DOCUMENT RESUME

ED 404 128 SE 054 950

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TITLE	Constructivist and Objectivist Approaches to Teaching Chemistry Concepts to Junior High School Students.
PUB DATE	Apr 94
NOTE	46p.; Paper presented at the Annual Meeting of the American Educational Research Association (New Orleans, LA, April 5-8, 1994).
PUB TYPE	Reports - Research/Technical (143) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	*Chemistry; Classroom Research; *Constructivism (Learning); Discussion; Foreign Countries; Junior High Schools; *Junior High School Students; *Learning Strategies; *Science Instruction; Scientific Concepts; *Thinking Skills
IDENTIFIERS	*Objectivity; *Taiwan

ABSTRACT

The primary purpose of this study was to understand what happens when some aspects of the constructivist approach, namely prediction, explanation, student-centered, and teacher-centered discussions, are applied to science teaching. The study involved 363 junior high school students in Taiwan. It combined the effectiveness of four alternative teaching strategies and the conventional teaching strategy using different combinations of the instructional design variables under study. The results showed that students who were asked to predict and explain provided better explanations than students who were asked to predict only. In addition, students in the constructivist student-centered approach produced much higher explanation scores than students in the conventional approach. However, students in the constructivist approaches did not perform significantly higher than students in the conventional treatment on multiple-choice scores. Students in the constructivist student-centered approach did not produce higher scores in higher-level questions (non-recall). A retention test revealed that regardless of the teaching strategy, teacher, or worksheet, no student performance differences persisted two weeks after instruction. The results of this study provide an insight into the extent to which constructivist approaches can be incorporated into current science teaching. Contains 37 references. (Author/ZWH)

CONSTRUCTIVIST AND OBJECTIVIST APPROACHES TO TEACHING CHEMISTRY CONCEPTS TO JUNIOR HIGH SCHOOL STUDENTS

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Abstract

The primary purpose of this study was to understand what happens when some aspects of the constructivist approach, namely prediction, explanation, student-centered, and teacher-centered discussions, are applied to science teaching. The study involved 363 junior high school students in Taiwan. It compared the effectiveness of four alternative teaching strategies and the conventional teaching strategy using different combinations of the instructional design variables under study.

The results showed that students who were asked to predict and explain provided better explanations than students who were asked to predict only. In addition, students in the constructivist student-centered approach produced much higher explanation scores than students in the conventional approach. However, students in the constructivist approaches did not perform significantly better than students in the conventional treatment on multiple-choice scores. Students in the conventional treatment performed significantly better in lower-level (recall) questions than students in the constructivist student-centered approach. Students in the constructivist student-centered approach did not produce higher scores in higher-level questions (non-recall). However, this comparison was based on six multiple-choice questions in lower-level questions and six multiple-choice questions in higher-level questions only. This comparison did not take students' explanations into account.

A retention test revealed that regardless of the teaching strategy, teacher, or worksheet, no student performance differences persisted two weeks after instruction. The results of this study provide an insight into the extent to which constructivist approaches can be incorporated into current science teaching.

Introduction

Constructivist approaches to teaching, unlike conventional teaching, are teaching strategies which assist students in actively constructing their own knowledge. In a review of 2,000 articles on empirical investigations and theoretical discussions about students' alternative conceptions, Pfundt and Duit (1991) noted that the constructivist view of learning has been recognized as a viable alternative learning strategy by researchers in the field of science education. However, this constructivist view of learning has not been adopted by the public schools. Most current teaching results in passive ways of learning. This study attempted to apply some instructional design variables suggested by the constructivists (O'Loughlin, 1991; Lavoie, 1991; Fosnot, 1989), and to evaluate the effectiveness of these applied variables in current science teaching.

Most instructional design theories are rooted in behaviorism (Reigeluth, 1989; Merrill, Li, & Jones, 1990; Jonassen, 1991). According to the predetermined objectives, instructional designers analyze students' entry behavior and instructional tasks, and they use criterion-referenced tests to assess students' performance. Learning is measured by how well a student achieves these objectives rather than what this learning means to the student. The instruction is primarily a transmission of particular information (Jonassen, 1991).

Generally, instructional design is based on pre-determined objectives and task analysis which determines the sequence of presenting materials and instruction. There are three major problems raised by objectivism.

1. Objectivism places more emphasis on task analysis than on analyzing what students think and believe during the phases of instruction. In other words, the sequence of content presentation is based on an expertise views, not necessarily on the development of the naive learners' views.

2. Objectivism places less emphasis on providing students with argument and evidence to convince them of the validity of ideas.
3. In addition, objectivism places more emphasis on providing clear presentations than on interacting with students.

Objectivist instructional designs also highlight the importance of entry behavior (Dick, 1991). However, entry behavior, as assessed, might not be the same as the individual's unique preconceptions.

Constructivism, on the other hand, claims that learning is an active process in which learners construct their own understanding (Pfundt et al., 1991). Constructivists claim that learners can only construct a new understanding based on their previous experiences (Jonassen, 1991). The perspective of students perceiving events differently suggests a reason why students form many conceptions prior to instruction.

The constructivist view of learning highlights the importance of students' preconceptions (Pfundt et al., 1991). Constructivists claim that each student has his or her unique previous experiences and concepts, and these should be addressed by instruction. Constructivists also claim that students must develop the skills of "hypothesizing, predicting, manipulating objects, posing questions, researching answers, imagining, investigating, and inventing" in order to construct a new conception (Fosnot, 1989, p. 20). Obviously, they believed that these skills have a positive impact on the process of construction.

The Study

Constructivist approaches are assumed by some educators to be better strategies to teach advanced, higher-order cognitive knowledge (Molenda, 1991; Spiro, Feltovich, Jacoson & Coulson, 1991; Jonassen, 1991), especially in science (Pfundt et al., 1991). Other educators doubt the effectiveness and efficiency of using the constructivist approach (Dick, 1991; Maor, 1991). A great many discussions regarding the constructivist approach versus the objectivist approach have been cited (Dick, 1991; Reigeluth, 1991). Only a few empirical studies (Kamii & Lewis, 1990) have been found.

The lesson used in this study includes four major concepts: particles of substances, melting and dissolving, speed of dissolving, and the amount of material dissolved. Among these, there are two major misconceptions that students might have. First, they might not be able to distinguish between melting and dissolving. Second, they might not be able to understand that a faster dissolving rate does not necessarily mean that more of the same material will be dissolved. Students usually confuse "melting" and "dissolving," especially Chinese students. In Chinese, the pronunciation of these two words is exactly the same; even the Chinese characters are similar. One has a "fire" shape on its left side (that means this character may deal with "heat" or "fire"), and it is "melting"; the other word has a "water" shape on its left side (that means this character may relate to water), and it is "dissolving". Many Chinese students and adults cannot distinguish between these two phenomena.

