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A five-stage Prediction-observation-explanation inquiry-based Learning Model to improve Students' Learning Performance in Science Courses

Hsien-Sheng Hsiao
National Taiwan Normal University, TAIWAN

Jyun-Chen Chen
National Taiwan Normal University, TAIWAN

Jon-Chao Hong
National Taiwan Normal University, TAIWAN

Po-Hsi Chen
National Taiwan Normal University, TAIWAN

Chow-Chin Lu
National Taipei University of Education, TAIWAN

Sherry Y. Chen
National Central University, TAIWAN

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ABSTRACT

A five-stage prediction-observation-explanation inquiry-based learning (FPOEIL) model was developed to improve students' scientific learning performance. In order to intensify the science learning effect, the repertory grid technology-assisted learning (RGTL) approach and the collaborative learning (CL) approach were utilized. A quasi-experimental design study was conducted to examine whether the students who used the FPOEIL model only had better learning performances than those who used FPOEIL with RGTL or CL. This study adopted purposive sampling, selecting 123 fourth grade students. The experimental process was conducted during five weeks. It was found that the FPOEIL model improved the students' learning performance. Moreover, the low prior knowledge students who learned science using FPOEIL with RGTL or CL had better learning performances than those who learned using the FPOEIL model only, and the effectiveness showed no significant differences between the low prior knowledge students and the high prior knowledge students. Using the FPOEIL model, the positive effects were intensified in the continuous inquiry-based learning activities and feedback-correction process for the students learning science. The RGTL approach helped the students find, remember, and comprehend scientific knowledge. In the CL process, the students spent more time discussing how to integrate clues to answer the science question.

Keywords: collaborative learning, inquiry-based learning, prediction-observation-explanation, repertory grid technology

Correspondence: Jyun-Chen Chen, *Department of Technology Application and Human Resource Development, National Taiwan Normal University, Taiwan.*
cv999999999@yahoo.com.tw

State of the literature

- The POE strategy help students think scientifically, participate in scientific problem-solving processes, begin scientific dialogue, provide the basis for further scientific exploration, and improve their science learning performance.
- If students use the cycle-mode POE method to solve a scientific problem, their learning effects should continue to improve throughout the repeated POE process.
- The low prior knowledge students failed to find the main points and underlying themes of the scientific concepts, so the instructors may be able to adopt CL or RGTL approach to help students.

Contribution of this paper to the literature

- A FPOEIL model was developed based on the cycle-mode POE inquiry-based learning approach, and students developed a deeper understanding of scientific concepts and knowledge in each POE inquiry-based activity.
- The low prior knowledge students used the FPOEIL model with the RGTL approach assisted the students interpret, integrate, and organize knowledge, which helped the students find, remember, and comprehend scientific knowledge.
- The low prior knowledge students used the FPOEIL model with the CL approach helped students pay attention to the explanation of the POE inquiry-based process and spent more time discussing how to integrate clues to answer the science question.

INTRODUCTION

Learning science advances students' inquiry abilities and promotes the comprehension of inquiry so that they can observe, think, generalize, and create like a scientist. Learning science also improves the scientific and technological literacy of citizens (Abd-El-Khalick et al., 2004; Ministry of Education, 2008). Hong, Hwang, Liu, Ho, and Chen (2014) indicated that by understanding the cause of a problem in science, students can comprehend scientific concepts through cognitive processes, and students' understanding of scientific concepts can be facilitated by developing prediction-observation-explanation (POE) inquiry-based learning contents. The POE strategy can be carried out on a conventional computer or on an intelligent mobile device, such as a tablet, and it complies with the three steps of "prediction, observation, and explanation" to help students think scientifically, participate in scientific problem-solving processes, begin scientific dialogue, provide the basis for further scientific exploration, and improve their science learning performance (Hong et al., 2014; Hsu, Tsai, & Liang, 2011; Karamustafaoğlu & Mamlok-Naaman, 2015; Kearney, Treagust, Yeo, & Zadnik, 2001; Wu & Tsai, 2005; Zacharia, 2005). Moreover, if students use the cycle-mode POE method to solve a scientific problem, their learning effects should continue to improve throughout the repeated POE process (Chen, Pan, Sung, & Chang, 2013; Pedaste et al., 2015).

When students embark on the scientific inquiry process, they might encounter some learning difficulties, such as the inability to judge the cause-and-effect relationships of scientific phenomena, organize and integrate scientific knowledge, and connect scientific theory and reality, which could result in the students not being successful in reaching the next step of inquiry (Abd-El-Khalick et al., 2004; Beck & Forstmeier, 2007; Hong et al., 2014; Lu, Hong, & Tsai, 2008). Therefore, instructors must adopt appropriate learning strategies, such as the collaborative learning (CL) approach, the repertory grid technology-assisted learning (RGTL) approach, etc., to help students improve their learning performance in the scientific inquiry process (Chen, 2012; Chu, Hwang, & Tsai, 2010; Hsueh, 2014; Hwang, Sung, Hung, Yang, & Huang, 2013; Peng et al., 2009; Raes, Schellens, De Wever, & Vanderhoven, 2012; Sato, 2010; Sung & Hwang, 2013). Collaborative learning is a reciprocal learning process, where all students are of the same peer status and they discuss and listen equally. With equal participation in discussions, students can solve problems and increase their learning outcomes (Chen, 2012; Hsueh, 2014; Raes et al., 2012; Sato, 2010). The RGTL approach can be part of the learning partnership in the learning process to help students interpret, integrate, and organize knowledge (Chu et al., 2010; Hwang et al., 2013; Peng et al., 2009; Sung & Hwang, 2013).

In this study, a five-stage POE inquiry-based learning (FPOEIL) model was developed based on the POE inquiry-based learning model. The students used the FPOEIL model during five stages to facilitate a deeper understanding of scientific concepts, and in the five stages, the students had to complete three POE inquiry-based learning activities in which they were challenged to think critically repeatedly. In each POE inquiry-based learning activity, the instructor provided feedback to help students' self-corrections in learning scientific concepts. The FPOEIL model was Web-designed so that it could be run on any intelligent mobile device. The students took the science course in a digital classroom, which was a general classroom supported by mobile technology that provided students with many opportunities to use digital technology to access digital resources that contained information in digital format to learn the subject's content (Chan, 2010; John & Wheeler, 2008).

