A Study of Improving Students' Competencies of Identifying Scientific Issues and Using Scientific Evidence Through Modeling-Based Inquiry Teaching

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This study aimed to improve students' competencies of "identifying scientific issues" and "using scientific evidence" by developing modeling-based inquiry teaching. The quasi-experimental design was adopted with the research subjects being three classes of eighth graders from a junior high school. There are the experimental group I (28 students), the experimental group II (30 students), and the control group (29 students). The modeling-based inquiry teaching with meta-thinking strategies was applied to the experimental group I, the modeling-based inquiry teaching with thinking strategies was applied to the experimental group II, and the lecture-cookbook experiment teaching was applied to the control group. The teaching units taught included "Refraction of light," "Formation of image of lens," and "The relationship between heat and temperature change of substance." There were three sessions for each unit for each group. The instruments used were the pre- and post- test questionnaires for "identifying scientific issues" and "using scientific evidence." The "identifying scientific issues" questionnaire contained two parts. The "identifying scientific inquiry" part contained five sections. And the "using scientific evidence" questionnaire contained two parts—argumentation and refutation. The covariates were the scores of the pre-test for "identifying scientific issues" and "using scientific evidence," while the dependent variables were the scores of the post-test for "identifying scientific issues" and "using scientific evidence." The analysis of covariance (ANCOVA) was applied and the research findings are summarized below: 1. Both the modeling-based inquiry teaching with meta-thinking and thinking strategies were more effective than the lecture-cookbook experiment teaching in terms of improving the students' competencies of "identifying scientific issues" and "using scientific evidence"; and 2. The modeling-based inquiry teaching with meta-thinking strategies was more effective than that with thinking strategies in terms of improving the students' competencies of "identifying experimental design" and "identifying conclusion" under "identifying scientific issues" and "refutation" under "using scientific evidence."

Keywords: identifying scientific issues, meta-thinking strategies, modeling-based inquiry teaching, thinking strategies, using scientific evidence

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Introduction

The 15-year-old student group (ninth and 10th graders) participated in the programme for International Student Assessment (PISA), which is an international assessment held by the Organisation for Economic Co-operation and Development (OECD) in 2006. Among the 57 participating countries, Taiwan ranked fourth in the overall performance in "science literacy." In the aspect of the three competencies of science literacy, Taiwan ranked third, ninth, and 17th in "explaining phenomena scientifically," "using scientific evidence," and "identifying scientific issues" (Lin, 2008). According to this result, in order to maintain Taiwan's competitiveness in the world, it was necessary to review and modify courses and teachings to improve students' competencies of "identifying scientific issues" and "using scientific evidence," as their performances in these two competencies were relatively low.

What the PISA 2006 international assessment corresponded to was inquiry-based teaching and learning. This can be seen from the basic features of science inquiry in the classroom suggested by the book *National Science Education Standards* (National Research Council [NRC], 2000). The book suggested that the features of science inquiry in the classroom include the followings:

1. Learner engages in a scientifically oriented question;
2. Learner gives priority to evidence in responding to questions;
3. Learner formulates explanations from evidence;
4. Learner connects explanation to scientific knowledge;
5. Learner communicates and justifies explanations.

About these features, there are three things worthy noticing:

1. The focuses of these features are all on the leaner's mental activity;
2. Apparently the purpose of this activity is to develop three competencies, "identifying scientific issues," "explaining phenomena scientifically," and "using scientific evidence";
3. The learner connects with science knowledge.

Thus, reviewing and adjusting the course design and teaching based on the above features of inquiry-based teaching and learning is feasible.

Although it is feasible to improve students' competencies of "identifying scientific issues" and "using scientific evidence" through inquiry-based teaching and learning, it does not mean that if students are devoted to a science inquiry activity to experience the process of inquiry, and then, they would immediately acquire from this experience the thinking methods and inquire competencies of scientists. Zohar (2004), Zion, Michalsky, and Mevarech (2005), and Zimmerman (2007) found that without related scientific thinking strategies, students cannot function normally in any of the stages of the inquiry process. As a result, their science inquiry competencies would not be developed efficiently. Currently, available studies on science inquiry-based teaching and learning are mostly about the fundamental features of inquiry-based learning and the variations of types of inquiry (NRC, 2000), the levels of openness of inquiry teaching (Tamir, 1983), proposing a framework for the process of science inquiry for students as their learning framework (Lee, Buxton, Lewis, & LeRoy, 2006), or proposing a learning framework based on question prompts. However, none of these studies stressed applying the explicit teaching approach to guide students to learn to use related thinking strategies for science in an inquiry activity. Instead, they tended to embed thinking strategies for science in an inquiry activity through the implicit teaching approach.