Theorectical Models and View Points in Constructivist Approach

Lately the constructivist approach to teaching has been frequently researched and discussed. Although some educators support the constructivist approach to teaching, some have different opinions about some aspects. The principles that Fosnot (1989) proposed, along with conceptual change models, can be seen to be representative of one form of the constructivist approaches. The following paragraphs present the information regarding this perspective.

Fosnot (1989) defines constructivism in terms of four principles. First, knowledge consists of past constructions. Second, constructions come about through assimilation and accommodation. Third, learning is an organic process of invention, rather than a mechanical process of accumulation. And last, meaningful learning occurs through reflection and resolution of cognitive conflict. These four principles indicate the importance of assessing students' preconceptions, and of creating a conflict between their existing knowledge schema and their new knowledge. In addition, this conflict should be reflected on and resolved in order to become meaningful.

The interpretation of student responses as alternative frameworks indicates that learning may involve a conceptual change other than adding new knowledge to the existing knowledge. This view has been developed into a model of learning as conceptual change by Posner et al. (1982). This conceptual change model is based on the constructivist perspective (Posner et al., 1982; Tomasini, Gandolfi& Balandi, 1990).. From this point of view, learning involves an interaction between new and existing conceptions. Thus, teachers and instructional designers must be concerned with conceptual change. According to this view, teaching is more than providing the correct views. It is establishing the setting by which students reconstruct a schema more consistent with evidence and argument.

The conceptual change model of instruction suggests that students' alternative conceptions be identified, and that students become engaged in conceptual conflict. Smith, Blakeslee, and Anderson (1993) in their study, noted that "making students aware of their own ideas, asking for explanations of familiar and discrepant events, and debating alternative conceptions" (p. 113) are the conditions for conceptual change. The present dissertation provides information which can be used in designing conceptual change models of instruction for teaching introductory chemistry.

Some educators provide additional perspectives on the constructivist approach. Jonassen (1991) proposed three stages of knowledge acquisition: introductory, advanced, and expert. He claimed that constructivist approaches are "most appropriate for the second stage, advanced knowledge acquisition," (p. 31) while objectivist approaches are more appropriate for the introductory knowledge acquisition. Because the objectivist approach tends to provide knowledge of facts and procedures, this knowledge is not similar to the knowledge which is gained through comparison, criticism, judgment, inference, and evaluation.

From the discussions mentioned above, active learning includes active student participation and reasoning. Active participation encourages students to exchange views. Exchanging views encourages students to clarify, evaluate, and change their thoughts. If students' alternative conceptions have been discovered, and if the design of instruction takes these alternative conceptions into account, then students' misconceptions might be removed. The effectiveness of a constructivist approach depends on students' active participation and reasoning. Since there are various ways of eliciting student participation and reasoning, this study, by examining alternative approaches to constructivist teaching, contributes to the development of constructivist methodology.

Key Variables

The key variables in this study were the extent to which students were requested to construct explanations (explanations requested, explanations not requested), the focus of discussions (student-centered, teacher-centered), and general instructional approach (constructivist, conventional). The decisions of choosing these variables were based on the conclusions generated by the reviewed empirical studies. The conclusions from the review of literature are as follows :

1. Constructivist approaches enhance student inquiry skills (Lawson, McElrath, Burton, James, Doyle, Woodward, Kellerman & Snyder, 1991; Maor, 1991; Tobin, Capie & Bettencourt, 1988; Kamii & Lewis, 1990).
2. The constructivist, conceptual change model can increase students' ability to reconstruct their own knowledge (Tomasini et al., 1990; Bednarz & Janvier, 1988).
3. Prediction activity is an appropriate means to assess students' understanding (Butts, Capie, Fuller, May, Okey & Yeany, 1978; Good, 1989; Lavoie 1989 a&b, 1991). However, it might not be necessary to promote students' performance. Successful predictions require certain conditions, such as students' initial knowledge(Lavoie, 1989b) and procedural or declarative knowledge(Lavoie, 1991).
4. Explanation activities can be used to assess students' understanding, and even more to promote conceptual change (Bromage & Mayer, 1981; Patel et al., 1991).
5. Prediction activities when associated with explanation activities can help students promote conceptual change (Smith et al., 1993; Hameed, Hackling & Garnett, 1993; Searle & Gunstone, 1990).
6. The empirical studies support a student-centered approach. However, current classroom teaching remains basically a teacher-centered approach (Cuban, 1982, 1987; Smith et al., 1993; Roth & Roychoudbury, 1993; Pulliam, 1992; Wilkinson, Treagust, Leggett & Glasson, 1988; Greeson, 1988; Sommers, 1992; Maroufi, 1989).
7. The interaction of prediction and explanation, and student-centered and teacher-centered approaches has not been investigated in the

experimental studies.

Research Questions

This study examined the following questions:

1. Are the different combinations of constructivist approaches (explanations requested or explanations not requested, and student-centered or teacher-centered approaches) better than the objectivist approach (conventional group) in enhancing students' learning ?
2. Are the constructivist approaches (student-centered and teacher-center approaches) able to produce higher post test scores than objectivist approach (conventional approach)?
3. Is student-centered teaching strategy better than teacher-centered teaching strategy on students' post test scores ?
4. Do the constructivist approaches result in fewer students' wrong explanations than the conventional approach?
5. Is there a significant difference between constructivist approaches (student-centered and teacher-centered) and the objectivist approach (conventional group) in lower-level (factual) and higher-level cognitive knowledge (synthesis) ?
6. Is there a significant difference between the constructivist approaches and the objectivist approach in retaining previous knowledge?

Hypotheses

1. Students in the PES and PET treatments (prediction and explanation) will reveal significantly greater understanding of chemistry concepts than students in the PNES and PNET (prediction but no explanation).
2. Students in the PES and PNES treatments (student-centered teaching strategy) will reveal significantly greater understanding of chemistry

concepts than students in the PET and PNET treatments (teacher-centered teaching strategy).

3. Students in the constructivist approaches (PES, PNES, PET, and PNET treatments) will reveal significantly greater understanding of chemistry concepts than students in the conventional group (the objectivist approach) on their post test scores.
4. Students in constructivist approaches will reveal significantly greater understanding of chemistry concepts than students in the conventional treatment on higher-level cognitive knowledge; students in conventional treatment will do significantly better than students in the constructivist approach on lower-level cognitive knowledge.
5. Students in the constructivist approaches (student-centered and teacher-centered) will have fewer wrong explanations than students in the conventional treatments.
6. Students in the constructivist student-centered approach will produce higher scores than students in the constructivist teacher-centered approach in the retention test.