In order to intensify the science learning effect, the FPOEIL model was used with the RGTL approach to help students interpret, integrate, and organize knowledge or with the CL approach to help student interact and learn with their peers. Upon entering a science course, the students' prior knowledge can affect their cognitive processing, and the differences in cognitive processing among students can affect their scientific learning performance (Liu & Hou, 2011). Low prior knowledge students usually have lower learning achievements, which will gradually deteriorate with age. Therefore, a scientific learning method that is suitable for low prior knowledge students was incorporated in this study to help them overcome learning difficulties.

THEORETICAL FRAMEWORK

POE inquiry-based learning model

An inquiry-based learning model can help students resolve science questions, guide them to become aware of problem-solving issues, and lead them to think critically (Holt & Kysilka, 2006; Lu et al., 2008; Raes et al., 2012; Zion, Michalsky, & Mevarech, 2005). Inquiry is defined as the process of self-correction and self-adjustment (Lipman, 2003), and it is a powerful way for students to develop strategic thinking and to master scientific content (Bell, Blair, Crawford, & Lederman, 2003). In the inquiry-based learning process, students combine scientific processes with scientific knowledge as they reason and think critically about evidence and explanations to develop their understanding of science and their ability to communicate scientific arguments (Goodrum, Hackling, & Rennie, 2000).

The POE model is a potential approach to promoting students' conceptual changes by actively confronting the students' prior knowledge and encouraging knowledge application as well as construction, which embraces the tenets of constructivism (Bednar, Cunningham, Duffy, & Perry, 1992). During the steps in the POE model, students must predict the outcome of an event or situation and provide a justification for their prediction, which provides opportunities for them to clarify and justify their own preconceptions. Then, they must observe the actions taking place and describe the possible discrepancies or congruencies between their prediction and their observation (White & Gunstone, 1992). The POE process can help students' self-corrections and self-adjustments (Lu et al., 2008), and improve their learning performance. The cycle-mode POE method provides more self-correction and self-adjustment opportunities to students and helps them to gradually eliminate scientific misconceptions (Chen et al., 2013; Pedaste et al., 2015).

In this study, the cycle-mode POE inquiry-based learning process was integrated into the FPOEIL model. A difficult science question was divided into five stages, and the learning material gradually became more difficult throughout the five stages. In stage 1, the students received a science question that they were required to understand by the end of stage five. In stage 2, the students had to complete POE inquiry-based learning activities and answer the question from stage 1. The instructor received the answers from the students and immediately gave feedback to help the students make self-corrections. In stage 3, the students completed more POE activities and again answered the question from stage 1. Again, the instructor immediately gave feedback to help the students make self-corrections. In stage 4, the same POE and feedback-correction learning process from the previous two stages was implemented. In stage 5, the students received the correct and complete explanation of the question to help them overcome their science misconceptions. The instructor facilitated the students throughout the learning process by appropriately providing initiatives and a scaffold for the learning objectives.

Repertory grid technology

TRepertory grid technology is one of the Mindtools that originated from the Personal Construct Theory proposed by Kelly (1955). The RGTL approach was originally used to explore the construct relationships of personal cognitive structures and it expanded to more fields with the development of computer tools (John, 2013). RGTL is (a) an approach that motivates students to be responsible for their own learning; (b) a means to get students to communicate their understanding and make this understanding open for inspection and scrutiny; (c) a way to negotiate the meanings of the concepts under study; (d) a tool to match

Table 1. Example of a repertory grid

Constructs	Trait	Elements		Opposite
		Moon	Sun	
Relevant calendar	Solar calendar	5	1	Lunar calendar
Glowing reasons	Self-bright	5	1	Reflected light

students' understanding with their instructor's knowledge; and (e) a way for students to structure their knowledge (Bezzi, 1996).

A repertory grid can be viewed as a matrix, as shown in **Table 1**, that identifies a set of learning targets (i.e., the moon in an elementary school science course). In the matrix, the columns represent elements and the rows represent constructs. An element can be a decision to be made, an object to be identified, or a concept (Chu, Hwang, Huang, & Wu, 2008). A construct consists of a trait and the opposite of that trait. A 5-scale rating mechanism is used to represent the relationships between the elements and the constructs, where "1" represents "the element is highly inclined to the trait"; "2" represents "the element is more or less inclined to the trait"; "3" represents "no inclination" or "no relevance"; "4" represents "more or less inclined to the opposite"; and "5" represents "highly inclined to the opposite" (Chu et al., 2010).

In this study, the RGTL approach was used as a learning tool to help students interpret, integrate, and organize knowledge related to the learning targets. The students using the FPOEIL model with the RGTL approach in stages 2 through 4 received several repertory grids at each stage according to the scientific inquiry-based learning materials. In stage 5, the previous repertory grids were integrated for further practice. Throughout the learning process of using RGTL, the instructor immediately received the students' progress and appropriately provided feedback for self-correction.

Collaborative learning

Collaborative learning (CL) is an alternative way of overcoming individual working memory limitations and is primarily based on the premise that actual learning is best achieved—in terms of effectiveness, efficiency, or both—interactively rather than individually (Kirschner, Paas, & Kirschner, 2009). Sato (2012) pointed out that students do not need a leader in the collaborative learning process because all of the students are of the same status in terms of learning with each other so they can share and criticize their knowledge; in other words, no one is an outsider. The instructor must establish students' habits so they can discuss the learning objectives with their peers; if they cannot solve the problem, they can ask their teacher for guidance. CL is a reciprocal learning strategy (Sato, 2012). The participants in a CL setting must interact simultaneously to solve problems, and all of the participants are equal in the discussion process (Chen, 2012).

