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ABSTRACT

This study examined the effects of an inquiry-based instructional method on secondary school students' achievement in earth science. Students (N=232) were treated as two experimental groups, one receiving 2 weeks of the inquiry-based instruction while the control group received the traditional lecture-type instruction. Data were analyzed employing an analysis of covariance (ANCOVA) on posttest scores with a pretest as the covariate. The results indicated that students who were taught using the inquiry-based instructional method scored significantly higher than those who were taught with the traditional lecturing approach. In addition, a significant improvement in the achievement test at the comprehensive- and integrated-level test items was accomplished. Contains 31 references. (DDR)

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Abstract

This study examined the effects of an inquiry-based instructional method on secondary school students' earth science achievement. Students chosen to participate in this study included 232 earth science students enrolled in six earth science classes. A quasi-experimental non-equivalent control group design was employed in finding any significant gains in student achievement. The experimental group (n=116) received two weeks of the inquiry-based instruction while the control group (n=116) received the traditional lecture-type instruction. Selected items from Taiwan Indicators of Educational Progress in Science Process Skills and Taiwan Entrance Examinations for Senior High School were used to measure students' achievement. The data were analyzed employing an analysis of covariance (ANCOVA) on posttest scores with pretest as the covariate. The results indicated that students taught using the inquiry-based instructional method did significantly score higher than those who were taught by the traditional teaching approach ($F=6.75$, $p<0.05$). In addition, there was also a significant improvement in the achievement test especially at the comprehensive ($F=3.94$, $p<0.05$) and integrated level test items ($F=6.47$, $p<0.05$).

Recent science education standards in the US. propose that all students should both learn about scientific inquiry and learn science through inquiry (NRC, 1996). Many studies have found that the inquiry-based instruction was more effective than a traditional approach in enhancing student performance (Chang & Barufaldi, 1997; Ertepinar & Geban, 1996; Gabel, Rubba, & Franz, 1977; Geban, Askar, & Ozkan, 1992; Hall & McCurdy, 1990; Henkel, 1968; Mulopo & Fowler, 1987; Richardson & Renner, 1970; Russell & Chiappetta, 1981; Saunders & Shepardson, 1987), laboratory skills or science process skills (Basaga, Geban, & Tekkaya, 1994; Mattheis & Nakayama, 1988; Tobin & Capie, 1982), content retention (Schneider & Renner, 1980), and attitudes toward science or science activities (Gabel, Rubba, & Franz, 1977; Shepardson & Pizzini, 1993).

Shymansky, Kyle, and Alport (1983) reported a meta-analysis of the impact of the NSF-reform inquiry-based science curricula on student performance and found that the science curricula improved students' science achievement and process skills, as well as attitudes toward science. Effect sizes were largest for biology and *weakest for earth science* and chemistry. Shymansky, Hedges, and Woodworth (1990) further employed refined statistical procedures to re-synthesize the aforementioned research and vindicated that mean effects on four performance clusters (achievement, process skills, problem solving, and attitude) were significantly positive. Wise and Okey (1982) also found the strongest effects for biology and *weakest for earth science* in a meta-analysis of the effects of various teaching strategies on student achievement. Furthermore, studies on inquiry-based instruction are more plentiful in the area of physics, chemistry, biology than in earth science. It is, therefore, essential and important to examine the effects of an inquiry-based instructional method on the achievement of students with an emphasis on earth science subject.

While some previous research has shown that an inquiry-based instructional method can improve students' achievement, science process skills, attitudes toward science, and concept learning (Kyle, Bonnstetter, & Gadsden, 1988; Kyle, Shymansky, & Alport, 1982); research on explicit teaching or traditional instruction has also revealed that student achievement is improved for certain kinds of students and for selected kinds of instructional objectives (Waxman, 1991). After reviewing research on inquiry-based teaching, Flick (1995) stated that "Research on inquiry-based instruction has produced mixed results with the clearest effects occurring with more capable students, who have well trained teachers, and a supportive classroom environment." (p. 17). Accordingly, it is interesting and necessary to make a comparison between the inquiry-based instruction and the traditional teaching method in the typical classroom settings within the context of earth science.