Experimental Design

A Quasi-experimental design was used in this study. The design of this dissertation included three groups but five treatments. The five treatments will be refered to as PES, PNES, PET, PNET, and conventional treatments. The PES treatment asked students to predict the outcome of a described situation and to explain the reasons for these predictions on their worksheets (Worksheet A). After students finished the task on their worksheets, the instructor used student-centered interaction as closure. This treatment represents the most constructivist oriented approach implemented in this study.

The PNES treatment asked students to predict the outcome of a described situation on their worksheets (Worksheet B), but did not ask students to explain why they made this prediction. After students finished their task on their worksheets, the instructor used student-centered interaction to reach closure.

The PET treatment asked students to predict the outcome of a described situation and to explain the reason for their prediction on their worksheets (Worksheet A). After students finished the tasks on their worksheets, the instructor used teacher-centered interaction to reach closure.

The PNET treatment asked students to predict the outcome of a described situation on their worksheets (Worksheet B), but did not ask students to explain why they made this prediction. After students finished their task on their worksheets, the instructor used teacher-centered interaction to reach closure. This treatment represents the least constructivist-oriented approach implemented in this study.

The conventional treatment is a traditional lectured-oriented instruction. Students in this treatment were not asked to predict and to explain for the outcome of a described situation. Students used worksheets (Worksheet C) to take notes when lecturing. The instructor lectured the whole session with the necessary demonstrations and provided a very brief closure. This treatment is referred to here as the objectivist approach, not because this approach is based on specific objectives (all five treatments used the same post-test, and therefore had the same instructional objectives), but because of the absence of the constructivist inspired factors of prediction, explanation, and student-centered discussion.

Students from three science classes were randomly assigned into three experimental groups in each session. Group one had two subgroups and was taught by one instructor, group two had another two subgroups and was taught by another instructor, and group three had no subgroup and was taught by the third instructor (see Figure 1).

Students in the experimental groups were assigned to three chemistry laboratories. Three science teachers were chosen to teach the experimental groups. In order to control "teacher effect" in this study, the same three teachers rotated and taught three different groups in three sessions. Therefore, each of the three teachers, employed each of the three teaching strategies, but with different group of students. Each session lasted for 100 to 110 minutes or so. A forty to fifty minute post test was conducted after instruction. A more detailed description of the subjects, worksheets, and instructors will be described in the following parts.

Students in the first (PES&PNES) and second (PET&PNET) groups were randomly assigned to work on either Worksheet A or Worksheet B. Each student in the first two groups was asked to follow the directions of the instruction written on his worksheet without discussion with peers. During the first part of instruction, students worked on the worksheets and were requested to stop at certain sections and wait for the instructor to demonstrate experiments for them. The instructor performed the experiments for students without offering explanations. The students were asked to carefully observe and record the results. Students in the third group (conventional group) listened to the instructor's lecture and observed the same experiments that were presented in the first and second groups. Students in the third group (conventional group) used Worksheet C for taking notes while listening to the lectures and observing the demonstrations.

	Treatments				
	Group 1		Group 2		Group 3
	PES	PNES	PET	PNET	Conventional
Worksheet:					
1. Students make predictions (Worksheets A & B)	v	v	v	v	--
2. Students explain predictions (Worksheet A)	v	--	v	--	--
3. Students take notes from lecture (Worksheet C)	--	--	--	--	v
4. Instructor demonstrates experiments	v	v	v	v	v
Teaching strategies:					
5. Instructor leads student-centered discussion (addresses students' ideas/misconceptions)	v	v	--	--	--
6. Instructor leads teacher-centered discussion (addresses students' ideas/misconceptions)	--	--	v	v	--
7. Instructor provides scientific views	v	v	v	v	v
8. Instructor summarizes the lesson	--	--	--	--	v

Fig. 1 Differences among five treatments

The instructors in the first and second groups used different approaches to help students construct their own knowledge after students finished their assignments on their worksheets. The instructor in the first group used a student-centered approach which allowed students to express their own explanations and to defend and debate their own opinions. The instructor in the second group used a teacher-centered approach in which students can explain their alternative explanations, but the analysis of these explanations was performed by the teachers. Instead, the instructor provided several possible alternative conceptions that students might hold, and explained the reasons for students.

The teachers in the third group used conventional teaching strategy and lectured the entire session except the demonstration of experiments while students listened and took notes. The instructor provided a very brief closure which highlighted the major concepts that students were to learn in this session.

Participants

A sample of 363 eighth-grade students in a junior high school in Taipei, Taiwan, were involved in this study. This study took place in three separate sessions in June, 1992. Each session included three different groups. A sample of 111 students in three different science classes were randomly assigned to three groups (groups 1-3) in the first session (6/8/92) (Fig. 2). A sample of 125 students in another three science classes were randomly assigned to three groups (groups 4-6) in the second session (6/9/92) (Fig. 3). Another 127 students from another three science classes were randomly assigned to three groups (groups 7-9) (Fig. 4) in the third session.

Test items in the pretest were the same as those in the post test. Students in the experimental groups were not given the pretest since exposure to the test might have conceivably affected learning during treatment. This study asked students to predict the outcome of described situations and assumed that the prediction will play an important role in learning. As the questions in the test items of pretest also asked students to predict, then students might actively construct their own concept. Therefore, it will influence the overall effect of latter lessons by what they learned through the experience of taking the pretest.

In the first experimental session of this study, six science classes were broken down and students were randomly assigned to one of six groups. Three groups were randomly chosen as experimental groups; the other three groups (groups 11, 22, and 33) were chosen as the pretest groups. Therefore, this study assumed the mean of the pretest scores in pretest groups would be equivalent to the mean of the pretest scores in the experimental groups in the first session. However, as stated, the experimental groups were not given a pretest in the first session, and neither did the second and third sessions. The pretest was administered only during the first session to the extra three groups of students which were not involved in the experiment.

Treatments

Students in the first group were in one classroom, but were randomly assigned into two subgroups. One subgroup was assigned to the PES treatment; the other subgroup was assigned to the PNES treatment. In the beginning of instruction, students in the PES treatment worked on Worksheet A (see appendix A), and at the same time students in the PNES treatment worked on Worksheet B (see appendix B).

Worksheet A asked students to predict the outcome of a described situation and to explain their predictions prior to an experiment. Worksheet B asked students to predict the outcome of a described situation, but did not ask students to explain the reasons why they made this prediction. After students completed the worksheets, the instructor conducted a student-centered discussion. During the student-centered discussion (Treatments PES & PNES), students were encouraged to defend and debate their explanations with their peers and the instructor. The instructor in this group worked as a facilitator who assisted the students in constructing their own knowledge.