In this study, heterogeneous groupings of four to five students used the FPOEIL model with the CL approach on a tablet. In stage 1, the FPOEIL model produced a science question and each group discussed and comprehended the question. In stages 2 through 4, all of the students had to complete three sets of POE inquiry-based learning activities, and they discussed their answers and their reasoning in each stage. The students shared with and listened to each other about the observed phenomena and integrated a team answer to present to the instructor, who immediately gave feedback. In stage 5, the students received the correct and complete explanation of the science question to help them overcome their science misconceptions. In the entire process, as the students discussed the question without solving it, the instructor provided some clues and guided the students in their scientific inquiry-based activities and discussions.

The relationship between prior knowledge and science learning

Prior knowledge strongly influences visualization and the comprehension of texts and diagrams, including the ability to move flexibly between texts and diagrams (Mathai & Ramadas, 2009). High prior knowledge students pay more attention to and are faster in conducting messages compared with low prior knowledge students (Liu & Hou, 2011; van Gog & Scheiter, 2010). In addition, low prior knowledge students transition more frequently between macroscopic and molecular representations, suggesting that these students experience more difficulty as they coordinate representations. Because these students use surface features to create linkages between representations, they are unable to understand the underlying themes (Cook, Wiebe, & Carter, 2008).

Kendeou and van de Broek (2005) pointed out that memory characterization was different between students who had misconceptions of the scientific material and those who had correct concepts of the material after reading science texts. This result shows that if students learn science under an improper predetermined stance, their scientific understanding and memory will be impaired. In other words, when students are involved in a science course, their prior knowledge can affect their cognitive processing, and that might further affect their learning performance (Liu & Hou, 2011). Because of different levels of prior knowledge among students, instructors should provide appropriate initiatives to reduce the study load and focus on efficient learning. In this study, the FPOEIL model was developed to help students learn science, and this model was used with the RGTL approach and the CL approach. The aim of this study was to discover an appropriate learning method for low prior knowledge students to help them reduce their science cognitive load and increase their learning performance.

Digital classrooms

The digital classroom is a new medium of instruction for both teachers and students, one where e-books replace textbooks and pencils, and e-boards replace blackboards and chalk (Chan, 2010). Digital classrooms help to create an ideal constructivist learning environment, in which learners are enabled to progressively develop a deep understanding of domain knowledge through convenient access to appropriate and sufficient resources and extensive sharing of useful information (Kong, 2011; Richardson, 2003). In the digital classroom, with safeguarded and comprehensive portfolios for each student, teachers can better protect and maintain student confidence (Cheng, Wu, Liao, & Chan, 2009).

In the current study, a digital classroom was constructed. The World Wide Web has received increasing attention in education because of its potential to support inquiry (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). The learning system of the FPOEIL model was developed using Web technology so that students could learn using any terminal supporting the Internet and a Web browser. The learning system was designed by the Joomla! management system, PHP backend, and MySQL database. The learning system of the FPOEIL model used in the digital classroom was connected to the Internet by a wireless AP and server. The students used tablets to receive learning materials, execute scientific inquiry-based activities, upload answers, and get feedback from their teacher. If most of the students experienced the same learning difficulties, the instructor could show the learning materials on an e-board and teach the whole class at once. In addition, the teacher used a tablet to send learning materials and feedback to the students. Most importantly, the teacher used the tablet to manage and monitor the students' learning situations while arbitrarily walking around in the class. By the messages received from the students regarding their learning situation, the teacher could give appropriate assistance, understand the students' learning requirements, and move to specific students to provide guidance.

RELEATED LITERATURE

The POE inquiry-based learning model can help students make self-corrections and eliminate scientific misconceptions. Hong et al. (2014) developed a POE inquiry-based learning model to teach science concepts, while Hsu et al. (2011) investigated the effects of the POE strategy in facilitating preschoolers' acquisition of scientific concepts regarding light and shadow. The latter study revealed that the students who learned science concepts using the POE model significantly outperformed their counterparts. Coştu, Ayas, and Niaz (2012) developed a POE-based teaching strategy to facilitate conceptual changes and their effectiveness in students' scientific understanding. They found that the POE inquiry-based learning model helped students eliminate scientific misconceptions and improved their scientific learning performance.

The RGTL approach can help students collect and organize knowledge related to the learning targets (Chu et al., 2010; Hwang, Chu, Lin, & Tsai, 2011; Sung & Hwang, 2013). Sung and Hwang (2013) used RGTL to facilitate the students in sharing and organizing what they had learned during the game playing process, while Hwang et al. (2011) used RGTL to help students organize and share knowledge to differentiate a set of learning targets. The results of those two studies found that RGTL improved students' learning achievement and self-efficacy owing to the provision of knowledge organizing and sharing. That is, with proper a design, repertory grid technology could be an innovative Mindtool for improving students' learning performance (Chu et al., 2010).

TCollaborative learning can help students overcome individual working memory limitations and facilitate learning effectiveness, efficiency, or both (Kirschner et al., 2009). Bell, Urhahne, Schanze, and Ploetzner (2010) used collaborative inquiry-based learning to help students learn to perform steps of inquiry similar to scientists and gain knowledge of scientific processes. Vogel, Spikol, Kurti, and Milrad (2010) used CL to help teachers infuse inquiry into a standards-based science curriculum. Manlove, Lazonder, and de Jong (2009) compared the use of regulative scaffolds within an inquiry and modeling environment between paired and single students. The results from these studies showed that CL can improve students' scientific learning motivation and learning performance.

PURPOSE OF THE RESEARCH

This study developed a FPOEIL model to help elementary school students improve their scientific learning performance. A study with a quasi-experimental, non-equivalent pretest-posttest, and control group design was conducted in two elementary schools in Taiwan to answer the following research questions:

(1) Will the students who used the FPOEIL model only have better learning performances than those who used FPOEIL with RGTL or CL?

(2) Will the low prior knowledge students who used the FPOEIL model only have better learning performances than those who used FPOEIL with RGTL or CL?

"Moon" was the selected science subject unit, which consisted of three sections: "Why does the moon glow?," "Position changes of the moon," and "Phase changes of the moon." The aim of the subject unit was to teach students about the different properties of the moon, such as why it glowed and the periodic changes of the moon regarding position and phase changes, and to increase the students' observational awareness and scientific inquiry abilities.