Literature Review

When explicit teaching is adopted, thinking strategies for science are introduced to students after their inquiry experience. There are two ways to do this. The first way is to introduce "thinking behind the doing" strategies to students (Li & Klahr, 2006; Roberts & Gott, 2000). For example, the thinking strategy for controlled experiments is to change only one factor at a time while all the other factors remain the same. The second way is to introduce "thinking behind the thinking" strategies to students (Zohar & Ben-David, 2008). Examples include thinking about why controlled experiments should be conducted, how they should be conducted, and when they should be conducted. The first way is related to the procedure aspect of thinking strategies for science, while the second is related to the meta-cognition aspect (Ben-David & Zohar, 2009). No matter for which thinking strategy for science, explicit teaching must be connected to students' inquiry experience. As thinking strategies for science are abstract, and thus, difficult for most students if only introduced through words (Li & Klahr, 2006; Zohar, 2004).

Moreover, the manifestations of inquiry-based teaching and learning for science in a classroom include observation, posing a question, proposing a hypothesis, performing an experiment, analyzing data, making a conclusion, and identifying a new issue (Windschitl, Thompson, & Braaten, 2008). Windschitl, Thompson, and Braaten (2008) believed that this type of inquiry lacks of a platform for inquirers to develop a preliminary model to pose questions and make hypotheses, and thus, all obtained data can merely be used to explain the relationship between results and conditions without fundamental explanation for these analyses. Scientific explanations are about not only discovering observable patterns in relationships, but also interpreting how these relationships play the role of evidence to explain why a phenomenon occurs under s certain mechanism. In addition, in a science class, the heuristics commonly used is "if I observe or operate these conditions, then we should be able to observe that result." However, in reality, predictions of results are not so important compared with hidden relationships in the model. Windschitl, Thompson, and Braaten (2008) proposed the heuristics for testing models, which is "if we believe these relationships in the model are correct, and then, when we observe or test these conditions, we should be able to observe these results."

Coll, France, and Taylor (2005) analyzed the roles that models and modeling play in science education. They suggested that both models and modeling are important tools for scientists, science teachers, and science learners. Using models and modeling in teaching is a way to help students understand scientific phenomena. Moreover, using diversified models in teaching is the most efficient, as students can compare models built by them with those built by scientists. They further argued that understanding science models and modeling processes allows students to develop meta-cognition in regard to the process of constructing knowledge of a science community and provides an instrument to reflect their degrees of understanding of scientific phenomena. A successful modeling-based teaching framework typically involves in guiding students to go though some processes, such as (Hestenes, 1992; Lehrer & Schauble, 2005, 2006; Lesh et al., 2000; Metcalf, Krajcik, & Soloway, 2000; Schwarz & White, 2005; Stewart, Hafner, Johnson, & Finkel, 1992; Stewart et al., 2005):

1. Becoming involved in an issue (usually from a natural phenomenon or material);

2. Developing a temporary model or hypothesis for the causal or compound relationship in the phenomenon;

3. Using a systematic observation method to test the hypothesis;

4. Building a model that can be used to explain what was observed;

5. Evaluating the model based on criteria such as practicability, prediction power, and explanation adequacy;

6. Modifying the model and applying it in a new situation.

This modeling-based teaching framework was used as the basis for this study to develop a modeling-based inquiry teaching. In sum, through modeling, scientists can explore the abstract mechanism behind a natural phenomenon. Through the built model, they can, little by little, construct the theory of how it works behind the phenomenon. In other words, models make scientific inquiry possible and allow us to create new and unexpected phenomena. Therefore, this approach can also be used in teaching science. In a modeling-based inquiry activity, if students can build their own models, their two competencies, "identifying scientific issues" and "using scientific evidence" can be improved through the modeling process. As mentioned above, in a modeling-based inquiry activity, it would be more appropriate to adopt explicit teaching for scientific thinking strategies to associate with students' modeling-based inquiry experiences, so that their related competencies can be developed in modeling-based inquiry.