Similar to the first group, students in the second group were in one classroom and were randomly assigned into two subgroups. One was assigned to the PET treatment, the other one was assigned to the PNET treatment. At the beginning of instruction, students in the PET treatment worked on Worksheet A (see appendix A) and at the same time students in the PNET treatment worked on Worksheet B (see appendix B).

The worksheets (Worksheets A and B) used in the second group were the same as the worksheets used in the first group. After students completed the worksheets, the instructor conducted a teacher-centered discussion. During the teacher-centered discussion (PET and PNET treatments), students were not encouraged to defend and debate their explanations with their peers or the instructor. The instructor in the second group provided all possible alternative conceptions that students might hold, offered evidence and argument relative to these alternative conceptions.

Unlike students in the first and second groups, students in the third group, the "conventional" group, listened to the instructor's lecture and took notes on Worksheet C (see Appendix C). The instructor in this group lectured for the entire class session (except the necessary demonstration and few questions) and provided a brief conclusion as a closure.

(Teacher X)		(Teacher Y)		(Teacher Z)
Group 1 (N=42)		Group 2 (N=34)		Group 3 (N=35)
Treat. PES (G1.1, N=22) (WK A & S-centered Approach)	Treat. PNES (G1.2, N=20) (WK B & S-centered Approach)	Treat. PET (G2.1, N=16) (WK A & T-centered Approach)	Treat. PNET (G2.2, N=18) (WK B & T-centered Approach)	Conventional group (N= 35) (WK C & L-closure)

* N represents the number of students.
* G represents the subgroup of original group.
* WK A (B or C) represents the worksheet A (B or C).
* S-centered Approach and T-centered Approach represent Student-centered and Teacher-centered approaches. L-Closure represents a brief lectured closure.

Fig. 2 The design in session 1 (6/8/92)

(Teacher Z)		(Teacher X)		(Teacher Y)
Group 4 (N=41)		Group 5 (N=41)		Group 6 (N=43)
Treat. PES (G4.1, N=21) (WK A & S-centered Approach)	Treat. PNES (G4.2, N=20) (WK B & S-centered Approach)	Treat. PET (G5.1, N=21) (WK A & T-centered Approach)	Treat. PNET (G5.2, N=20) (WK B & T-centered Approach)	Conventional group (N= 43) (WK C & L-closure)

* The abbreviations shown in this figure are the same as in Figure 1.

Fig. 3 The design in session 2 (6/9/92)

(Teacher Y)		(Teacher Z)		(Teacher X)
Group 7 (N=42)		Group 8 (N=42)		Group 9 (N=42)
Treat. PES	Treat. PNES	Treat. PET	Treat. PNET	Conventional group
(G7.1, N=21)	(G7.2, N=21)	(G8.1, N=20)	(G8.2, N=22)	(N= 42)
(WK A &	(WK B &	(WK A &	(WK B &	(WK C & L-closure)
S-centered	S-centered	T-centered	T-centered	
Approach)	Approach)	Approach)	Approach)	

* The abbreviations shown in this figure are the same as in Figure 1.

Fig. 4 The design in session 3 (6/10/92)

Procedures

In the first experimental session, six science classes were broken up and randomly assigned into six groups. Three of them were chosen randomly as the experimental groups; the other three groups of students were assigned to do a pretest in the first session. In the second and third sessions, three science classes were broken up and students were randomly assigned to one of three groups

In the first session, three science teachers were randomly assigned into three groups, and they rotated in the following two sessions. In other words, each teacher taught three different groups and used three different strategies in three sessions.

Three observers were randomly assigned to three groups. They observed, took notes, and video taped the whole class session. Each observer observed the same teaching approach at the same classroom across three sessions. In other words, each observer watched three teachers who used the same teaching strategy in three sessions. The purpose of these observations was to provide the qualitative information regarding classroom participation and activities, and offer information regarding teachers' implementation of different strategies.

In the first experimental session, six science classes were broken up and randomly assigned into six groups. Three of them were chosen randomly as the experimental groups (groups 1-3); the other three groups of students were assigned to do a pretest in the first session (see Fig. 2). In the second and third sessions, three science classes were broken up and students were randomly assigned to one of three groups (groups 4-6 in the second session see Fig. 3; groups 7-9 in the third session, see Fig. 4). The treatment of the experimental groups has been mentioned earlier under the heading of "treatment".

In the first session, three science teachers were randomly assigned into three groups, and they rotated in the following two sessions. Teacher X who taught Group 1 (Student-centered approach) in the first session, taught Group 5 (Teacher-centered approach) in the second session and taught Group 9 (conventional group) in the third session. Teacher Y who taught Group 2 (Teacher-centered approach) in the first session, taught Group 6 (conventional group) in the second session and taught Group 7 (Student-centered approach) in the third session. Teacher Z who taught Group 3 (the conventional group) in the first session, taught Group 4 (Student-centered approach) in the second session and taught Group 8 (Teacher-centered approach) in the third session. In other words, each teacher taught three different groups and used three different strategies in three sessions.

Three observers were randomly assigned to three groups. They observed, took notes, and video taped the whole class session. Each observer observed the same teaching approach at the same classroom across three sessions. In other words, each observer watched three teachers who used the same teaching strategy in three sessions. The purpose of these observations was to provide the qualitative information regarding classroom participation and activities, and offer information regarding teachers' implementation of different strategies.

The observers took notes during the classroom session and reported observations of students' participation and the teaching strategies. A seminar was conducted after the three sessions for the instructors who participated in this experiment. During the seminar the instructors shared their experiences with the researcher.

A retention test was given two weeks after the experiment. The purpose of retention test was to examine how the different teaching approaches affected students' retrieving the information which had been taught.

Statistical Treatment

The factorial analysis of variance was applied to compare the performance of students in this study. A 3 x 3 (three teachers and three teaching strategies) and a 3 x 2 x 2 (three teachers, two worksheets, and two teaching strategies) factorial analyses were applied to check the interaction among different variables.

The qualitative information of this dissertation included the observers' notes, the interview of instructors, the examination of students' worksheets, and the information from video and audio tapes.

Analysis of Data

A 3 x 2 x 2 and a 3 x 3 analysis-of-variance factorial design were used to analyze the data obtained from this experiment. Three experimental variables were arranged in the 3 x 2 x 2 ANOVA. The first variable was Teachers: Teachers X, Y, and Z. The second variable was the type of Worksheets: Worksheets A and B. Worksheet A asked students to predict and explain; Worksheet B asked students to predict, but not explain. The third variable was the kind of Teaching Strategies: student-centered approach and teacher-centered approach.

Two experimental variables were included in the 3 x 3 ANOVA. The first variable was Teachers: Teachers X, Y, and Z. The second variable was the kind of Teaching Strategies: student-centered, teacher-centered, and conventional approaches.

A one-sample chi-square test was used to determine whether the frequencies of correct, incorrect, and non-explanations differed among the four constructivist and conventional approaches.