METHOD

A study with a quasi-experimental, non-equivalent pretest-posttest, and control group design was conducted in an elementary school science course to evaluate the effectiveness of the innovative learning approach. This study compared the learning performance of the students who participated in the task using the FPOEIL model only, FPOEIL with RGTL, and FPOEIL with CL.

Participants

This study adopted purposive sampling, selecting 123 fourth grade students from six classes among two elementary schools in Taipei, Taiwan. One class was assigned to be the Control Group (22 students), one class was Experimental Group A (20 students), two classes were Experimental Group B (35 students), and two classes were Experimental Group C (46 students). The Control Group did not participate in the experimental activities, apart from the pretest and posttest to check the tests effectiveness as measuring tools. The other Experimental Groups were taught by the same instructor to avoid the influence of different instructors. The

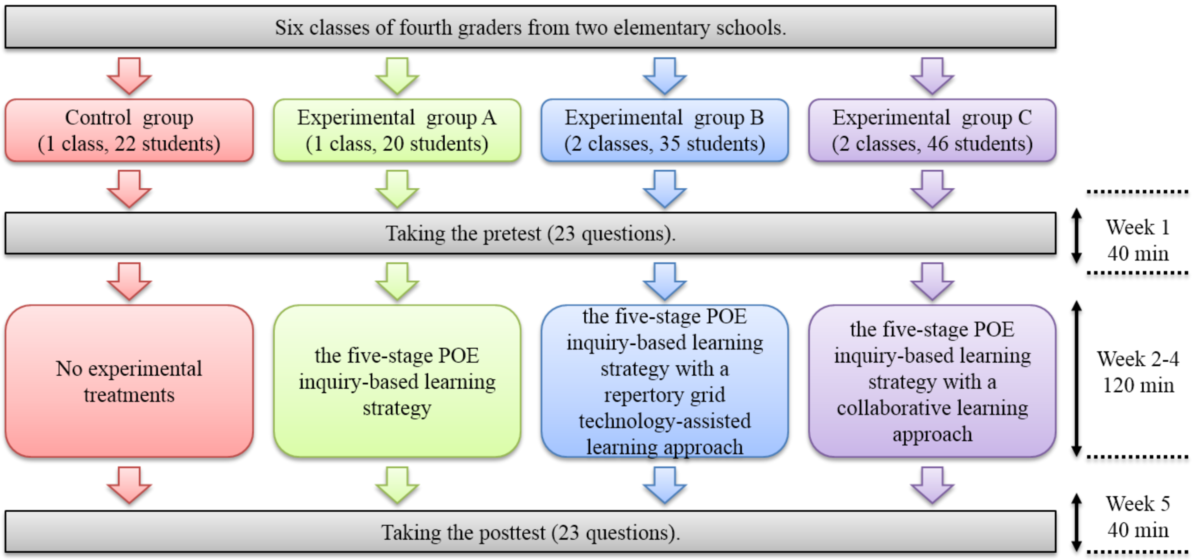

Figure 1. Experimental process for the learning activities

students in Experimental Group A learned the chosen science unit using the FPOEIL model only. Each student had to finish the five stages of the model on their individual tablets. The students in Experimental Group B learned the unit using FPOEIL with RGTL on their individual tablets to help them interpret, integrate, and organize scientific knowledge during the inquiry-based activities. The students in Experimental Group C learned the unit using FPOEIL with CL on their individual tablets to learn and discuss what they learned with their peers.

Experiment process

The experiment was conducted using the "Moon" unit of an elementary school science course, which aimed to teach the students about the different properties of the moon and increase their observational awareness and scientific inquiry abilities. The experimental process for the learning activities, which was conducted during five weeks, is shown in Figure 1:

In week 1, each group took a pretest, which lasted 40 minutes. In weeks 2 through 4, the Control Group did not participate in the experimental activities, while the students in the other groups participated in the experimental activities using the FPOEIL model only, FPOEIL with RGTL, or FPOEIL with CL. Each week featured a 40-minute lesson on the moon: "Why does the moon glow?," "Position changes of the moon," and "Phase changes of the moon." In week 5, each group took a posttest, which lasted 40 minutes. The pretest and posttest consisted of the same questions but in a different order.

Figure 2. The FPOEIL model provided thinking directions to guide students in analyzing the science question

Development of the five-stage POE inquiry-based learning model

The five-stage POE inquiry-based learning model was developed based on the cycle-mode POE inquiry-based learning process to help students understand science concepts and cause-and-effect relationships. It also provided students with a feedback-correction learning process and offered sufficient practice opportunities. The learning process of the FPOEIL model is as follows:

(1) Stage 1: Present a science question. The FPOEIL model provided a science question to the students' learning devices. The students were required to understand the question using scientific thinking and predict the answer and the cause-and-effect relationships. This was the prediction stage of the POE model.

(2) Stage 2: Guide thinking directions. The FPOEIL model provided several thinking directions to help the students analyze the science question. Students could work on the inquiry-based activities based on these directions and search for relevant information on the Internet. When students found the answer and the cause-and-effect relationships, they answered the science question by multiple choice, typing in their reason for choosing their answer. The instructor immediately gave feedback to help the students make self-corrections. This was the observation and explanation stages of the POE model, as shown in **Figure 2**.

(3) Stage 3: Provide learning tools. The FPOEIL model provided several learning tools, such as Web sites, videos, and flash animation. The students had to find the answers and the cause-and-effect relationships in the learning materials, and then answer the science question by multiple choice, typing their reason for choosing their answer again. In this stage, the students went through the observation and explanation stages of the POE model again, as well as the feedback-correction process.

(4) Stage 4: Provide similar examples. The FPOEIL model provided several examples of similar scientific concepts for reference. The students had to find similarities and explore the cause-and-effect relationships to reach the correct answer. Then, the students had to answer the science question and explain their reasoning a third time, and the instructor still provided feedback. In this stage, the students went through the observation and explanation stages of the POE model a third time.