There are two explicit teachings method, the one of thinking strategies and the one of meta-thinking strategies. Hung (2010) indicated that even though both of the methods are explicit teachings of scientific thinking strategies in inquiry-based teaching, the differences in the influences on improving students' scientific inquiry competencies between these two methods is still an issue worthy further exploring. Therefore, this study aimed to improve students' two competencies—identifying scientific issues and using scientific evidence, using modeling-based inquiry teaching with both the explicit teaching with meta-thinking strategies and the one of thinking strategies. The strategy adopted by this study was to compare the effects of the modeling-based inquiry teaching with meta-thinking strategies, the modeling-based inquiry teaching with thinking strategies, and the lecture-cookbook experiment teaching on improving students' two competencies—identifying scientific issues and using scientific evidence. This strategy is for the purpose of exploring the individual effect of the modeling-based inquiry teaching with meta-thinking strategies and the modeling-based inquiry teaching with thinking strategies.

Research Design

This study adopted the quasi-experimental design method with the research subjects being eighth graders. The modeling-based inquiry teaching with meta-thinking strategies was applied to the experimental group I, the modeling-based inquiry teaching with thinking strategies was applied to the experimental group II, and the lecture-cookbook experiment teaching was applied to the control group. The teaching units taught included "Refraction of light," "Formation of image of lens," and "The relationship between heat and temperature change of substance." There were three sessions for each unit for each group. The instruments used were the pre- and post- test questionnaires for "identifying scientific issues" and "using scientific evidence." The "identifying scientific issues" questionnaire contained two parts—recognizing scientific inquiry and identifying scientific inquiry. The "identifying scientific inquiry" part contained five sections—identifying research question, identifying research hypothesis, identifying variables, identifying experimental design, and identifying conclusion. In addition, the "using scientific evidence" questionnaire contained two parts—argumentation and refutation. The pre-test for "identifying scientific issues" and "using scientific evidence" were conducted before the treatments were applied, and the post-test for "identifying scientific issues"

and "using scientific evidence" were conducted after the treatments were applied. The covariates were the scores of the pre-test for "identifying scientific issues" and "using scientific evidence" and the dependent variables were the scores of the post-test for "identifying scientific issues" and "using scientific evidence." The analysis of covariance (ANCOVA) was applied.

Subjects

The research subjects were three classes of eighth graders from a junior high school. All the subjects are divided into three groups: the experimental group I (28 students), the experimental group II (30 students), and the control group (29 students), respectively. The two experimental groups were taught by the seed teacher (Mr. Feng) of this study, while the control group was taught by Mr. Huang, a teacher of similar age and experiences in teaching.

Treatments

The modeling-based inquiry teaching with meta-thinking strategies was applied to the experimental group I. The modeling-based inquiry teaching with thinking strategies was applied to the experimental group II. The lecture-cookbook experiment teaching was applied to the control group. The teaching units taught included "Refraction of light," "Formation of image of lens," and "The relationship between heat and temperature change of substance." There were three sessions in each unit for each group. The teaching models and activities for each group are summarized below.

The "lecture-cookbook experiment teaching" for the control group. The teaching model applied to the control group was a lecture method. Mr. Huang taught the students using the slides with text and images that he prepared. In the process, there were interactions as he asked questions and the students gave short answers. During the experiment class, the students performed the experiment according to the steps from their textbook. After the experiment was completed, the students recorded their data and analysis results in the experiment log and handed the log to Mr. Huang, along with their answers to the discussion questions from the textbook for scoring. Then, the experiment activity was completed. Afterwards, Mr. Huang would discuss the questions under "questions and discussions" and "knowledge cultivation" with the students based on their log.

The "modeling-based inquiry teaching with meta-thinking strategies" for the experimental group I. After the students learned some modeling and inquiry experiences, meta-thinking strategies were introduced to them. Below is an example of the meta-thinking strategies for the "modeling" step.

