What went wrong? A case study of hypothesis-verification process in science inquiry teaching

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ABSTRACT

Hypothesis generated based on individual's curiosity and doubt suggests tentative answers to the reason why phenomena happen. Hypothesis-verification process requires students to predict reasons and explanations for certain phenomena and to test variables in order to verify the hypothesis. Science inquiry teaching with hypothesis-verification process is generally adapted in elementary science classrooms in Korea, regarded as effective ways of enhancing children's inquiry minds and skills. However, without understanding the nature of hypothesis, teachers often utilize this method as a simple process of predicting-checking without scientific reasoning and explanation. To understand how pre-service teachers could understand and adapt the method of investigative inquiry in their elementary science teaching, we conducted a case study with sixteen fourth year university students in elementary teacher education program in Korea. We observed their teaching practice on investigative inquiry and examined their difficulties of teaching with this method. We videotaped, transcribed and analyzed their lessons and group discussions on challenges of inquiry teaching. We also collected their lesson plans and reflective writings as written data. Based on the data collected, this study examines pre-service teachers' difficulties in teaching hypothesis construction, test, and data interpretation in hypothesis-based inquiry approach.

INTRODUCTION

There have been various forms and approaches of inquiry-based teaching to enhance children's scientific mind and skills since scientific inquiry is recognized as one of the main goals in science education (AAAS, 1989; NRC, 1996, 2000). Among various approaches of inquiry teaching, hypothesis-based inquiry has been recognized as an effective way to develop children's scientific reasoning and problem solving in science teaching. Studies suggested that hypothesis construction and evidence-based reasoning can be taught to young children (Jeong, Songer, & Lee, 2007; Joung, 2008; Tytler & Peterson, 2003), this approach is commonly accepted and practiced in elementary science classrooms. Despite the pervasive practice of hypothesis-verification process, there are some pedagogical concerns in terms of classroom implementation. Firstly, even though that hypothesis is the central part of investigative process, the definition and role of hypothesis have not been examined thoroughly among science educators and teacher practitioners (Wenham, 1993); thus, it has been difficult to agree on its practice and outcomes accordingly. Secondly, there has not been sufficient discussion on pedagogical framework and practice of hypothesis-based inquiry teaching in classroom settings. In this regard, this study attempts to raise some pedagogical issues of hypothesis-based inquiry teaching in science classrooms based on the discussion of the nature of hypothesis and verification in scientific investigation.

The nature of hypothesis-verification

Hypothesis is the principle intellectual techniques of investigation in the history of scientific development. Scientists construct hypotheses based on the phenomena they observe and carry out numerous experiments to test their hypotheses throughout the history of science, e.g., Loffler and Roux's hypothesis and test on diphtheria and the therapeutic use of antiserum resulted in a significant development of Germ Theory in medical science history (Beveridge, 1961). A good hypothesis indeed brings out an important contribution to problem solving. A good hypothesis, at first, is a hypothesis, but eventually transformed into a fact through evidence afforded by subsequent further investigation. If the hypothesis holds right explanation for all situations, it can be evaluated as a theory or even law if sufficiently profound (Beveridge, 1961). There have also been wrong hypotheses which have led fruitful scientific development in the history. For example, in Western Australia, H. W. Bennet made a hypothesis that nervous disease of swayback (sheep) was due to lead intoxication and carried out his tests with ammonium chloride which is the antidote to lead. However, test results suggested him that the disease might be due to deficiency of some mineral which was present in small amounts in the first batch of ammonium chloride. Bennet soon found out that it was due to deficiency of copper, a deficiency never previously known to animal's disease (Beveridge, 1961). In fact, a scientific development can also result from a false hypothesis followed by continuous trials, refuting, and reconstructing it. These examples indicate the importance of constructing hypotheses and critical analysis of test results and re-examination.

The main function of hypothesis in scientific investigation is to suggest new methods (new observation, experiments, etc.) to test if the explanation is true or not. That is, our attention to what to observe, test, and to collect as data are directed by the tentative explanation or solution to the problem. To verify hypothesis is "to trace out its consequences by deduction, to compare them with results of experiment by induction and to discard the hypothesis, and try another, as soon as the first has been refuted; as it presumably will be" (Peirce, 1877, p138)

The structure of hypothesis as conjecture of phenomena and experimental design as method of dealing with evidential phenomena must be suitable for each other's end. In other words, the following tests must be purposefully designed and practiced to verify the explanations. Without the connection between hypothesis and testing, many hypotheses cannot be proved and many experiments become disconnected with no outcomes or benefits to accepting or refuting the hypothesis. In the understanding of the purpose of experiments, there requires our attention to the temptation too attached to our hypothesis in the process of data interpretation. "We must strive to judge the data objectively and modify or discard it as soon as contrary evidence is brought to lift. Vigilance is needed to prevent our observations and interpretations being biased in favor of the hypothesis" (Beveridge, 1961, p. 52). That is, we need to design experiments and methods based on presupposition that the hypothesis is true and yet, collect and interpret data without over-inclination to the hypothesis. The data interpretation and analysis must require critical, open-minded approach.