(5) Stage 5: Answer and explain. In this stage, the FPOEIL model integrated the previous learning resources, including thinking directions, learning tools, and similar examples, to explain the science concept in detail. The students received the correct answer, cause-and-effect relationships, and constructs of the scientific concepts and knowledge.

The FPOEIL model helped the students understand the main points of the science question by providing thinking directions, using tools, combining theories and examples, and, finally, constructing complete scientific concepts. The students learned problem-solving methods during the continuous POE inquiry-based learning activities and mastered the scientific concepts in the feedback-correction process. As a facilitator, the instructor appropriately provided scaffolds, initiatives, and feedback to assist student learning in the inquiry-based activities. By providing a support structure, the students were able to internalize the learning techniques. As the students advanced in their learning process, the teacher provided less support until the students could complete the learning mission on their own (Lu, Hong, & Chen, 2011).

The students who used FPOEIL with RGTL received two or more repertory grids (shown in **Figure 3**) in stages 2 through 4 to help them interpret, integrate, and organize scientific knowledge during the inquiry-based activities. In stage 5, the students received

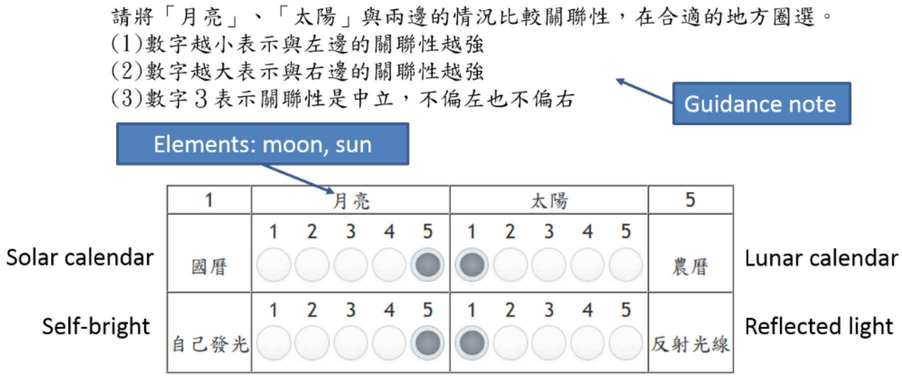

Figure 3. Students received repertory grids to help them organize scientific knowledge

several integrated repertory grids that were constituted by previous repertory grids as practice, and the teacher provided appropriate feedback and guidance.

The students who used FPOEIL with CL were placed in heterogeneous groups of four or five students based on their science grades from the previous semester, so that all of the students in each group were of the same status. In all five stages, the students learned and discussed with their peers. If the student discussion failed to yield the correct answer, the instructor provided assistance to keep the scientific inquiry-based activities and discussions going. Finally, each group combined their opinions and formulated a conclusion, and the teacher gave feedback based on their conclusion.

Instruments

The measuring tools consisted of the learning performance tests (pretest and posttest), which were used to evaluate the students' learning outcomes in the "Moon" unit. This study composed a test developed by a team of 10 experienced elementary school teachers, who each had taught an elementary science course for more than three years. There were 23 questions on the learning performance tests, which were identical but in a different order, and the total score for each was 23 points. Each question, which was developed by one teacher and edited by two other teachers, was followed by multiple-choice answers. In order to verify the reliability and the validity of the learning performance tests, 979 fourth grade students participated in a pretrial of these questions and each question was answered by more than 250 students.

To verify that the scores were equal in terms of the statistics of the capability values, the Rasch (1960) model was used for parameter estimation. In terms of reliability, conditional reliability (Raju, Price, Oshima, & Nering, 2007) was calculated from the capability values and the measurement error was estimated using the Rasch model. The conditional reliability value was 0.7, which, according to Nunnally and Bernstein (1994) was good.

Table 2. Descriptive data of the learning performance of the four groups

Group	N	Pretest		Posttest	
		Mean	S D	Mean	S D
(1) Control Group	22	10.32	2.15	10.23	3.15
(2) Experimental Group A	20	10.25	4.29	11.90	5.02
(3) Experimental Group B	35	10.46	3.50	14.14	4.32
(4) Experimental Group C	46	10.48	3.53	13.67	4.06

Table 3. Paired-samples t-test of the pretest and the posttest learning performance of the four groups

Group	Posttest – Pretest			*t*	*p*
	Mean	SD	Std. Error		
(1) Control Group	-0.09	2.37	0.51	-0.18	0.859
(2) Experimental Group A	1.65	2.66	0.60	2.77*	0.012
(3) Experimental Group B	3.68	3.19	0.54	6.84***	<0.001
(4) Experimental Group C	3.19	2.64	0.39	8.22***	<0.001

$^*p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.001$

In addition, this study used weighted MNSQ (mean squares) to test the data-model fit of the Rasch model in terms of construct validity. The weighted MNSQ of these 23 questions were between 0.7 and 1.3, corresponding to the data-model fit of the Rasch model (Wright, 1994). Based on these statistics, the learning performance tests had good validity.

Data analysis

The collected data from the pretest and posttest were examined by descriptive statistics, paired-samples t-test, analysis of covariance (ANCOVA), and pairwise comparisons. These approaches were used to analyze the variations between the pretest and posttest for each group and the differences between the four groups.

RESULTS

Learning performance

Table 2 shows the descriptive data of the students' learning performance. For the three Experimental Groups, the posttest scores were better than the pretest scores. **Table 3** shows the paired-samples t-test of the pretest and the posttest learning performance of the four groups. In the Control Group, the paired-samples t-test was applied to examine whether significant differences existed between the pretest and posttest scores, and no significant difference (t = -0.18, p > 0.05) was found. Regarding Experimental Group B, the results show that a significant difference (t = 6.84, p < 0.001) was found between the posttest scores and the pretest scores. The results for Experimental Group C were similar to the other two Experimental Groups, as a significant difference (t = 8.22, p < 0.001) was found between the posttest scores and the pretest scores.