> What: To build a model to understand a natural phenomenon, one must find out what the main factors that can be used to describe this phenomenon are and the causal relationships between/among them, in order to explain the phenomenon.
>
> When: Modeling is a suitable method when the aim is to understand how a natural phenomenon works.
>
> How: To build a model, it is essential to identify its components and their relationships with each other, illustrate and explain how these components result in the phenomenon through interactions, and identify the rules behind the phenomenon and the relationships.
>
> Why: To find out how a phenomenon works is why modeling is necessary.

The "modeling-based inquiry teaching with thinking strategies" for the experimental group II. After the students learned some modeling and inquiry experiences, thinking strategies were introduced to them. The difference between the modeling-based inquiry teaching with thinking strategies applied to the experimental

group II and the modeling-based inquiry teaching with meta-thinking strategies applied to the experimental group I was that the contents of meta-thinking strategies involve in what, when, how, and why, while the contents of thinking strategies involve in only what. All the other parts of the teaching processes for the two groups were the same. The related thinking strategies were printed out and given to the students of the experimental group II when the treatment was applied.

Instruments

Pre-test instruments. Two pre-test instruments were used. The first one was a based on the test about conducting experiments from the book *Integrated Science Laboratiry Manual* by Prentice Hall Science Explorer (2000) and modified based on the reviewed by two science education experts and test results of a class of eighth graders. The inquiry process for the situation that "a scientist wanted to explore the reason why the freezing temperature of seawater is lower than that of fresh water" was described using nine statements with nine corresponding numbers. The test contained 13 items. The first nine items were related to "recognizing scientific inquiry." For each item, the students had to pick the relevant one from the nine statements as the answer. For example, the answer to Item 1—Which ones of the statements above include a conclusion was "8 and 9." It represents "8 (The scientist wrote down in his notebook that this phenomenon shows the freezing temperature of seawater is lower than that of fresh water)" and "9 (The scientist continued to write I believe the reason why the freezing temperature of seawater is lower than that of fresh water is because there is dissolved salt in seawater but not in fresh water)" Items 10 to 12 were related to "identifying variables." For example, Item 10—What was the independent variable in this experiment? And the answer to this item was "the independent variable was the salt content in water." Item 13 was related to "argumentation" with three sub-items. Item 13.1 was to decide "whether the result of this experiment supported the scientist's theory," Item 13.2 was to "give evidence," and Item 13.3 was to "state the reason." Moreover, the scores of Items 13.1, 13.2, and 13.3 were simultaneously used as the pre-test scores of "identifying conclusion." The three graders (including the researcher) rated the student's answers based on the grading criteria. The inter-rater reliability for Item 10 to 13 was obtained using Kendall coefficient of concordance and the reliability was 0.95.

The second pre-test instrument used was a test with the situation designed based on the multi-variate causal structure using the previously taught unit "Changeable sounds" as the example with three variables—material, length, and cross-sectional area. The treatment for the experiment in this test contains nine combinations, meeting the modeling purpose of "identifying the relationships between/among the factors used to describe the phenomenon in order to explain that phenomenon." After the students finished reading the description of the situation of the test, they were asked to answer the following questions:

1. What were the three questions John was studying?

2. What was the hypothesis for each of the questions?

3. To verify hypotheses 1-3, which strings should be used for experiments, respectively?

The first question was related to "identifying research question," the second one was "identifying research hypothesis," and the third one was "identifying experimental design." The inter-rater reliability for Items 10 to 13 were obtained using Kendall coefficient of concordance and the reliability was 0.92.

Post-test instruments. Two post-test instruments were used. The first one was the first pre-test instrument. The second one was a test with two sets of items. The situation for the first set was designed based on the

multi-variate causal structure using the unit (The relationship between heat and temperature change of substance) being taught, as the example with seven variables—type of liquid, volume, mass, heating time, initial temperature, final temperature, and temperature increase. Some of the variables were irrelevant variables. The treatment for the experiment in this test contains 15 combinations, meeting the modeling purpose of "identifying the relationships between/among the factors used to describe the phenomenon in order to explain that phenomenon." After the students finished reading the description of the situation of the test, they were asked to answer four questions:

1. What were the questions Brown was studying?

2. What was the conclusion for each of the question?

3. For each conclusion, which experimental group(s) was (were) the evidence from?

4. For the experiment which generated the evidence and what were the independent variable, dependent variable, and control variable?