To avoid having a pretest influence upon students' thinking during instruction and testing, students who were given instruction (experimental subjects) were not pretested. Pretests, however, were given to 128 students (pretest groups) who did not participate in the treatments. Because of random assignment, the pretest group mean is assumed to be the best estimate of the experimental groups' knowledge prior to instruction or treatment. A comparison of pretest means and post test means should indicate the extent to which learning took place as a consequence of instruction. Table 1 shows a 37.1% "increase" in multiple-choice means and a 142.9% "increase" in explanation scores. Apparently, students in the experimental groups did learn from the instruction.

Table 1

Means of Pretest and Post Test in Experimental Group in Session 1

Group	Multiple-choice	S. D..	Explanation	S. D..	Total	S. D..
Pretest group	40.2049	13.2571	2.6484	2.7136	42.6508	14.9323
	(127)		(128)		(126)	
Experiment group	55.1351	9.5902	6.4346	3.6343	61.5841	12.2207
	(111)		(107)		(107)	
Change scores (%)	14.9302		3.7862		18.9333	
	(37.14%)		(142.96%)		(44.39%)	

Hypotheses 1 and 2 were based on the 3 x 2 x 2 factorial analysis of variance. Each post test included two parts: multiple-choice and explanation question. It was predicted in this study that the experimental subjects who were under different treatments would have different performances in the multiple-choice or explanation items. Instead of summing up multiple-choice and explanation scores, this study measured the performance of students in terms of multiple-choice and explanation scores separately.

Table 2

Summary Table for 3 x 2 x 2 ANOVA of Multiple-Choice Scores of Post Test

Source	DF	SS	MS	F	Pr> F
Teacher	2	1330.4146	665.2073	6.25	0.0023 *
Group (teaching strategy)	1	490.0817	490.0817	4.60	0.0329 *
Worksheet	1	193.8994	193.8994	1.82	0.1785
Group * Worksheet	1	22.9362	22.9362	0.22	0.6429
Teacher * Group	2	804.5506	402.2753	3.78	0.0243 *
Teacher * Worksheet	2	244.1277	122.0638	1.15	0.3195
Teacher * Group * Worksheet	2	349.8231	174.9116	1.64	0.1956

Note. The "*" in the Pr> F column indicates the significance of the test

The results shown in Table 2 indicate that there are two main effects and one interaction for multiple-choice scores. Two main effects are Teacher effect and Group effect. Teacher effect means that teachers made a significant difference in students' multiple-choice scores regardless of the worksheet or teaching strategy used. Care must be taken, however, in interpreting the "teacher effect" as such. In the experimental design, each student group studied only one lesson, by one strategy, with on teacher. Therefore, the apparent teacher effect could also be caused by lack of success in equalizing students' abilities or prior knowledge of the subject during the group randomization of process.

Group effect (teaching strategy) indicates that teaching strategies made a significant difference in students' multiple-choice scores regardless of the teacher and worksheets used.

Table 3

Summary Table for 3 x 2 x 2 ANOVA in Explanation Scores of Post Test

Source	DF	SS	MS	F	Pr > F
Teacher	2	138.3043	69.1522	4.86	0.0086 *
Group	1	29.8735	29.8735	2.10	0.1488
Worksheet	1	81.2890	81.2890	5.71	0.0177 *
Group * Worksheet	1	2.8382	2.8382	0.20	0.6556
Teacher * Group	2	173.4507	86.7253	6.09	0.0026 *
Teacher * Worksheet	2	22.2307	11.1154	0.78	0.4592
Teacher * Group * Worksheet	2	13.3388	6.6694	0.47	0.6265

Note. The "*" in the Pr> F column indicates the significance of the test

The results shown in Table 3 indicate that there are two main effects (Teacher and Worksheet), and one interaction (Teacher and Group) for explanation scores. Students who used Worksheet A produced more correct explanations (mean = 7.71) than did students who used worksheet B (mean = 6.54). Thus, the type of worksheets made a significant difference in students' explanation scores regardless of different teachers or the teaching strategy used.

Table 4

Summary Table for 3 x 3 ANOVA of Students' Multiple-Choice Scores of Post Test

Source	DF	SS	MS	F	Pr > F
Teacher	2	1371.6643	685.8321	7.58	0.0006*
Group (teaching strategy)	2	1481.2649	740.6324	8.19	0.0003*
Teacher * Group	4	1005.4016	251.3504	2.78	0.0268*

Note. The "*" in the Pr > F column indicates the significance of the test.

The results shown on Table 4 reveal two significant main effects (Teacher and Group effects) and one interaction (between teacher and group) on students' multiple-choice scores of post test. In this case, teachers made a significant difference in students' multiple-choice scores regardless of teaching strategies used. However, this may also be due to imperfect randomdization of students. Also, teaching strategies made a significant difference in students' multiple-choice scores regardless of the teachers' differences.

Table 5

Summary Table for 3 x 3 ANOVA of Students' Explanation Scores of Post Test

Source	DF	SS	MS	F	Pr > F
Teacher	2	51.7616	25.8808	2.02	0.1343
Group	2	95.5492	47.7746	3.73	0.0250*
Teacher * Group	4	269.3699	67.3425	5.25	0.0004*

Note. The "*" in the Pr > F column indicates the significance of the test.

The results in Table 5 show that there is one main effect (Group effect) and one interaction (Teacher and Group) on students' explanation scores in the post test. Again, the group effect indicates that teaching strategies made a significant difference in students' explanation scores regardless of the teachers' differences.

Hypothesis 1

The first hypothesis of this study concerned the effect of the use of prediction and explanation tasks (in terms of Worksheets A and B) in this study. The analysis of variance which is presented in Table 2 reveals no significant Worksheet effect on students' multiple-choice scores on the post test. However, there is a Worksheet effect on students' explanation scores ($F=5.71$, $P < 0.02$). The mean of students who worked on Worksheet A (mean = 54.7) was not significantly different with the mean of students who worked on Worksheet B (mean = 52.98) in terms of multiple -choice scores. However, the mean of students who worked on Worksheet A (mean = 7.71) was greater than the mean of students who worked on Worksheet B (mean = 6.54) in terms of explanation scores. The results show that students who engaged in prediction and explanation tasks (Worksheet A) produced better scores on explanation tasks than students who engaged in prediction tasks only (Worksheet B).

Hypothesis 2

The second hypothesis of this study predicted that students in the student-centered approach will do significantly better than students in the teacher-centered approach on both multiple-choice and explanation scores. The analysis of variance presented in Table 2 reveals that there is a Group main effect (teaching strategy) on students' multiple-choice scores ($F=4.60$, $P < 0.033$). Students in the teacher-centered teaching strategy gained higher multiple-choice scores (mean = 55.4) than in the student-centered teaching strategy (mean = 52.3). This result is contrary to the hypothesis. Table 3 shows that there is no Group main effect (teaching strategy) on students' explanation scores. This is also contrary to the hypothesis.