Table 4. The ANCOVA results of the posttest for the four groups

Group	Adjusted Mean	Std. Error	*F*	*p*	η^2
(1) Control Group	10.31[a]	0.59	10.33***	< 0.001	0.208
(2) Experimental Group A	12.04 [a]	0.62			
(3) Experimental Group B	14.10 [a]	0.47			
(4) Experimental Group C	13.61 [a]	0.41			

*p < 0.05 **p < 0.01 *** p < 0.001; [a] pretest scores used as the covariate = 10.41

Table 5. The pairwise comparison results of the posttest for the four groups

Group (I)	Group (J)	Difference of Mean (I - J)	Std. Error	*p*	Post Hoc
(1) Control Group	(2) Experimental Group A	-1.73*	0.85	0.044	(1) < (2)
	(3) Experimental Group B	-3.79***	0.75	< 0.001	(1) < (3)
	(4) Experimental Group C	-3.30***	0.72	< 0.001	(1) < (4)
(2) Experimental Group A	(3) Experimental Group B	-2.06**	0.77	0.009	(2) < (3)
	(4) Experimental Group C	-1.57*	0.74	0.036	(2) < (4)
(3) Experimental Group B	(4) Experimental Group C	0.49	0.62	0.432	

*p < 0.05 **p < 0.01 *** p < 0.001

ANCOVA was conducted in this study. From the non-significant interaction of the independent variable and the covariate of the learning performance test (F = 0.20, p = 0.897 > 0.05), the use of ANCOVA was appropriate. After excluding the impact of the pretest scores, the ANCOVA results showed that a significant difference (F = 10.33, p < 0.001) was found between the posttest scores of these group (see **Table 4**). In addition, a partial η^2 value was provided as a substitute for the effect size (F = 10.33, p < 0.001, η^2 = 0.208) (large effect > 0.138) (Pallant, 2007). The posttest scores were significantly different due to the different experimental approaches used.

Table 5 shows the pairwise comparison results of the posttest. The significantly better scores of each Experimental Group compared with the Control Group suggests that these three experimental approaches enhanced the students' learning performance in science. Comparing the adjusted posttest scores for Experimental Groups A and B, it was found that Experimental Group B achieved significantly better (p = 0.009) scores. Comparing the adjusted posttest scores for Experimental Groups A and C, it was found that Experimental Group C achieved significantly better (p = 0.036) scores. Comparing the adjusted scores for Experimental Groups B and C, no significant difference (p = 0.432) was found between the two groups.

Learning performance of students with different prior knowledge

This study explored the learning performance of students with different prior knowledge. Students in the same class were divided into high and low prior knowledge groups based on their pretest score, where the top 50% were high prior knowledge students and the bottom 50% were low prior knowledge students. The data was collected using

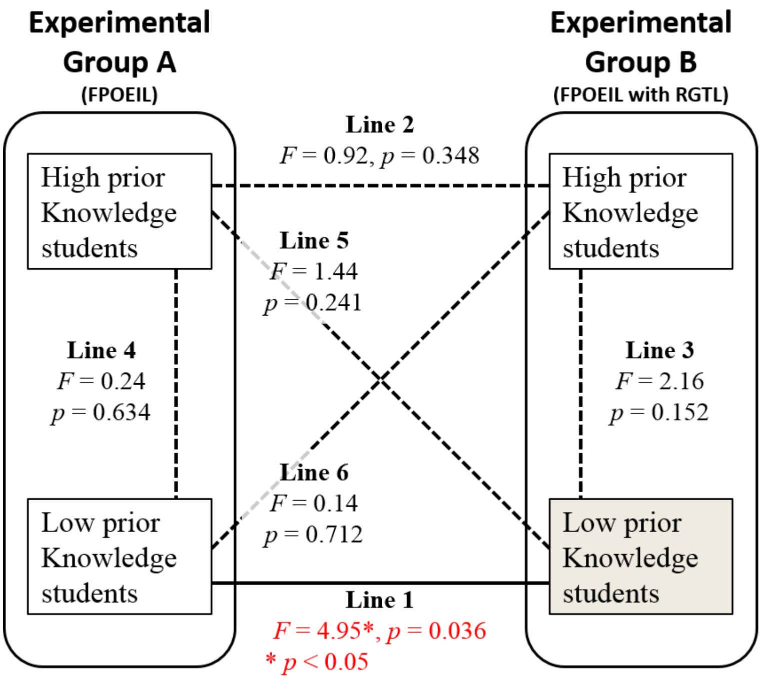

Figure 4. The ANCOVA results of the posttest for students with different prior knowledge and the learning effect of RGTL

ANCOVA, and pretest scores were the covariate to exclude the impact of the pretest on the students' science learning.

Figure 4 shows the relationships constituted by Experimental Group A, Experimental Group B, and different prior knowledge students, as well as the learning effect of RGTL on different prior knowledge students. Each situation in Figure 4 is described as follows:

(1) Line 1 compared the learning effect difference between the low prior knowledge students using FPOEIL only and those using FPOEIL with RGTL. From the test of homogeneity regression ($F = 0.10$, $p = 0.760$), the use of ANCOVA was appropriate. The ANCOVA results showed that the low prior knowledge students using FPOEIL with RGTL achieved significantly better scores ($F = 4.95$, $p = 0.036 < 0.05$). The pretest score of the covariate was 7.30, the adjusted mean score was 8.85 for the low prior knowledge students using FPOEIL only, and the adjusted mean score was 11.85 for the low prior knowledge students using FPOEIL with RGTL.

(2) Line 2 compared the learning effect difference between the high prior knowledge students using FPOEIL only and those using FPOEIL with RGTL. The results showed no significant difference ($F = 0.92$, $p = 0.348$).