The first question was related to "identifying research question," the second one was "identifying conclusion," the third one was "identifying experimental design," and the fourth one was "identifying variables." The inter-rater reliability for this instrument was obtained using Kendall coefficient of concordance and the reliability was 0.93.

The first situation for the second set was designed based on the multi-variate causal structure with four variables—water quality, S wave velocity, snake movement, and type of soil. There were three possible levels (low, medium, and high) of the resulting seismic intensity. The treatment for the experiment in this test contains seven combinations, meeting the modeling purpose of "identifying the relationships between/among the factors used to describe the phenomenon in order to explain that phenomenon." After the students finished reading the description of the situation of the test, they were asked to answer the following questions:

1. What were the three questions John was studying?

2. What was the hypothesis for each of the question?

3. To verify the hypotheses, which experimental group(s) should be selected?

The first question was related to "identifying research question," the second one was "identifying research hypothesis," and the third one was "identifying experimental design."

The second situation included one more variable—earthquake probability. After the students finished reading the description of the situation of the test, they were asked to answer four questions:

1. Which hypotheses were supported by the experiment result and which were not?

2. What was the conclusion based on the experiment result?

3. Brown, John's classmate, suggested that both "type of soil" and "S wave velocity" could be used to predict earthquake probability. Do you agree with him or not?

4. What is your evidence and reason?

The first and second questions were related to "identifying conclusion," and the third and fourth was "refutation." The inter-rater reliability for this instrument was obtained using Kendall coefficient of concordance and the reliability was 0.91.

Data Collection and Analyses

The software package used for statistical analyses was statistic package for social science (SPSS) 17.0. The analyses performed included:

1. The ANCOVA with the pre-test scores of "recognizing scientific inquiry," "identifying scientific inquiry," "argumentation," and "refutation" as covariates, and their post-test scores as dependent variables;

2. The ANCOVA with the pre-test scores of "identifying research question," "identifying research hypothesis," "identifying variables," "identifying experimental design," and "identifying conclusion" as covariates, and their post-test scores as dependent variables.

The effect sizes (ESs) of the experiments were measured by using η^2. The ESs were small, medium, and large, and the η^2-value was 0.01, 0.06, and 0.14, respectively (Cohen, 1992).

Findings and Discussions

Data Analysis Results

The ANCOVA was performed with the pre-test scores of "recognizing scientific inquiry," "identifying scientific inquiry," "argumentation," and "refutation" as covariates, and their post-test scores as dependent variables. Table 1 shows the descriptive statistics of the post-test scores of "recognizing scientific inquiry," "identifying scientific inquiry," "argumentation," and "refutation" and the test results of regression homogeneity within group which were not significant. It meant that the relationships between the covariates and the dependent variables would not be different due to any change in the treatment level of an independent variable. The hypothesis for regression homogeneity within group was supported.

Table 1

The Descriptive Statistics of the Post-Test Scores for the Groups Taught Using Different Teachings

Content for assessment	Modeling-based inquiry teaching with meta-thinking strategies (I)				Modeling-based inquiry teaching with thinking strategies (II)				Lecture-cookbook experiment teaching (III)			
	N	*M*	*SD*	*AdjM*	*N*	*M*	*SD*	*AdjM*	*N*	*M*	*SD*	*AdjM*
Recognizing scientific inquiry[1]	28	5.39	1.07	5.49	30	4.90	0.85	4.91	29	4.47	2.10	3.04
Identifying scientific inquiry[2]	28	37.57	7.29	36.13	30	33.83	10.01	33.86	29	26.69	8.25	28.06
Argumentation[3]	28	2.71	0.60	2.66	30	2.63	0.67	2.58	29	1.45	1.12	1.56
Refutation[4]	28	2.29	1.08	2.21	30	1.13	0.73	1.06	29	1.21	0.82	1.35

Notes. [1] The covariate was the pre-test score of "recognizing scientific inquiry" ($\bar{x}$ = 5.22); [2] The covariate was the pre-test score of "identifying scientific inquiry" ($\bar{x}$ = 7.25); [3] The covariate was the pre-test score of "argumentation" ($\bar{x}$ = 1.82); and [4] The covariate was the pre-test score of "refutation" ($\bar{x}$ = 1.82).