Hypothesis 3

The third hypothesis of this study predicted that students in constructivist approaches would do significantly better than students in the conventional group on both multiple-choice and explanation scores.

The 3 x 3 analysis of variance in Table 4 shows that there is a Group main effect (teaching strategy) on students' multiple-choice scores ($F=8.19$, $P < 0.0003$). Table 5 shows that there is a Group main effect on students' explanation scores ($F=3.73$, $P < 0.0250$). Table 6 shows the comparison of the means of three different teaching strategies in the post test.

Table 6

Comparison of the Means of Three Different Teaching Strategies in Post Test

Teaching strategies	Mean of M.C. scores (N)	Duncan Grouping	Mean of Expl. scores (N)	Duncan Grouping
Student-centered (PES & PNES)	52.344 (125	B	7.440 (124)	A
Teacher-centered (PET & PNET)	55.397 (121)	A	6.811 (114)	A. B
Conventional	57.149 (121)	A	6.220 (118)	B

* The comparison of Duncan Grouping was read on the same column.
* Means with the same letter are not significantly different in Duncan Grouping.
* $P < .05$

The results in Table 6 show that students in both teacher-centered (PET & PNET treatments, mean = 55.4) and conventional approaches produced significantly greater multiple-choice scores than in the student-centered approach (PES & PNES treatments mean = 52.3). The student-centered approach (mean = 7.44) produced significantly greater explanation scores than the conventional approach (mean = 6.22).

Hypothesis 4

Hypothesis four predicted a significant difference in students' performances between constructivist approaches and the conventional approach in basic lower-level cognitive knowledge and higher-level cognitive knowledge. Lower-level cognitive knowledge refers to factual knowledge which students can recall from instruction. Higher-level cognitive knowledge refers to the kind of knowledge requiring synthesis, judgment, and application.

The higher-level cognitive questions in this study were considered to be the six two-tiered questions. These six questions required students to understand particular concepts, and then to synthesize their understanding as they constructed explanations.

Table 7 shows that there are two main effects from the 3 x 3 ANOVA of Lower-level post test knowledge: Teacher main effect ($F=4.26$, $P < 0.0149$) and Group main effect (teaching strategy) ($F=6.90$, $P < 0.0012$). Teacher effect indicates that teachers made a significant difference in student lower-level post test knowledge regardless of the different teaching strategies used. Group effect shows that teaching strategies made a significant difference in student lower-level post test knowledge regardless of the teachers' differences. Table 8 shows that there is no main effect from the 3 x 3 ANOVA in relation to higher-level post test knowledge; however, there is an interaction between Teacher and Group in higher-level post test knowledge. ($F=4.67$, $P < 0.001$).

Table 7

Summary Table for 3 x 3 ANOVA of Lower-level Knowledge in Post Test

Source	D.F.	S.S.	M.S.	F	Pr > F
Teacher	2	83.6680	41.8340	4.26	0.0149 *
Group	2	135.5750	67.7875	6.90	0.0012 *
Teacher * Group	4	53.5823	13.3956	1.36	0.2464

Note. The "*" in the Pr > F column indicates the significance of the test.

Table 8

Summary Table for 3 x 3 ANOVA of High-level Knowledge in Post Test

Source	D.F.	S.S.	M.S.	F	Pr > F
Teacher	2	30.7760	15.3880	1.70	0.1848
Group	2	39.1177	19.5589	2.16	0.1172
Teacher * Group	4	169.4387	42.3597	4.67	0.0011 *

Note. The "*" in the Pr > F column indicates the significance of the test.

Table 9 shows the comparison of the means of higher- and lower-level knowledge on the post test. The results shown in Table 9 indicate that the conventional approach produced significantly higher scores than the student-centered approach on lower-level knowledge (basic skills) test items. The prediction that constructivist approaches (student-centered and teacher-centered approaches) would produce significantly higher scores than the conventional approach on higher-level knowledge test items was not substantiated.

Table 9

Comparison of the Means of Lower- and Higher- level Knowledge in Post Test

Teaching strategies	Mean of LL scores (N)	Duncan Grouping	Mean of HL scores (N)	Duncan Grouping
Student-centered approach	14.808 (125)	B	15.192 (125)	A
Teacher-centered Approach	15.513 (117)	A, B	14.845 (116)	A
Conventional approach	16.264 (121)	A	15.645 (121)	A

* The comparison of Duncan Grouping was read on the same column.
* Means with the same letter are not significantly different in Duncan Grouping.
* P < .05

Hypothesis 5

Hypothesis five predicted that there would be significant difference in the number of students' wrong explanations between constructivist approaches (PES, PNES, PET & PNET) and the conventional approach. Table 10 shows the frequency of distribution in Right, Wrong, and No explanations between constructivist and conventional treatments. The percentages shown on Table 10 are percentages of all explanations given by each group (construstivist and conventional groups). The results seem to indicate that the constructivist approaches result in fewer "no explanation", more "correct explanations", and fewer "incorrect explanations" than does the conventional approach. Twenty six percent of the explanations given by students taught by conventional method were wrong. Twenty-three percent of the explanations given by students taught by constructivist approaches were wrong. However, the difference in percentages is not large.

Table 10

Frequencies of N. R. W. in Students' Explanation

	Blank	No Expl	Right Expla	Wrong Expla	
Conv.	7 (1%)	183 (25%)	346 (48%)	190 (26%)	726
Constru.	13 (1%)	295 (20%)	805 (55%)	339 (23%)	1452
	20	478	1151	529	

Hypothesis 6

Hypothesis six predicted that students in the constructivist student-centered approach would produce higher scores than students in the constructivist teacher-centered approach and than students in the conventional treatment in the retention test. This retention test was given two weeks after the actual experiment. The results show that there are no main effects and interactions for the 3 x 2 x 2 ANOVA of the multiple-choice scores of the retention test. However, there is an interaction between Teacher and Group on explanation scores (F=3.18, P < 0.04) of the retention test.

The results also show that there is no main effect and interaction on this 3 x 3 ANOVA of multiple-choice scores in the retention test. However, there is still one main effect (group effect) (F = 3.24, P < .04) and one interaction (teacher and group) (F = 4.41, P < .0017) on the 3 x 3 ANOVA of explanation scores in the retention test. Students in the constructivist student-centered approach produced higher explanation scores in the retention test (mean = 5.8) than students in the constructivist teacher-centered approach (mean = 5.0) or students in the conventional treatment (mean = 4.9). It revealed that students in the constructivist student-centered approach retained more previous knowledge regarding explanation than students in the constructivist teacher-centered approach than students in the conventional treatement.

