instruction and evaluation.

Finally, since teachers who participated in the process skill inservice were better able to promote process skill achievement in their students, one could also determine whether there is a relationship between teacher mastery of specific process skills and subsequent student achievement of these skills.

Table 1

Class Means and Standard Deviations for the Middle Grades Integrated Process Skills Test (MIPT)

Teacher*	n	Pretest[c]		Posttest[c]	
		mean	s.d.	mean	s.d.
Modeling					
3	14	9.6	2.7	12.0	3.7
6	20	10.0	2.4	13.8	1.4
8	8	10.4	5.7	10.5	4.8
9	21	10.8	2.2	11.3	3.6
10	15	8.3	3.2	7.5	3.2
11	15	13.8	4.0	18.2	4.9
Control I[a]					
13	29	15.0	4.0	14.7	4.2
14	23	18.2	4.0	22.0	3.2
16	26	14.8	5.2	15.7	4.8
20	21	15.6	4.6	17.2	4.4
22	12	9.3	1.7	8.8	3.0
23	24	8.0	3.4	10.7	3.9
25	18	9.7	3.3	10.4	3.1
Control II[b]					
A	11	6.5	2.9	11.7	3.9
B	27	12.3	3.4	6.8	2.3
C	28	12.3	4.5	10.7	4.7
Total	327	12.2	4.8	13.4	5.4

* Teacher numbers refer to those in Tables 1 & 2

[a] Learning Cycle Treatment Group

[b] Non-equivalent Comparison Group

[c] Total test items = 28

Table 2

Cell Means, Standard Deviations and Adjusted Means for Two-Way ANCOVA of Teaching Strategy by Cognitive Level with Respect to Integrated Process Skill Ability

Cell[b] Number	n	Pretest Mean	Pretest s.d.	Posttest Mean	Posttest s.d.	Adjusted Mean[a]
1	99	10.7	3.8	12.7	4.9	14.5
2	9	13.2	3.8	18.3	5.4	18.1
3	121	12.6	5.1	14.0	5.4	14.3
4	32	16.4	4.9	17.3	5.5	14.6
5	61	11.1	4.3	10.2	4.1	11.6
6	5	13.8	5.7	14.0	5.2	13.4
Total	327	12.2	4.8	13.3	5.5	

[a] Adjusted for pretest scores

[b] Key for cell numbers:

Cognitive Level	Teaching Strategy: Modeling	Control I	Control II
Concrete	1	3	5
Above Concrete	2	4	6

Table 3

Two-Way ANCOVA of Teaching Strategy by Cognitive Level with Respect to Integrated Process Skill Ability

Source	ss	df	ms	F
Among Strategies	178.5	2	89.3	6.51*
Between Cognitive Levels	84.1	1	84.1	6.13*
Interaction Strategy x Level	74.7	2	37.4	2.73
Error	4386.3	320	13.7	

* $p < 0.05$

Table 4

Scheffe' Comparisons Between Teaching Strategies with Respect to Adjusted Mean Scores on the MIPT

Comparison[a]	Computed Value	Table Value
1 vs 2	1.9*	1.15
1 vs 3	3.8*	1.43
2 vs 3	1.9*	1.34

* $p < 0.05$

[a] Strategy 1: Modeling
Strategy 2: Control I (Learning Cycle)
Strategy 3: Control II (Non-equivalent comparison)

Table 5

Strategy Group Means, Standard Deviations and Adjusted Means for the Middle Grades Integrated Process Skill Test (MIPT)

Group	n	pretest		posttest		adj.
		mean	s.d.	mean	s.d.	mean[a]
Modeling	108	10.9	3.8	13.1	5.2	16.3
Control I[b]	153	13.4	5.3	14.7	5.6	14.4
Control II[c]	66	11.3	4.4	10.4	4.3	12.5
Total	327	12.2	4.8	13.4	5.5	

[a] Adjusted for pretest scores

[b] Learning Cycle

[c] Non-equivalent comparison

Table 6

Class Means and Standard Deviations for the Group Test of Logical Thinking (GALT)

Teacher*	n	Pretest[c] mean	Pretest[c] s.d.	Posttest[c] mean	Posttest[c] s.d.
Modeling					
3	14	1.9	1.1	1.8	0.7
6	20	2.0	1.4	1.8	1.2
8	8	1.4	1.0	2.0	1.4
9	21	0.8	1.0	2.3	2.4
10	15	1.8	1.3	1.0	0.8
11	30	2.8	2.0	2.7	1.4
Control I[a]					
13	29	4.2	3.5	5.0	4.1
14	23	4.0	2.2	5.0	2.6
16	26	2.3	1.6	3.9	2.0
20	21	3.8	1.4	7.5	2.0
22	12	2.3	1.4	1.7	1.2
23	24	1.5	1.0	2.4	1.7
25	18	2.6	1.5	2.3	1.4
Control II[b]					
A	11	1.2	1.2	1.3	1.1
B	27	1.7	1.7	1.6	1.4
C	28	2.6	1.4	2.8	2.2
Total	327	25	2.0	3.0	2.6

* Teacher numbers refer to those in Tables 1 & 2

[a] Learning Cycle Treatment Group

[b] Non-equivalent Comparison Group

[c] Total test items - 12

Scale
0-4: Concrete Operational Level
5-7: Transitional Level
8-12: Formal Operational Level

Table 7

Cognitive Level Group Means, Standard Deviations and Adjusted Means for the Middle Grades Integrated Process Skill Test (MIPT)

Group	n	pretest		posttest		adj.
		mean	s.d.	mean	s.d.	mean[a]
Concrete	281	11.6	4.6	12.7	5.2	13.5
Above Concrete	46	15.5	4.9	17.1	5.5	15.4
Total	327	12.2	4.8	13.3	5.4	

[a] Adjusted for pretest scores

Table 8

One-Way ANCOVA of Teaching Strategy with Respect to Formal Reasoning Ability

Source	ss	df	ms	F
Among Strategies	155.9	2	77.9	18.8*
Error	1341.7	323	4.2	

* $p < 0.05$

Table 9

Strategy Group Means, Standard Deviations and Adjusted Means for the Group Assessment of Logical Thinking Test (GALT)

Group	n	pretest		posttest		adj.
		mean	s.d.	mean	s.d.	mean[a]
Modeling	108	1.8	1.6	2.0	1.6	2.3
Control I[b]	153	3.0	2.3	4.1	3.0	3.7
Control II[c]	66	2.0	1.7	2.0	1.8	2.3
Total	327	2.5	2.0	3.0	2.6	

[a] Adjusted for pretest scores

[b] Learning Cycle

[c] Non-equivalent comparison

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