Many researchers in the area of earth science education have attempted to develop or employ inquiry-based instructional methods at the college level of school setting. For example, Stefanich (1979) implemented an inquiry-based teaching method which encouraged students to gather data in order to interpret geological events. McKenzie and Fuller (1987) adopted one modified guided-design instructional option, Group Approach to Solving Problems (GRASP), in the introductory geology course at The Ohio State University for non-science majors that focused on problem solving and group dynamics. The GRASP format emphasized fewer lectures and many laboratory exercises based on problem solving sessions. The results indicated that the GRASP approach interested students in active learning and provided students the opportunity for group cooperation. Starr (1995) also examined the effects of cooperative-learning strategies on geology achievement and student attitude toward science. The results indicated an improvement in both achievement and enhancement of student attitude toward science.

Purpose

The main purpose of this study was to compare an inquiry-based instructional method with a traditional teaching approach on the achievement of earth science students in the secondary school in Taiwan.

Method

Subjects and Design

Participants in this study were 232 ninth grade students enrolled in six earth science classes at a public junior high school in Taiwan. The instructor was one earth science teacher with several years of teaching experiences. This study employed a quasi-experimental non-equivalent control group design with pretest-posttest described by Campbell and Stanley (1966). Three intact sections (n=116) were randomly assigned to the inquiry-based instruction group; the other three sections (n=116) were randomly assigned to the traditional group. These students were typical secondary school students at about 15 years of age; gender was equally distributed among the classes. The students' socioeconomic background also reflected the typical students' family backgrounds in the nation.

Independent Variables

The inquiry-based instructional method was developed and served as the independent variable (treatment) in this study. It is important to distinguish between "inquiry-based" and "traditional" instruction for this study. Welch, Klopfer, Aikenhead, and Robinson (1981) identified one major theme in science inquiry skills which includes observing and interpreting data. The inquiry-based instructional method developed and employed in the current study emphasized gathering and interpreting data of students in a cooperative-learning setting with the goal to improve students learning of earth science content. Moreover, students also critically examine data for relationships by interpreting related data and then draw conclusions. Another key feature of the inquiry-based teaching is cooperative learning, including small group discussions. Small group discussion is intended to increase interaction between students and the instructional materials. During group discussion, students clarify their own ideas and communicate with each other.

The inquiry-based instruction and instructional units employed in this study focused on the topic, "The Movement of the Sun in the Sky". The treatment consisted of an approximately two-week period of earth science instruction. Student engagement was followed by gathering information and interpreting data generated from hands-on activities and group discussion. Class presentation of results and teacher's discussions with students were followed by the teacher's explanation of the Earth-Sun system. The most important characteristics of the lessons are "student-centered" activities designed to encourage students to become more skillful in using science process skills and more understanding of earth science concepts. The instructor served as a facilitator in the learning process. It is noted that the inquiry-based instruction proposed in this study did not exclude the use of textbooks or other instructional materials, but emphasizing the active search process by students. It is also noted that the instructional materials prepared for the experimental group were also provided to the control group as a placebo control.

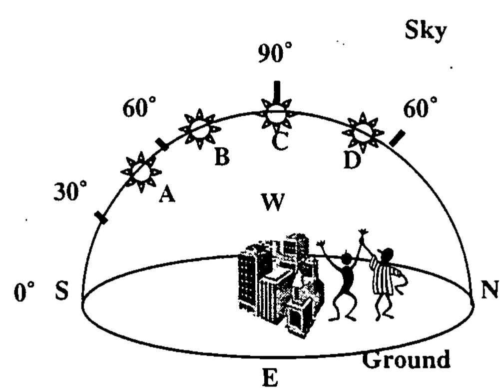
Traditional instructional method in this study stressed teacher's direct lectures and clear explanations of the Earth and Sun system; occasional demonstrations on the Earth-Sun Model and a review of these topics were included. The key feature of this "teacher-centered" instruction was to provide students with clear and detail instructions and explanations. The teacher assumed the role of the "provider" of information.

Dependent Variables

The Achievement Test. Student achievement was measured by selected items from the following tests: Taiwan Indicators of Educational Progress in Science Process Skills (TIEPSPS) and the Taiwan Entrance Examination for Senior High School (TEESHS) – astronomy topic. The researchers compiled the test items selected from TIEPSPS and TEESHS. Twenty-seven test items were selected and used as both pretest and posttest to measure student achievement.