The calculation of change scores was based on the following formula.

$$\text{Changes score} = \left(\frac{\text{post test scores} - \text{retention test scores}}{\text{post test scores}} \right) \times 100\%$$

Table 11

Summary Table for 3 x 3 ANOVA of Lower-level Knowledge of Retention Test

Source	DF	S.S.	M.S.	F	Pr > F
Teacher	2	55.2070	27.6035	1.56	0.2115
Group	2	60.5786	30.2893	1.71	0.1819
Teacher * Group	4	53.2624	13.3156	0.75	0.5566

Table 11 and 12 illustrate the summary table of 3 x 3 ANOVA students' retention test on higher- and lower-level knowledge. The results show that there is no any main effect in both higher- and lower-level knowledge among three teaching strategies in retention test.

Table 12

Summary Table for 3 x 3 ANOVA of Higher-level Knowledge of Retention Test

Source	DF	S.S.	M.S.	F	Pr > F
Teacher	2	7.6156	3.8078	0.23	0.7973
Group	2	29.5079	14.7539	0.88	0.4165
Teacher * Group	4	159.0428	39.7607	2.37	0.0526

Discussion and Conclusion

Function of Predictions and Explanations

Good, Strawitz, Franklin, and Smith (1988), Good and Lavoie (1986), and Sinclair & Good (1991) have expressed the importance of incorporating prediction activities in science learning. Lavoie (1989a&b) and Good et al. (1988) also expressed the need of assessing students' misconceptions by the use of prediction activities. Bromage et al. (1981) claimed the function of explanation activities make people "go beyond the established facts and to make new predictions in new domains." (p. 451)

This study used student prediction and explanation as ways of revealing students' existing knowledge and creating discrepancies when the evidence from the instructor's demonstration was different from students' alternative explanations. Worksheet A asked students to predict and explain; Worksheet B asked students to predict, but did not ask them to explain. Worksheet C did not ask students to predict or explain. Worksheet C provided space for students to take notes and record observations.

The first hypothesis of this study addressed students' post test performance regarding the use of different worksheets. The purpose of designing different worksheets was to investigate the difference between explanations and non-explanations in relation to students' learning.

A previous study (Sinclair & Good, 1991) on the effects of prediction activities on students' learning of genetics showed no significant difference between the experimental group and the control group. The test of the hypothesis one in this dissertation showed that students who worked on prediction and explanation tasks (Worksheet A) explained scientific concepts significantly better than students who worked on prediction tasks only (Worksheets B). However, students who worked on prediction and explanation tasks (Worksheet A) did not produce higher multiple-choice scores than students who worked on prediction task only (Worksheet B).

The results on the effect of prediction and explanation activities (Worksheet A) showed that there was no support in this study for the hypothesis that the use of prediction and explanation activities can increase students' multiple-choice scores. However, when prediction and explanation were joined in instruction as in the case of worksheet A, then students performance on explanations was improved. The improved performance of students was only significant in terms of their capacity to explain the reasons for their conceptions. This finding supports Good and Lavoie's (1986) belief that predicting is effective when multiple variables are operating.

Worksheet A asked students to explain and might have sensitized them to the importance of explanation. With a focus on explanation, students might attend to aspects of instruction related to explanation and consequently produced relatively high explanation scores on the post test. From a more constructivist perspective, the request for explanation on Worksheet A might have produced discrepancies when students compared their initial explanations to the arguments and evidence which followed during the instruction and discussion. These discrepancies might have, in turn, led to conceptual change and the greater understanding revealed in relatively high post test explanation scores. It should be noted that the requests for explanation in Worksheet A came before the instruction and discussion, that students did not receive corrective feedback on their explanations, and that students did not practice constructing correct explanations. Therefore, practice of acceptable and correct behavior could not be claimed as a reason for the higher explanation scores.

Why did the use of prediction tasks only (Worksheet B) fail to enhance students' synthesizing skills (explanations) learning ? One reason could be as follows. The request for a prediction alone may not stimulate students to evaluate their predictions or reflect on the bases of those predictions. Predictions for many students might be simply guesses. Without reason to support predictions, evidence which runs contrary to the predictions does not necessarily result in conceptual change and meaningful learning.

The request for explanations after predictions might encourage students to think more deeply and identify experiences and ideas which support the predictions. Students may form their ideas more clearly as a consequence of attempting to explain. The discussion which followed might have a greater impact on either reinforcing or challenging these ideas. The result could be that students who explain and discuss are able to construct more scientifically correct explanations.

Although students who used worksheet A (with prediction and explanation) did not have significantly higher multiple-choice scores than students who used worksheet B, they did not have significantly lower scores, either. This indicates that the use of prediction and explanation tasks in teaching does not decrease students' performance in multiple-choice scores. However, the prediction tasks combined with explanation tasks did actually enhance students' ability to explain chemical phenomena.

Effect of Student-centered and Teacher-centered Discussion

Previous studies generally revealed more favorable results from student-centered approaches than from teacher-centered approaches. However, some other studies have reported different findings regarding these two instructional environments (student-centered and teacher-centered).

The only difference between student-centered and teacher-centered discussion in the present study was that the former encouraged students to address their alternative conceptions and asked them to defend and to debate their opinions with their peers or instructors. The instructor in the teacher-centered discussion provided possible alternative conceptions and explained the strengths and weaknesses of the conceptions. Students in the teacher-centered teaching strategy listened and did not defend, debate or discuss.

The results of the present study showed that students exposed to the teacher-centered approach did significantly better than those in the student-centered approach on multiple-choice scores. Explanation scores in the student-centered approach were not superior to those in the teacher-centered approach. These results can not support the second hypothesis.

One of the possible explanations for these results might be related to students' abilities and attitudes, as student-centered teaching strategy demanded that students address their alternative conceptions and defend or debate with their peers or instructors. However, if students were not able to express their explanations well, lacked self-confidence, or were unwilling to participate in student-teacher interaction, then the effectiveness of the student-centered approach would be reduced.

Teaching and learning in Chinese society is taken more seriously than in Western countries. There is a Chinese saying--"If one is your teacher for a day, you must respect him as you respect your parents for your whole life." The Chinese respect their teachers as parents. Confucius is the greatest teacher in Chinese minds. The Chinese in Taiwan chose Confucius' birthday as Teacher's Day and as a national holiday. In this kind of culture the teacher in a classroom has absolute authority. Students have been taught to obey their teachers. In this dissertation, students were encouraged to argue, defend, or debate with their peers and instructors. Obviously, it was difficult for students to defend their own alternative conceptions with their instructors. Even during interaction with their peers, if the eye contact from their instructors did not seem to encourage them to defend their opinion, the students might quit. Jensen (1983) in his study also noted that most Asians thought that it is disrespectful to ask questions in the classroom, and most Asian students are shy about participating in discussion. Therefore, the student-centered approach used in this dissertation was at some cultural disadvantage.