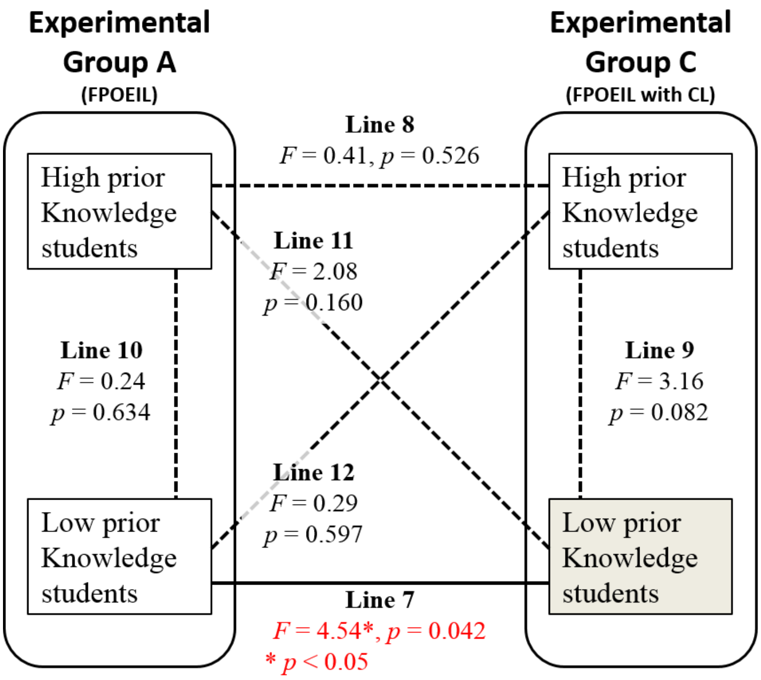

Figure 5. The ANCOVA results of the posttest for students with different prior knowledge and the learning effect of CL

(3) Line 3 compared the learning effect difference between the high and low prior knowledge students using FPOEIL with RGTL. The results showed no significant difference ($F = 2.16$, $p = 0.152$).

(4) Line 4 compared the learning effect difference between the high and low prior knowledge students using FPOEIL only. The results showed no significant difference ($F = 0.24$, $p = 0.634$).

(5) Line 5 compared the learning effect difference between the low prior knowledge students using FPOEIL with RGTL and the high prior knowledge students using FPOEIL only. The results showed no significant difference ($F = 1.44$, $p = 0.241$).

(6) Line 6 compared the learning effect difference between the high prior knowledge students using FPOEIL with RGTL and the low prior knowledge students using FPOEIL only. The results showed no significant difference ($F = 0.14$, $p = 0.712$).

Figure 5 shows the relationships constituted by Experimental Group A, Experimental Group C, and different prior knowledge students, as well as the learning effect of CL on different prior knowledge students. Each situation in Figure 5 is described as follows:

(7) Line 7 compared the learning effect difference between the low prior knowledge students using FPOEIL only and those using FPOEIL with CL. From the test of homogeneity regression ($F = 0.16$, $p = 0.692$), the use of ANCOVA was appropriate.

The ANCOVA results showed that the low prior knowledge students using FPOEIL with CL achieved significantly better scores (F = 4.54, p = 0.042 < 0.05). The pretest score of the covariate was 7.61, the adjusted mean score was 9.22 for the low prior knowledge students using FPOEIL only, and the adjusted mean score was 11.51 for the low prior knowledge students using FPOEIL with CL.

(8) Line 8 compared the learning effect difference between the high prior knowledge students using FPOEIL only and those using FPOEIL with CL. The results showed no significant difference (F = 0.41, p = 0.526).

(9) Line 9 compared the learning effect difference between the high and low prior knowledge students using FPOEIL with CL. The results showed no significant difference (F = 3.16, p = 0.082).

(10) Line 10 and Line 4 achieved the same results.

(11) Line 11 compared the learning effect difference between the low prior knowledge students using FPOEIL with CL and the high prior knowledge students using FPOEIL only. The results showed no significant difference (F = 2.08, p = 0.160).

(12) Line 12 compared the learning effect difference between the high prior knowledge students using FPOEIL with CL and the low prior knowledge students using FPOEIL only. The results showed no significant difference (F = 0.29, p = 0.597).

DICSUSSION

Students achieved significantly better learning performances

The results from the Control Group represent no testing effect for the learning performance tests. One possible explanation for this finding is that the pretest and posttest were taken with an interval of four weeks between them. Agarwal, Karpicke, Kang, Roediger, and McDermott (2008) pointed out that if the initial test questions matched the final test questions, then a two-week delay before the final test was better for reducing the testing effect.

The results show that the students who used the FPOEIL model only improved their learning performance in the science course. One possible reason for this improvement is that the students used the cycle-mode POE method to solve the scientific problem, which provided more self-correction and self-adjustment opportunities to students and helped them to gradually eliminate scientific misconceptions (Chen et al., 2013; Pedaste et al., 2015). Moreover, the POE strategy helped the students to achieve better conceptual understanding of the scientific concepts (Coştu et al., 2012). The students' learning effects also improved throughout the repeated POE process (Chen et al., 2013; Pedaste et al., 2015). It could be inferred that the effectiveness of the FPOEIL model was attributed to the feedback-correction learning process of the cycle-mode POE inquiry-based learning approach. As the students participated in continuous POE inquiry-based learning activities, this deepened their understanding of the scientific concepts and knowledge in each POE inquiry-based activity. In this way, the students gradually eliminated scientific misconceptions and improved their learning performance in the science course.

The results also show that students who used the FPOEIL model with the RGTL approach improved their learning performance. Moreover, they had better learning performances than those who used FPOEIL only. One possible reason for this result is that the RGTL approach helped the students interpret, integrate, and organize knowledge. Thus, the RGTL approach is an efficient learning tool for helping students collect and organize knowledge related to the learning targets (Chu et al., 2010; Hwang et al., 2011; Sung & Hwang, 2013). The results in this study echo those in previous studies. It could be inferred that RGTL was part of a learning partnership that helped students improve their learning performance in the continuous POE inquiry-based learning activities.

The results also show that students who used the FPOEIL model with the CL approach improved their learning performance. Moreover, they had better learning performances than those who used FPOEIL only. One possible reason for this result is that the students discussed scientific knowledge with their peers and interacted simultaneously to solve problems, clarify scientific concepts, and improve their learning performance in the science course. Thus, the CL approach combined with other inquiry-based learning models can help students achieve significantly higher learning outcomes compared with individual students (Bell et al., 2010; Hong et al., 2014; Manlove et al., 2009; Vogel et al., 2010). The results presented here support previous studies. It could be inferred that the peers' discussion and interactions were effective, and that equal participation in the discussions helped the students solve problems and clarify scientific concepts.