Table 2 shows the results of the ANCOVA. The findings included:

1. The post-test scores of "recognizing scientific inquiry" of the three groups were significantly different ($p < 0.001$). The average scores of the experimental group I and the experimental group II were higher than the average score of the control group. The ES $\eta^2 = 0.336$, which is a large ES;

2. The post-test scores of "identifying scientific inquiry" of the three groups were significantly different ($p < 0.001$). The average scores of the experimental group I and the experimental group II were higher than the average score of the control group. The ES $\eta^2 = 0.150$, which is a large ES;

3. The post-test scores of "argumentation" of the three groups were significantly different ($p < 0.001$). The average scores of the experimental group I and the experimental group II were higher than the average score of the control group. The ES $\eta^2 = 0.234$, which is a large ES;

4. The post-test scores of "refutation" of the three groups were significantly different ($p < 0.001$). The average scores of the experimental group I was higher than the experimental group II and the control group. The ES $\eta^2 = 0.254$, which is a large ES.

Table 2
Summary of the ANCOVA of the Effects of Different Teaching Treatments

Content for assessment	Source of variation	SS	df	MS	F	η^2	Posteriori comparison
Recognizing scientific inquiry	Covariate	0.231	1	0.231	0.113	0.001	
	Group	85.940	2	42.970	21.040***	0.336	I > III; II > III
	Error	169.507	83	2.042			
Identifying scientific inquiry	Covariate	1,935.436	1	1,935.436	31.205***	0.273	
	Group	910.247	2	455.123	7.338***	0.150	I > III; II > III
	Error	5,147.973	83	62.024			
Argumentation	Covariate	14.257	1	14.257	21.268***	0.204	
	Group	17.025	2	8.513	12.699***	0.234	I > III; II > III
	Error	55.637	83	0.670			
Refutation	Covariate	6.872	1	6.872	9.119**	0.099	
	Group	20.253	2	10.126	13.436***	0.254	I > II; I > III
	Error	62.553	83	0.754			

Notes. ** $p < 0.01$; *** $p < 0.001$.

A further analysis for "identifying scientific inquiry" was conducted. The ANCOVA was performed with the pre-test scores of "identifying research question," "identifying research hypothesis," "identifying variables," "identifying experimental design," and "identifying conclusion" as covariates and their post-test scores as dependent variables. Table 3 shows the descriptive statistics of the post-test scores of "identifying research question," "identifying research hypothesis," "identifying variables," "identifying experimental design," and "identifying conclusion" and the test results of regression homogeneity within group which were not significant, meaning the relationships between the covariates and the dependent variables would not be different due to any change in the treatment level of an independent variable. The hypothesis for regression homogeneity within group was supported. The results of the ANCOVA are summarized in Table 4.

The findings from this analysis included:

1. Both the post-test scores of "identifying research question" and "identifying research hypothesis" of the three groups were not significantly different ($p > 0.05$);

2. The post-test scores of "identifying variables" of the three groups were significantly different ($p < 0.001$). The average scores of the experimental group I and the experimental group II were higher than the average score of the control group. The ES $\eta^2 = 0.216$, which is a large ES;

3. The post-test scores of "identifying experimental design" of the three groups were significantly different ($p < 0.001$). The average score of the experimental group I was higher than the experimental group II and the control group, and the average score of the experimental group II was higher than the control group. The ES $\eta^2 = 0.516$, which is a large ES;

4. The post-test scores of "identifying conclusion" of the three groups were significantly different ($p < 0.001$). The average score of the experimental group I was higher than the experimental group II and the control group. The ES $\eta^2 = 0.099$, which is a medium ES.