The content validity of the instrument was verified by a panel of experts including four professors from Department of Earth Science, National Taiwan Normal University and six secondary school earth science teachers. These experts checked the correspondence between the textbook content and test items, and determined that the nature of the test items is strongly related to the important concepts introduced in the textbook. Reliability was established through internal consistency. The reliability coefficients (Cronbach alpha) of 0.61 for the pretest and 0.83 for the posttest were reported. Three sample multiple-choice items used in the posttest follow:

The following figure represents the angle between the Sun and the Ground. If you face southward, A is located at about 45 degree 、B is at 66.5 degree 、and C is right at the top of your head. Incidentally, when you are facing northward, D is also at about 66.5 degree. Please answer the following questions based on your observation from the figure below:



1. Which one of the following letter might represent the location of the Sun at noon on December 21 or 22 (Solstice) in Taiwan? (1) A (2) B (3) C (4) D.
2. Which one of the following situation might represent the movement of the Sun from March 21 or 22 (Equinox) through September 21 or 22 (Equinox) in Taiwan? (1) A→B→C (2) B→C→D (3) B→C→B (4) C→B→A.
3. If the Sun is located at C at noon in Taiwan, which one of the following might represent the location of the Sun during Sunset at the very same day? (1) West (2) Northwest (3) Southwest.

The instrument was further classified into three categories (factual, comprehensive, and integrated items) which correspond to Bloom's Taxonomy (1956) of knowledge (factual), comprehension and application (integrated) levels. The same panel of the aforementioned experts, who were knowledgeable about the criteria of these categories, classified these items into three categories with high agreement. Consequently, the instrument included seven items at the factual level, thirteen items at the comprehensive level and seven items at the integrated level. The classification of test items aimed at investigating students' levels of understanding and achievement of earth science concept.

Procedures and Data Analysis

Each instruction group was exposed to the same topics over a two-week period. The topics covered in the instruction included: the Earth-Sun system and the apparent movement of the Sun. *The Achievement Test* was given as the pre- and posttest for all students at the beginning and end of the treatment. Controlling variables in this study were the same secondary students, the same participating teacher, the same school administration, and the same instructional content and duration. The only variable for this study was the inquiry-based instruction versus the traditional teaching method. The data were analyzed by using an analysis of covariance (ANCOVA) on posttest scores with the pretest as the covariate to determine any significant differences between the experimental group and the control group. The assumptions[1] of ANCOVA were first checked to be met in the analysis of covariance for the study. ANCOVA was also conducted at the factual, comprehensive, and the integrated level of the posttest measures to determine if there were significant differences between the two groups at these levels of understandings. A significant level of 0.05 was considered appropriate for this study. Test of assumptions for analysis of covariance (ANCOVA) and inferential statistical analyses were attained by using the SPSS (Statistical Package for Social Sciences version 7.0).

Results

The results of ANCOVA on students' achievement are summarized in Table 1, Table 2, Table 3, and Table 4. It is statistically indicated that the inquiry-based instructional method did significantly improve earth science student achievement than the traditional teaching method ($F = 6.75$, $p < 0.05$) as shown in Table 1. Additionally, significantly higher achievement scores for the experimental group were found at the comprehensive ($F = 3.94$, $p < 0.05$) and integrated levels ($F = 6.47$, $p < 0.05$) as presented in Table 2 and Table 3 respectively. However, there were no significant gains of students achievement at the factual level among the experimental groups when compared with the control groups as shown in Table 4 ($F = 3.43$, $p > 0.05$).

Table 1
Summary of Analysis of Covariance on Students' Posttest Scores

ANCOVA					
Source of Variation	*SS*	*df*	*MS*	*F*	*F Prob.*
Between Groups	122.23	1	122.23	6.75*	<0.05
Within Groups	4145.49	229	18.1		
Total	4267.72	230	140.33		

[1]Preliminary test for homogeneity of regression slope performed significant test on interaction between the covariate and the variables. The results indicated the assumption of parallelism of the regression slope is tenable because F ratio yielded non significant values for all the variables.

