American Journal of Educational Research, 2017, Vol. 5, No. 1, 50-55
Available online at http://pubs.sciepub.com/education/5/1/8

DOI:10.12691/education-5-1-8

Development and Evaluation of a Practice Model Based on Questioning Framework in Science for Inducing Cognitive Conflicts in Case of the After-image Effect

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Abstract The purpose of this study was to investigate the practice model in science based on questioning framework for inducing cognitive conflicts. Using "puzzling picture" effectively depends on the questions that the teacher asks. First, the teacher uses divergent questions to elicit various responses. After that, the teacher uses convergent questions to focus on science topics. The content of the experiment was to perform a description of the after-image effect. When one tries to observe the water droplets using a stroboscope, water droplets appear to fall, be stopped, or climb. The lesson pertaining to this educational program was administered to 96 in the 10th grade students to determine the effects of the questioning framework. The content of the survey-questionnaire and worksheet were analyzed by using quantitative manner. The following were the results of the study: 1) it is not just fun, it is also beneficial at learning principles of natural science; 2) through the use of "think-pair-share" worksheet describing the interaction with others, the results of reasons were to be easily observed; 3) using the prior knowledge, obtaining new knowledge from others, and formulating new questions.

Keywords: *questioning framework, cognitive conflicts, Think-Pair-Share, Puzzling picture*

Cite This Article: Takekuni Yamaoka, and Shinji Matsumoto, "Development and Evaluation of a Practice Model Based on Questioning Framework in Science for Inducing Cognitive Conflicts in Case of the After-image Effect." *American Journal of Educational Research*, vol. 5, no. 1 (2017): 50-55. doi: 10.12691/education-5-1-8.

1. Introduction

In "Aristotle's Metaphysics," Aristotle observed that "All human beings have a thirst for knowledge of nature." (Aristotle, trans. 1924) [1]. In other words, we all have a strong desire to solve unknown problems for ourselves, albeit to varying degrees. Yamaoka, Matsumoto and Sumida (2015) studied teachers' actual responses and students' expected responses focused on the wrong answers of students in a junior high school science class [2]. The results of the survey show that the students had a tendency to want students to solve the unknown problems for themselves. Furthermore, teachers tended to call on the same students to answer the given questions. Their study suggests that the teaching method in accordance with each grade was an essential factor in students' expectations. Also, the teacher needed to provide guidance in consideration of students' emotional and cognitive responses. One of the reasons why students wanted teachers' cognitive responses was in order to obtain immediate feedback on what the answer was.

From the point of view of accounting for all natural phenomena, it is important to develop the ability to experience the fun and mystery of nature; and it is necessary for students to learn how to get to the bottom of it. On the other hand, from the point of view of preparing for the entrance examination, even acquiring knowledge both from reading textbooks and listening to teachers was likely to satisfy the students' wants. In this case, the exploration activities of students in science and technology is passive. In short, it simply involves memorizing knowledge of science and examining that knowledge. Furthermore, students take advantage by gaining points through their accumulated knowledge, so that the entrance exam problem appears solvable. This system works on the assumption that only one correct answer underlies problem solving. However, the real world does not only consist of one correct answer as described in the textbooks. Murakami (1979) notes that the fact is established for the first time depending on the theoretical premise [3]. That is, there is no clear solution to natural phenomena. They were caused by a clear process to which the solution corresponds. In order to learn this process in the classroom, it is important to induce cognitive conflict and to deepen thinking through the teachers' questioning and interactive activity among the students.

Walsh and States (2005) organized a program of questioning based on the research [4]. The effective questioning program they developed, the "Questioning and Understanding to Improve Learning and Thinking" (QUILT) framework, employed a variety of teaching strategies. Yamaoka and Matsumoto (2015) have performed theoretical research on the QUILT framework, further developing a science-specific questioning framework based on it, including a variety of teaching strategies [5]. This was designed to support the practice of science teaching that raises cognitive conflict in junior high school students.

The "Puzzling Picture" is the teaching strategy developed by Styre and Sound (1975) that describes the importance of effective questioning through picture riddles [6]. Using the "Puzzling Picture" strategy effectively is dependent on the questions that the teacher asks. At first, the teacher uses divergent questions to elicit various responses, after which he or she asks convergent questions to focus on science topics.