Table 3

The Descriptive Statistics of the Post-Test Scores for the Groups Taught Using Different Teachings

Content for assessment	Modeling-based inquiry teaching with meta-thinking strategies (I)				Modeling-based inquiry teaching with thinking strategies (II)				Lecture-cookbook experiment teaching (III)			
	N	M	SD	AdjM	N	M	SD	AdjM	N	M	SD	AdjM
Identifying research question[1]	28	7.07	1.90	6.83	30	7.17	2.00	7.16	29	7.21	1.86	7.45
Identifying research hypothesis[2]	28	4.00	0.00	3.93	30	3.47	1.38	3.44	29	3.79	0.82	3.89
Identifying variables[3]	28	11.68	2.97	11.81	30	11.70	3.68	11.80	29	8.38	3.29	8.15
Identifying experimental design[4]	28	8.50	2.72	8.38	30	6.37	1.92	6.48	29	3.48	2.01	3.48
Identifying conclusion[5]	28				30				29			

Notes. [1] The covariate was the pre-test score of "identifying research question" ($\bar{x}$ = 1.43); [2] The covariate was the pre-test score of "identifying research hypothesis" ($\bar{x}$ = 1.92); [3] The covariate was the pre-test score of "identifying variables" ($\bar{x}$ = 1.91); [4] The covariate was the pre-test score of "identifying experimental design" ($\bar{x}$ = 2.00); and [5] The covariate was the pre-test score of "identifying conclusion" ($\bar{x}$ = 1.82).

Discussions

According to Table 2, we can see the followings:

1. In the aspect of the performances in "recognizing scientific inquiry," "identifying scientific inquiry," and "argumentation," the average scores of the experimental group I and the experimental group II were higher than the control group, while there was no statistically significant difference between the experimental group I and the experimental group II.

2. In the aspect of the performances in "refutation," the average score of the experimental group I was higher than the experimental group II and the control group, while there was no statistically significant difference between the experimental group II and the control group.

These results are consistent with the findings by Zohar (2004), Zion, Michalsky, and Mevarech (2005), and Zimmerman (2007), who believed that students cannot function normally in any stage of the inquiry process without relevant scientific thinking strategies, and thus, their scientific inquiry competencies cannot be developed efficiently. These results are also consistent with the findings by Windschitl, Thompson, and Braaten (2008), who suggested that students cannot experience or learn the process of scientific inquiry through cookbook experiments, while the modeling-based inquiry teaching may lead to positive learning effects. Moreover, this study further discovered that in the aspect of the performances in "recognizing scientific inquiry," "identifying scientific inquiry," and "argumentation," the effect of the explicit teaching with meta-thinking strategies was the same as that of the explicit teaching with thinking strategies. However, in the aspect of the performances in "refutation," the effect of the explicit teaching with meta-thinking strategies was better than that of the explicit teaching with thinking strategies.

This discovery is correspondent with the suggestion proposed by Hung (2010) that the difference in the influences on improving students' scientific inquiry competences between applying the explicit teaching

with meta-thinking strategies and the explicit teaching with thinking strategies in inquiry teaching is an issue worth further exploring. Zohar and Ben-David (2008) indicated that meta-strategic knowledge regarding argumentation and refutation should be taught to students using the explicit teaching. However, this study found that the influences of the explicit teaching with meta-thinking strategies and the explicit teaching with thinking strategies on "argumentation" and "refutation" were not the same. The influences of the explicit teaching with meta-thinking strategies and the explicit teaching with thinking strategies on the performances in "argumentation" were the same, while the influence of the explicit teaching with meta-thinking strategies on the performances in "refutation" was significantly higher and those of the explicit teaching with thinking strategies and the lecture-cookbook experiment teaching were not significantly different. This means that to improve the learning effect regarding "refutation," the explicit teaching with meta-thinking strategies is required.