Table 2

Summary of Analysis of Covariance at the Comprehensive Level Items on Students' Posttest Scores

ANCOVA					
Source of Variation	*SS*	*df*	*MS*	*F*	*F Prob.*
Between Groups	26.33	1	26.33	3.94*	<0.05
Within Groups	1529.58	229	6.68		
Total	1555.91	230			

Table 3

Summary of Analysis of Covariance at the Integrated Level Items on Students' Posttest Scores

ANCOVA					
Source of Variation	*SS*	*df*	*MS*	*F*	*F Prob.*
Between Groups	16.26	1	16.26	6.47*	<0.05
Within Groups	575.37	229	2.51		
Total	591.63	230			

Table 4

Summary of Analysis of Covariance at the Factual Level Items on Students' Posttest Scores

ANCOVA					
Source of Variation	*SS*	*df*	*MS*	*F*	*F Prob.*
Between Groups	8.5	1	8.5	3.43	>0.05
Within Groups	567.74	229	2.28		
Total	576.24	230	10.78		

Discussions and Implications

The results of achievement investigation revealed that the experimental group achieved significantly better than their counterparts receiving the more traditional approach. The results of this study support previous work (Bredderman, 1985; Ertepinar & Geban, 1996; Gabel, Rubba, & Franz, 1977; Geban, Askar, & Ozkan, 1992; Henkel, 1968; Mulopo & Fowler, 1987; Richardson & Renner, 1970; Russell & Chiappetta, 1981; Saunders & Shepardson, 1987), in which those studies demonstrated positive effects of an inquiry-based instruction on students' science achievement. The superiority of the inquiry-based instruction over that of the traditional teaching method in promoting science achievement renders the following rationale:

1. The emphasis of the inquiry-based instruction on science process skills of students might help students ways that the differences of students' learning earth science were thus reflected on the overall achievement performance between the treatment and control group. Pupils exposed to the treatment had the opportunity to observe, record, and interpret data on their own during hands-on investigative activities. Correspondingly, these science process skills might help the experimental group learn better on the earth science content than the control group.
2. The nature of the posttest items is generally in alignment with the fundamental elements of science process skills emphasized by the inquiry teaching because there are 74% of the upper-level items (comprehensive and integrated levels) in the posttest. Therefore, students in the experimental group may outperform students in the control group on the posttest as a result of enhancement of the aforementioned skills.

The result of the investigation found no significant differences in the achievement of students at the factual level items between the experimental group and the control group. Subjects taught by the inquiry-based instructional method might not perform better at the factual level items than those taught by the more traditional approach, because rote memorization may favor students' performance at that level. On the other hand, the inquiry-based instruction as opposed to the conventional approach resulted in significantly better performance of the students on the achievement test at the comprehensive and integrated level test items, which apparently resulted from the science process skills emphasis of the inquiry-based instructional method. The results of subtest investigation also lend support to previous studies, which recorded the improved science achievement of pupils at higher cognitive levels of Bloom's Taxonomy (Chang & Barufaldi, 1997; Chiappetta & Russell, 1982; Ertepinar & Geban, 1996; Gabel, Rubba, & Franz, 1977; Geban, Askar, & Ozkan, 1992; Henkel, 1968; Mulopo & Fowler, 1987; Saunders & Shepardsön, 1987).

Welch et el. (1981) stated "Thus, in an inquiry classroom there is a time for doing... a time for reflection... a time for feeling... and a time for assessment." (p.35). The inquiry-based instruction proposed in the present study emphasizes students' inquiry, interpretation of data, group discussions, cooperative learning; these strategies might help develop students' higher mental skills and facilitate learning of earth science concepts. It is, therefore, suggested that students could learn earth science through the inquiry approach. It is also believed by the researchers that effective instruction of earth science such as the inquiry-based instruction should emphasize "student-centered activities" and de-emphasize "teacher-centered lectures" in terms of helping students learn earth science concepts.

The hands-on and minds-on activities during inquiry-based instruction seemed to enhance earth science content achievement since they provided students with first-hand experience in doing science and the opportunities to collect and interpret data and to make valid conclusions. Therefore science teachers and educators should continue to promote inquiry-based instruction in the earth science classroom. The results of this study also support the notion that teachers need to encourage students to develop their inquiry skills as early as possible in the educational system in order to promote science learning in the classroom. Moreover, students should be provided with the opportunities to search and collect information, interpret and analyze data, draw conclusions, and share or communicate ideas at the secondary level.

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