"Think-Pair-Share" is the teaching strategy that aims to build discussion. The problem is first considered alone, then discussed by two people, and finally shared with the whole group. This study focuses on this strategy, as described in the worksheet, to deepen the discussion process.

Science classes based on this questioning framework are adapted to the level of junior high school students, and not to that of high school students. In order to explore further practicable possibilities of the questioning framework, this study developed a high school science education program based on the questioning framework and tested it out on high school students.

2. The Purposes of this Study

The purpose of this study was to investigate the practice model in science based on questioning framework for inducing cognitive conflicts.

Using the "Puzzling Picture" strategy effectively depends on the questions that the teacher asks. An attempt was therefore made to develop a science education program at the high school in order to solve the mystery of which type of questions are effective. First, the teacher used divergent questions to elicit various responses, after which convergent questions were applied to focus on science topics. To clarify the effect of the "Puzzling Picture" technique and "Think-Pair-Share" activity an evaluation was further performed.

3. The Method of this Study

3.1. Subjects of Analysis

The lesson pertaining to this educational program was administered to 96 Grade 10 students to determine the effects of the questioning framework. Science classes were conducted December 2015 in Ehime Prefecture public A high school. The breakdown of participating classes and students was as follows.

(1) Class A: The participants comprised 32 Grade 10 students in the prefectural public high school taking the subjects "science and human life." These mainly represented job applicants.

(2) Class B: The participants comprised 64 Grade 10 students in the prefectural public high school taking the subject "chemical basis." These mainly represented advanced education candidates.

3.2. The Teaching Strategy to Induce Cognitive Conflict

Assuming dialogue and coexistence activities with nature, and replacing the "natural" in science and technology with the "social" or "human," social science and science and technology can be considered to be exactly equal. On the basis of the attitude of experiencing natural phenomena to be strange, clarification involves not only encouraging the development of science and technology, as well as communication with the students, but also achieving the transformation of awareness of conceivable science. In this study, as an opening for the dialogue activities, it was decided to use a teaching strategy to induce cognitive conflict. Cognitive conflict, according to Berlyne (1970), is described according to type, such as doubt, embarrassment, contradiction, cognitive disharmony, confusion, and inappropriateness [7]. According to Jones & Carter (1998), cognitive growth occurs as students try to integrate and make sense of everyday and more formal, school-based knowledge [8]. The "Puzzling Picture" is a technique for integrating school knowledge and everyday knowledge, rather than deriving scientific answers. Its objective is to bring forth various opinions. Through this activity, after eliciting several opinions, a solution is considered in order to overcome the cognitive conflict through doing actual observations and experiments in the discussion activity "Think-Pair-Share," which can deepen understanding. According to Ogawa (1998), scientific theory, scientific hypotheses, and scientific facts that are not directly tied to an experiment or observation are not called science but neo-science [9]. The "Puzzling Picture" is a teaching strategy that produces opinion as much as possible from the wonder phenomenon so that it becomes an opportunity for change from neo-science to science. That is, the practice model in this study is the neo-science experience of the "Puzzling picture," which changes to that of science in the discussion activity known as "Think-Pair-Share." The teaching strategy of cognitive conflict used in this study can be summarized as shown in Figure 1.

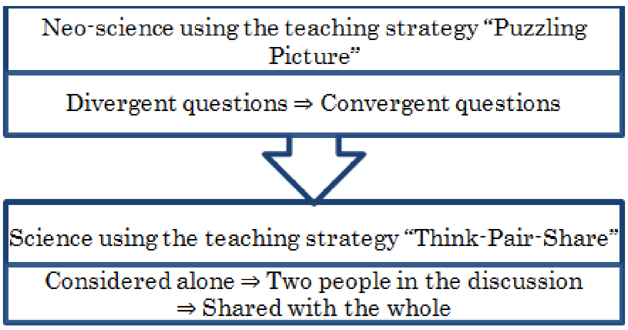

Figure 1. Teaching strategy to induce cognitive conflict

3.3. Implementation of the Worksheet and Questionnaire

For the purpose of analyzing the students' deepening of understanding, a "Think-Pair-Share" worksheet with reference to Pope (2013) was created to be used in class, which enabled a focus on the description content [10]. In this worksheet, it was decided to have the following two questions. (For the "Think-Pair-Share" worksheet that was actually used in class, see Appendix 1.)