Low prior knowledge students achieved significantly better learning performances

The low prior knowledge students who used the FPOEIL model with RGTL had better learning performances than those who used the FPOEIL model only. Based on the results, one possible explanation for these findings is that the learning effect differences were caused by the RGTL approach for both the high and low prior knowledge students. The low prior knowledge students were more easily distracted and slower in getting through tasks compared with the high prior knowledge students (Liu & Hou, 2011; van Gog & Scheiter, 2010). Thus, the RGTL approach is an appropriate learning strategy to help low prior knowledge students reduce their cognitive load in science learning processes.

In Line 1, the low prior knowledge students using FPOEIL with RGTL achieved significantly better learning performances. One possible reason for this result is that the RGTL approach helped the students interpret, integrate, and organize knowledge (Chu et al., 2010; Hwang et al., 2011; Sung & Hwang, 2013) and reduced their learning burden and cognitive load. Therefore, the RGTL approach is an appropriate learning strategy for low prior knowledge students in improving their scientific learning performance. In Line 2, the RGTL approach did not affect the learning outcomes of the high prior knowledge students. One possible reason for this result is that the high prior knowledge students could interpret, integrate, and organize knowledge by themselves. The high prior knowledge students also had better scientific comprehension and cognitive processing abilities regarding scientific knowledge in texts, graphs, etc. (Liu & Hou, 2011). Once more, in Line 3 and Line 5, the low prior knowledge students using FPOEIL with RGTL had an equivalent learning effect to the high prior knowledge students. To sum up, using the FPOEIL model combined with the RGTL approach helped the low prior knowledge students improve their learning performance without affecting the learning outcomes of the high prior knowledge students.

The low prior knowledge students who used the FPOEIL model with the CL approach had better learning performances than those who used the FPOEIL model only. Based on the results, one possible explanation for these findings is that the learning effect differences were caused by the CL approach, which is a reciprocal learning strategy (Sato, 2012) where the participants must interact simultaneously to solve problems (Hsueh, 2014). Thus, the CL approach is an appropriate learning strategy to help low prior knowledge students focus on the main points and understand the underlying themes of scientific concepts.

In Line 7, the low prior knowledge students using FPOEIL with CL achieved a significantly better learning performance. One possible reason for this result is that the CL approach helped the students via an interactive process, where each student had to contribute to finishing the whole learning mission by discussing, listening, thinking, and criticizing the scientific concepts with their peers. The CL approach also helped deepen their involvement in scientific inquiry-based activities and clarify scientific concepts and knowledge (Hong et al., 2014; Sato, 2012; Sung & Hwang, 2013). It could be inferred that the low prior knowledge students discovered the main points and understood the underlying themes of the scientific concepts through the interactive process of the CL approach, which is an appropriate learning strategy for these students in improving their scientific learning performance. In Line 8, the CL approach did not affect the learning outcomes of the high prior knowledge students. One possible reason for this result is that these students achieved appropriate learning effects from the words in the texts by themselves during the scientific inquiry process, and they preferred to learn scientific concepts through texts (Liu & Hou, 2011). Once more, in Line 9 and Line 11, the low prior knowledge students using FPOEIL with CL had an equivalent learning effect to the high prior knowledge students. To sum up, using FPOEIL with CL helped the low prior knowledge students improve their learning performance without affecting the learning outcomes of the high prior knowledge students.

CONCLUSION

In this study, a FPOEIL model was developed based on the cycle-mode POE inquiry-based learning approach. When the students made a memory or comprehension mistake, the instructor immediately gave feedback to help the students make self-corrections. In the feedback-correction process, the students engaged in intellectual activities to improve their scientific memory and comprehension. The POE inquiry-based model promoted the students' conceptual changes. When the students engaged in the POE inquiry-based process, they had to apply, analyze, and synthesize scientific knowledge when observing and explaining scientific phenomena, and these high-level intellectual activities improved their abilities. Using the FPOEIL model, the positive effects were intensified in the continuous POE inquiry-based learning activities and feedback-correction process for the students learning science. The students developed a deeper understanding of scientific concepts and knowledge in each POE inquiry-based activity they participated in, which gradually improved their learning performance in the science course.

The low prior knowledge students failed to find the main points and underlying themes of the scientific concepts. To provide the low prior knowledge students with an appropriate learning strategy, the students used the FPOEIL model with the RGTL approach or the CL approach. The RGTL approach helped the students interpret, integrate, and organize knowledge. RGTL was part of the learning partnership in the learning process, which helped the students find, remember, and comprehend scientific knowledge. The suggestion in this study is that when using the RGTL approach as a learning tool, one must consider the development of the students' seriation and class inclusion abilities. In the CL process, the students paid attention to the explanation of the POE inquiry-based process and spent more time discussing how to integrate clues to answer the science question. The students also applied their existing scientific knowledge to analyze and synthesize new science concepts. The construction of the science concepts was intensified and accelerated throughout the discussion process. Although a few high prior knowledge and strong students were opinionated in their CL group, after the teacher's initiative, the group integrated one conclusion as a team.

The FPOEIL model showed significant effectiveness in improving the students' learning performance in the science course, but some limitations need to be noted. For example, RGTL was effective in helping the students interpret, integrate, and organize knowledge in science learning; however, in developing learning materials using repertory grid technology, one must consider the characteristics of the learning targets. Scientific knowledge with the same attributes should be included in repertory grids, while including different attributes would produce many useless materials. Moreover, CL was effective in helping the students share, discuss, and criticize scientific knowledge with their peers. However, instructors must pay more attention to the discussion process to avoid wasting time on quarreling among students who are opinionated. Furthermore, the high and low prior knowledge students displayed different learning speeds and interactions with their peers; thus, instructors must meet the different prior knowledge students' learning needs at the same time.

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