Table 4
Summary of the ANCOVA of the Effects of Different Teaching Treatments on "Identifying Scientific Inquiry"

Content for assessment	Source of variation	SS	df	MS	F	η^2	Posteriori comparison
Identifying research question	Covariate	5.817	1	5.817	1.603	0.019	
	Group	4.029	2	2.014	0.555	0.013	
	Error	301.212	83	3.629			
Identifying research hypothesis	Covariate	1.769	1	1.769	2.033	0.024	
	Group	4.416	2	2.208	2.536	0.058	
	Error	72.252	83	0.871			
Identifying variables	Covariate	9.887	1	9.887	0.922	0.011	
	Group	245.437	2	122.718	11.447***	0.216	I > III; II > III
	Error	889.780	83	10.720			
Identifying experimental design	Covariate	106.794	1	106.794	27.128***	0.246	
	Group	347.733	2	173.866	44.167***	0.516	I> II > III
	Error	326.738	83	3.937			
Identifying conclusion	Covariate	79.681	1	79.681	17.121***	0.171	
	Group	42.480	2	21.240	4.564*	0.099	I > II; I > III
	Error	386.277	83	4.654			

Notes. * $p < 0.05$; *** $p < 0.001$.

According to Table 4, after further analyses for "identifying scientific inquiry," in the aspect of the performances in "identifying variables," "identifying experimental design," and "identifying conclusion," the average score of the experimental group I was higher than the control group. In the aspect of the performances in "identifying variables" and "identifying experimental design," the average score of the experimental group II was higher than the control group. In the aspect of the performances in "identifying experimental design" and "identifying conclusion," the average score of the experimental group I was higher than the experimental group II. Because the modeling-based inquiry teaching with meta-thinking strategies helped the students to find out the main factors behind the phenomenon studied and the causal relationships between/among these factors in order to explain that phenomenon (Romberg, Carpenter, & Kwako, 2005; Windschitl, Thompson, & Braaten, 2008), along with the effects of the explicit teaching with meta-thinking strategies, it was reasonable that the students taught using this method scored higher in "identifying variables," "identifying experimental design,"

and "identifying conclusion." The study by Zohar and Ben-David (2008) also supported this inference. They adopted explicit teaching with the meta-strategic knowledge of "controlled variables" to associate students' learning experiences in relation to controlled variables, and found that this method could indeed result in higher performances in their competencies related to controlled variables. Regarding "identifying variables" and "identifying experimental design," the average scores of the experimental group II were higher than the control group. This finding was consistent with the result of the study by Hung (2010). However, regarding "identifying conclusion," the average score of the experimental group II was not higher than the control group. This is an issue to be further studied.

Conclusions and Implications

Based on the findings and discussions above, this study drew four conclusions as below:

1. The modeling-based inquiry teaching with meta-thinking strategies and the modeling-based inquiry teaching with thinking strategies were better than the lecture-cookbook experiment teaching in improving eighth graders' competencies of "identifying scientific issues" and "using scientific evidence."

2. The modeling-based inquiry teaching with meta-thinking strategies was better than the modeling-based inquiry teaching with thinking strategies in improving eighth graders' competencies of "identifying experimental design" and "identifying conclusion" under "identifying scientific issues" and "refutation" under "using scientific evidence."

3. The modeling-based inquiry teaching with meta-thinking strategies and the modeling-based inquiry teaching with thinking strategies were the same in improving eighth graders' competencies of "recognizing scientific inquiry" and "identifying variables" under "identifying scientific issues" and "argumentation" under "using scientific evidence."

4. Although the modeling-based inquiry teaching with meta-thinking strategies was superior in improving eighth graders' competencies of "identifying scientific issues" and "using scientific evidence," the modeling-based inquiry teaching with thinking strategies was still better than the lecture-cookbook experiment teaching in improving eighth graders' competencies of "identifying scientific issues" and "using scientific evidence."

The process of the modeling-based inquiry teaching with meta-thinking strategies was cyclic instead of linear. In every step of the process, after the students learned some related experiences, meta-thinking strategies were introduced to them. It is suggested that teachers new to this teaching can start with the explicit teaching with thinking strategies and move to the explicit teaching with meta-thinking strategies after getting some experiences. This way is more appropriate for both teachers and their students in terms of cognitive load. The measurement tool used by this study for "identifying scientific issues" was based on questions of "recognizing scientific inquiry" and "identifying scientific inquiry." Strictly speaking, these two competencies were not quite students' competencies in actual inquiry. It is suggested that future studies can focus on comparing the modeling-based inquiry teaching with meta-thinking strategies, the modeling-based inquiry teaching with meta-thinking strategies, and the lecture-cookbook experiment teaching in improving students' competencies in actual inquiry, to further explore the differences among these three methods in teaching effects.

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