Question 1: A drop of water has continued to fall. How is the path traced by a drop of water?

Question 2: How does this phenomenon occur?

Question 1 was set in order to explain the description method of the "Think-Pair-Share" worksheet. The aim of the lesson focuses on whether it is possible to explain the phenomenon as shown in Question 2. In this study, the tendency of the description is seen in Question 2 of the worksheet. Furthermore, it was decided to create a questionnaire to be carried out after class in order to measure the effect of the teaching strategy on the high school science education program based on the questioning framework.

4. Results and Discussion

4.1. Mysterious Photograph

As a science education experiment to induce cognitive conflict, the observation and experiment were selected on the basis of what neo-science is likely to be considered difficult in order to lead to scientific thinking and a scientific attitude. It was decided to take into account the fact that neo-science will change to science. As a result, the experiment that was extracted is that which is shown in Figure 2. Although the experiment holds strong interest for many students in their daily lessons, it is difficult to explain why the phenomenon is happening.

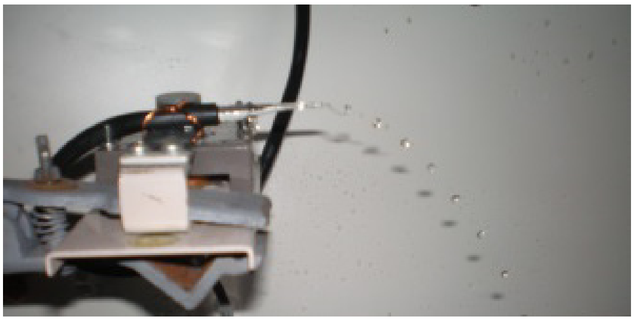

Figure 2. Mysterious photograph to be used in the "Puzzling Picture"

The experiment shown in Figure 2 is generally well-known. For example, it has been introduced in "A demonstration handbook for physics" written by Freier & Anderson, trans. (1986) [11]. When one tries to observe the water droplets using a stroboscope, water droplets appear to fall, be stopped, or climb. However, the purpose of this experiment is to show the state of all parabolic movement. As far as I know, the experiment has not been used for the purpose of explaining the principles of natural phenomena. In fact, when performing this experiment in class, the impact of the experiment itself is strong and likely to remain in the memory of the students. However, it is almost incapable of increasing understanding to arrive at a description of the principle. In short, it often becomes neo-science. Therefore, the experiment as the subject aims to explain the principles through the discussion activities. From the viewpoint of whether it would enable an understanding that overcomes neo-science, it was judged to be suitable to show the effect of the questioning framework. Then, in the introduction of the subject to the class, the photograph of Figure 2 was presented to the students in order to set the scene for inducing cognitive conflict. To investigate the feasibility of implementing the questioning framework in high school, it is considered what reactions were to be expected of students upon being presented with this scene. The results are shown in Table 1.

4.2. Implementing the Science Education Program

In the actual class, the lesson was to start from the activity of showing the photograph of Figure 2., that is called the "Puzzling Picture" strategy. At first, this would involve divergent questioning with "What is this photo of?" For this question, many of the students would focus on the water droplets and space arrangement. Then, for the second step, it was decided to perform convergent questioning with "How does this phenomenon occur?" With this design, rather than foregrounding scientific correctness, we decided to give priority to the fact that expressing opinion stood the students in good stead. At the same time, it was intended that priority be given to the rational thinking of students rather than their scientific correctness. Thereafter, it was decided to perform the dialogue activity "Think-Pair-Share" to deepen understanding of the phenomenon. In addition, Figure 3 and Figure 4 were shown to engage the students in the activities involving description of this phenomenon. At first, an experiment was conducted regarding an after-image effect using a fan with written characters, as shown in Figure 3.