In this study, the subjects and instructors were randomly assigned to each experimental condition. Both students and instructors were unfamiliar with each other. With unfamiliar instructors, students might feel uncomfortable and might not actively participate in the discussion. Some students might have kept their alternative conceptions in mind, without asking question or making comments. Because of the particular cultural and social norms in Taiwan, the effect of a student-centered approach might be minimized.

The teacher-centered approach did not ask students to actively participate in discussion. The instructor addressed all the possible alternative explanations that students might have. Students in this approach gathered much information from the instructor. This information might be much more than that obtained from their peers (student-centered). In other words, the more students' alternative conceptions were addressed, the more opportunities the instructors provided students to engage in critical thinking. A similar opinion was cited in Sinclair and Good's (1991) interview of the teachers participating in their study. The teachers expressed that deeper levels of students' understanding occurred because misunderstandings were dealt with directly and immediately through classroom interaction and dialogues.

In the present study, all three teachers when interviewed predicted that students in the constructivist teacher-centered approach would do significantly better than students in the conventional approach, and better than students in the constructivist student-centered approach. The results of the present study were partly consistent with their predictions.

In sum, the students' attitudes and abilities, the atmosphere of the classroom, and the particular culture in Taiwan, might have caused the results to be opposite to those predicted by hypothesis two.

Effects of Constructivist and Objectivist Approaches on Learning

The prediction that students in constructivist lessons would score significantly higher than students in conventional lessons was not generally supported by the results. This result seems consistent with the findings on student-centered and teacher-centered teaching strategies. Thus, the particular cultural influences on the results of this experiment (in terms of multiple-choice scores) and the strengths of the teacher-centered approach seemed to appear again. In terms of explanation scores, however, the constructivist student-centered approach did significantly better than the conventional strategy.

In addition to the unique cultural environment in this experiment, another possible reason why no significant differences between constructivist approaches and the conventional approach were found in multiple-choice scores might be that only one lesson was taught in this study. If we were to continue using these approaches to teach several lessons, the development of critical thinking skills (prediction and explanation) might accumulate from lesson to lesson, and may result in a clear distinction.

Effect of Constructivist and Objectivist Approaches in Lower- and Higher-level Cognitive Knowledge

Students in the three different instructional approaches (student-centered, teacher-centered and conventional) did not produce significantly different higher-level knowledge scores. However, students on the conventional treatment did significantly better than students in the student-centered approach on lower-level cognitive questions. These results supported the second part of hypothesis four.

Although students in the constructivist approach produced higher scores than students in the conventional treatment on higher-level knowledge (multiple choice) scores, this difference was not statistically significant. This result did not support the first part of research hypothesis four. This result also did not support Jonassen's (1991) assumption that the constructivist approaches would be better for advanced knowledge acquisition. The reasons might rest in both the numbers of questions used for comparison (only six in each category) and the use of multiple-choice only as a measure of higher-level cognitive knowledge in the two-tiered questions. If we increased the number of lower- and higher-level cognitive questions, and if the higher-level question scores would combine their reasoning explanations with multiple-choice scores, then the difference between the treatments in relation to lower- and higher-level cognitive learning might be seen more clearly. Although, the results in this test failed to show that constructivist approaches were significantly better than a conventional approach in producing higher-level knowledge acquisition, they revealed that the introduction of constructivist approaches into science teaching will not hinder student acquisition of higher-level knowledge.

Findings from Students' Alternative Explanations

In this study, students in constructivist approaches were hypothesized to have fewer wrong explanations, and have more correct explanations than students who were involved in the conventional approach.

The results show that students in the constructivist groups had fewer wrong and no explanations, but had more right explanations than students in the conventional treatment. However, the percentage of students who had wrong explanations after getting multiple-choice answers correct in each question was very high. This evidence casts doubt on the validity of multiple-choice questions. The instructor should not rely on multiple-choice questions as the only assessment of students' understanding.

Discussion of Retention Test Data

Regardless of the teaching strategy, teacher, or worksheet, no student performance differences persisted two weeks after the instruction. Change scores in explanation scores are not very different.

Finally, there is no main effect and interaction among the three teaching approaches in relation to retention test scores on lower- and higher-level questions.

There are two factors that might have affected the retention test. Students might not have been excited about repeating the same test. During the retention test one student said: "We did this before. Why are we being tested on this again?" The other factor was a fire-drill announcement during the retention test.

Discussion of Teacher Effect

A Teacher main effect appeared in the results of 3 x 2 x 2 and 3 x 3 ANOVA analyses. This means that teachers made significant differences on students' post test scores regardless of the worksheet or teaching strategy used. Students taught by Teacher Z in the teacher-centered approach performed significantly better than students taught by the other two teachers in the same strategy. Indeed, it revealed that the uniqueness of teacher's characteristics perhaps was the principal factor which determined whether or not the constructivist approach can actually be successful in current science teaching.

Recommendations for Instructional Design Practice

1. The results indicate prediction activities associated with explanations will have a better learning outcome. Therefore, it is recommended that teachers introduce other activities, such as explanation, hands-on activities, or simulation with prediction activities in their teaching.

2. The importance of students' alternative conceptions has been discussed throughout the present study. It is recommended that practitioners find out students' alternative concepts as much as possible, emphasize the discrepancy between students' existing knowledge and new knowledge and provide the activities for students to test their hypotheses. Thus, students' alternative conceptions could be removed.

3. Multiple assessments of students' understanding have to be implemented. Findings from students' explanations in Tables 1 and 2 of Appendix F revealed that quite a few of the students gave wrong or no explanations after getting multiple-choice answers correct. Thus, using only multiple-choice tests to assess students' understanding in science teaching is not enough. The instructors can assess students' understanding through the participation of students in discussion, the worksheets that students use during or after instruction, and short essay questions or two-tiered type questions.

4. Instructional designers and teachers should take a close look at students' pre-conceptions, since student's pre-conceptions play an essential role in students' understanding. Instructional designers and teachers can use what has been discovered in this study to address some of the mistaken ideas students have or might construct during instruction. Furthermore, the findings also

revealed the need for teachers and instructional designers to constantly be teasing out students' ideas as instruction take place.

5. Finally, it is recommended that researchers and educators, rather than adopting a polarized "position" in opposition to one another, (for example, "constructivism" versus "objectivism"), seek to implement strong or useful aspects from various philosophies in a truly integrated, or "systemic" manner. In this way, aspects of constructivism and aspects of objectivism might be incorporated together to produce effective instruction.

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