Table 1. Expected students' answers in response to the scene that induces cognitive conflict when introduced in science class

Teacher's question	Supervisory Viewpoints	A probable student's answer
【The first step】 Divergent questions to elicit various responses. "What is this photo of?"	A drop of water (※ To focus on the tip of the nozzle.)	・A glass ball. ・A drop of water.
	Laboratory equipment	・What is the black hose? ・What is the code of electricity? ・What is the machine?
	Space arrangement (※ To pay attention to horizontal and vertical axes.)	・There are regular intervals. ・It is a parabolic motion.
【The second step】 Convergent questions to focus on science topics. "How does this phenomenon occur?"	An experimental technology	・Dropping a drop of water, it hits the wind from behind. ・At regular intervals of time, the horse is crushed. ・Special equipment is used such that water can automatically flow out like a pitching machine.
	Photographing techniques	・The fact is that it is a single drop of water, the photo is processed to make it look continuous.

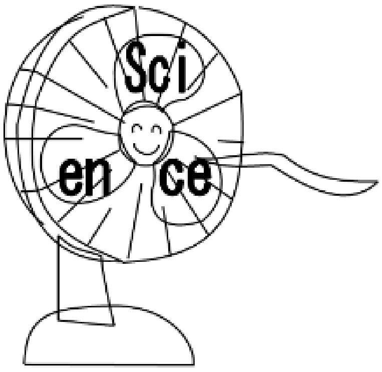

Figure 3. An after-image effect

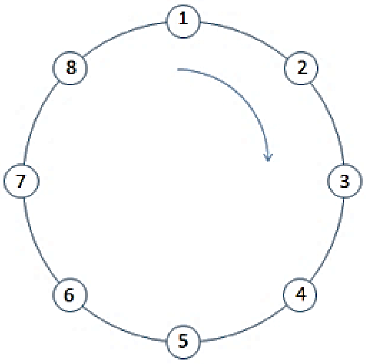

Figure 4. Principle to proceed in reverse

The light of a stroboscope is shone onto this fan. When the rotation speed of the blades of the number of emissions and the fan of the stroboscope matches, it looks like it has stopped the number of actual wings. At that time, by confirming that the characters written on the blades of the fans rotate so that they are readable, it is possible to perform a description of the after-image effect. Then, the experiment is conducted to think about the principle of water droplets falling, stopping, or climbing. Arranged in eight circles as shown in Figure 4, it is voiced in order, that is, 1, 2, 3, ... and so on. At the same time, the person who said 1 raises their hand.

For example, if everyone said 1, everyone raises their hands because everyone utters 1. In this case, the information about voice and hands shows that the students are advancing in the right direction. Then, if everyone says the order 1, 2, 1, 2 ...,that is from 1 to 2, there will be a show of hands every second time. Such is the case here—through the information about voice and hands, it can be seen that they are advancing in the right direction. However, if everyone says the order 1, 2, 3, 4, 1, 2, 3, 4, ..., that is from 1 to 4, there will be a show of hands only by People 1 and 5 in Figure 4. In this case, the information about voice shows that they are advancing in the right direction; but, the information about hands is flashing.

Furthermore, if everyone says the order 1, 2, 3, 4, 5, 6, 7, 1, 2, 3, 4, 5, 6, 7, ..., that is from 1 to 7, there will be a show of hands every seven counts. In this case, the information about voice shows that they are advancing in the right direction; but, the information about hands is in the left direction. Thus, it is possible to experience the principle of sampling. The students' impressions after practice were as follows. "I see that my thinking is deepening more and more." "Water drops flow backwards. At first I thought it was a lie. However, I can confirm the principle by using a fan and the activities of raising my hand, so I was able to understand. It was a funny experiment. "Raising one's hand in the activity was easy to understand."

In this way, the practice of science education programs based on the questioning framework received many favorable opinions in terms of comprehension. In the following sections, the effect of the "Puzzling Picture" and "Think-Pair-Share" will further be analyzed in detail. For that purpose, a quantitative analysis is carried out both of the questionnaire and the description of the contents of the completed worksheets.

4.3. Analysis of the Free Description of the Experimental Results

In order to analyze the deepening of understanding, a field for free description of the experimental results was integrated into the worksheet that was used in class (see Appendix 1). It was decided to focus on the presence or absence of description content of both the "observation and experiment results" and the "result of reason" in the worksheet. A convenient manner is shown in Table 2, in which the answers were divided into three standards: A, B, and C. Then, the description content for Question 2 written on the worksheets was analyzed.

Based on the classification method shown in Table 2, the results of the analysis in the description content of the Think column, the Pair column and the Share column are summarized as shown in Table 3. It should be noted that the figures in the table show the number of respondents.

The results of chi square calculation for the Think column of Table 3 reject the null hypothesis and accept the alternative hypothesis (χ^2=0.33, df=2, ns). In other words, at the stage of thinking alone, the trend of descriptions in the results about observation and experiment did not change on the basis of the class, that is, on whether it was the Class A or the Class B.

Table 2. Classification Method of description

Standards	Classification method
A	Both "observation and experiment results" and "result of reason" are described.
B	Either "observation and experiment results" or "result of reason" is described.
C	Neither "observation and experiment results" nor "result of reason" are described.

Table 3. Analysis of the descriptive content in the worksheet

		A	B	C
Think	Class A	1 (-0.4)	11 (-0.9)	20 (1.0)
	Class B	3 (0.4)	28 (0.9)	33 (-1.0)
Pair	Class A	2 (-1.1)	11 (-1.8)	19 (2.6**)
	Class B	9 (1.1)	35 (1.8)	20 (-2.6**)
Share	Class A	4 (-3.2**)	9 (0.3)	19 (2.8**)
	Class B	29 (3.2**)	16 (-0.3)	19 (-2.8**)

※ The numbers in parentheses represent the adjusted residuals.

The results of chi square calculation for the Pair column of Table 3 accept the null hypothesis as true (χ^2=71.3, df=2, p< .05). The results of residual error analysis revealed that in the Class A, there were many standard Cs, while in the Class B, there were few standard Cs. Thus, it is clear that in the discussion activity with two people, "observation and experiment results" and "the result of reason" were noted in the Class B.

The results of chi square calculation for the Share column of Table 3 accept the null hypothesis as true (χ^2=11.5, df=2, p< .01). The results of residual error analysis revealed that in the Class A, there were few standard As and there were many standard Cs, while in the Class B, there were many standard As and there were few standard Cs. Thus, it is clear that it was able to share with the whole group in the Class B. In the discussion activities "Think-Pair-Share," which were divided into three stages, the discussions between two people were very important. In other words, if there is a good discussion between two people, it is considered to be easier to share with the whole group. Then, to understand the relevance between the activities shared by the whole and activities that made up the discussion involving two people, there was more detailed analysis. Based on the classification method of describing the contents of Table 2, the results were conveniently scored with standard A as 3 points, standard B as 2 points, standard C as 1 point. This is regarded as the investigation object of the 3-point scale, which enabled the calculation of the average score and the standard deviation as shown in Table 4.

As shown in Table 4, the results of analysis of variance and the main effect of the discussion method were significant (F(2,188)=18.06, p< .01). In addition, the main effect of the treatment in both the Class A and the Class B was significant (F(1,94)=8.07, p< .01). The interaction effect of the method and treatment of discussion was also significant (F(1,188)=8.03, p< .01). Multiple comparison of the treatment was significant at the 1% level. In the method, in any of the discussions, the Class B had the higher average score. Therefore, the discussion activities with two people can affect the sharing with the whole group. Thus, changes in the stepwise description contents were observed. From one point of view, "Think-Pair-Share" can be said to be based on a scaffold that enables the students to obtain knowledge by performing interactions with others, thereby advancing up the ladder to better understanding in a stepwise manner.

4.4. Analysis of the Questionnaire

In order to investigate the effect of discussion activities in the questioning framework, a questionnaire was carried out with all of the students on the content after class. It should be noted that questionnaire Item (1) used the term "print" rather than the "worksheet," with which the students were familiar, in order to ensure that there was no misunderstanding.

Item (1): With regard to the class print, it required you to write three items, that is, your ideas, the ideas you discussed with your partner, and the ideas and you shared with the whole group. Using this print, were you able to deepen your thoughts?

Item (2): Were you able to take advantage of your previous knowledge in the discussion activity?

Item (3): Were you able to discover new knowledge in the discussion activity?

Item (4): Were you able to come up with new questions in the discussion activity?

The questionnaire therefore consisted of 4 questions, which were answered according to a 5-point Likert scale (1: I strongly disagree, 2: I do not think so, 3: I cannot say either way, 4: I think so, 5: I strongly think so). Furthermore, for each item, it was decided to elicit an answer on the reason for thinking so in an open-ended section. The data reduction is regarded as the values obtained in the reply and the strength. In the questionnaire, 5 points were regarded as the perfect score. The results show the average points, standard deviation, and the t-test, as in Table 5.

In the questionnaire, both Items (1) and (2) were subjected to a t-test, for which no significant difference was observed. The average score for both the Class A and the Class B ranged from 3.8 points to 3.9 points for Item (1). Therefore, from questionnaire Item (1), the 3-step lesson worksheet for "Think–Pair–Share" was generally favorably evaluated. The average score for both the Class A and the Class B was about 3.2 points for questionnaire Item (2). It therefore appears that the knowledge that students already had seems to have been hard to use. However, from the free description column the reason could also be seen, such as "The first place did not have the knowledge that I already had." On the other hand, a response such as "It's the same phenomenon as the rotation of the car's wheels" was also seen. This was intended to take advantage of the knowledge gained in daily life.

For the questionnaire, both Items (1) and (2) were subjected to a t-test, as shown in Table 5, whereby the null hypothesis was accepted as true. From a comparison of the Class A and the Class B, it is possible to discover that new knowledge is more relevant to the Class B, in which the discussion activity with two people was helpful, also in raising new questions. Incidentally, new questions such as "How are you using the many pieces of the picture in one second in the anime?" arose.

Table 4. The average score and the standard deviation of the investigation object of the 3-point scale

Method of discussion	Think	Pair	Share
Class A	1.41 (0.55)	1.47 (0.61)	1.53 (0.71)
Class B	1.53 (0.59)	1.83 (0.65)	2.16 (0.85)

※ The numbers in parentheses represent the standard deviation.

Table 5. The questionnaire with 5 points as the perfect score

The questionnaire	Class A	Class B	t-test
Item (1)	3.78 (0.87)	3.92 (0.72)	t(94)=0.84 (*ns*)
Item (2)	3.16 (1.05)	3.23 (0.96)	t(94)=0.37 (*ns*)
Item (3)	3.60 (1.12)	4.20 (0.80)	t(94)=2.60 (p< .01)
Item (4)	3.28 (1.11)	3.76 (0.89)	t(94)=2.31 (p< .05)

※ The numbers in parentheses represent the standard deviation.

5. Summary

In this study, an experiment was selected through teacher training in order to induce cognitive conflict. On that basis, a high school science education program was developed and implemented. The lesson pertaining to this educational program was administered to 96 in the 10th grade students to determine the effects of the questioning framework.

The content of the questionnaire and worksheets was analyzed using quantitative methodology. The results show that the science education experiment of inducing cognitive conflict is effective in selecting the less likely leads to scientific thinking and scientific attitude. The science education program effectively supports the change in understanding from neo-science to science of the students. Because it may be possible to face the phenomenon without this representing an end in itself, it was fun to experiment. In other cases, the class and teacher would usually look back on whether or not the understanding has become a neo-science. For this reason, the study is anticipated to impact teacher education programs. Furthermore, it is clear that the discussion activities with two people can affect the share scene of "Think-Pair-Share" in the whole group. In addition, the discussion activity with two people leads to obtaining new knowledge, and it became clear that this tended to easily lead to new questions being brought up. From now on, when holding the discussion activity, it is important to secure time for discussions in small groups. Furthermore, discussion in the whole group format is considered important.

Acknowledgements

This work was supported by 11th Hakuho Research Grant for Child Education.

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Appendix 1. Think-Pair-Share Worksheet

Questioning by the teacher	**My ideas**	**Partner's ideas**	**Share contents**
			
【Question 1】 A drop of water has continued to fall. How is the path traced by a drop of water?	①	②	③
【Question 2】 How does this phenomenon occur?	④	⑤ 【Your hypothesis】	⑥
Let's write your thoughts about today's class. By writing in this print, did you put together the idea			