With the nature of hypothesis in scientific investigation, its role has been emphasized in science education, especially in the area of scientific inquiry & problem solving, scientific explanations, and argumentation. In learning problem-solving process, hypothesis plays a central role in posing and articulating the aspiration and direction of problems (Lawson, 1995, Klahr & Dunbar, 1988), in collecting and analyzing data systematically (Hempel, 1966; Wenham, 1993) and in explaining why problematic phenomena happen (Hanson, 1958; Millar, 1989). Furthermore, hypothesis in the inquiry process can be a logical tool for students to examine and develop scientific knowledge. This suggests that it is crucial for teachers to understand how to construct good and testable hypothesis and how to test and analyze test results in the teaching of investigative inquiry. However, the understanding of hypothesis has been perplexing and challenging among science educators with multiple aspects of prediction, presupposition, and anticipations (Jeong & Kwon, 2006). Hypothesis and prediction are used occasionally for the same purpose without understanding the presupposition of assumption, that is, co-operations of material and imaginary experiences, clues, and identifiers to explain anticipated results. Especially in elementary levels, prediction was suggested as hypothesis considering the level of conceptual knowledge and capacity of problem solving (Gilbert & Matthews, 1986). Because of the multiple understanding of hypothesis, the approach of hypothesis-based inquiry has also been practiced in various formats and directions.

In this paper, differentiating hypothesis and prediction, we attempt to discuss that without understanding the nature of hypothesis, hypothesis-based inquiry cannot sufficiently develop scientific reasoning and evidence-oriented mind which theoretically expected in hypothesis-verification approach. To claim this notion, we will show some episodes of teaching scenes later on in this paper. Among various definitions of hypothesis, we take the view of hypothesis as a tentative explanation. Hypothesis as tentative/suggested explanation or solution is the most widely used one in science education (Park, 2006; Wenham, 1993). It is a tentative explanation when we encounter an unusual situation and try to make sense of the unusualness (Peirce: CP 5.374-5). In other words, hypothesis is a kind of tentative answer to the question 'why a present phenomenon happens' (Lawson, 1995; Salmon, 1998). Based on tentative explanation or solution, students determine their observation and variables and data interpretation and conclusion tightening the original explanation and data collected in inquiry process. Without this tentative explanation or solution, students' hypotheses in science classrooms turned out to be simple prediction on what will happen in the end. Lawson (1995) explained that 'prediction' is a thing that is posed from hypothesis by deduction, and is to be compared with the result of experiment, then is to be verified by inductive process. That is to say, the nature and role of prediction is different from hypothesis However, hypothesis is different from prediction, requiring certain process of thinking and testing. Many scholars explain how to verify certain hypothesis with a sequence of abduction, deduction, and induction (e.g., Hanson, 1958; Lawson 1995; Park, 2006).

To discuss the challenges of the nature of hypothesis and verification practiced in the real situations of classroom teaching, this study examines how pre-service teachers implement this approach in elementary science classrooms and what difficulties and conflicts emerge during their practice with elementary students. Observing their teaching and reflecting together with the pre-service teachers on their teaching, we, as science teacher educator and researchers attempt to understand the challenges of hypothesis-based inquiry teaching in classroom practice, pre-service teachers' difficulties in practicing inquiry teaching, and ways of helping pre-service teachers with understanding hypothesis-based inquiry.

RESEARCH CONTEXT

Research Design & Process

This study took place during science methods course in elementary teacher education in Korea. Sixteen fourth-year pre-service teachers participated in designing and practicing inquiry-based science during the course over 15 weeks. The participants were divided into three groups and prepared and taught one inquiry science lesson as group. For the first half of the course (1st -6th week), the preservice teachers were engaged in exploring strategies to help children with problem solving process based on hypothesis making, designing experiments and controlling variables, collecting data, and making a conclusion. The second part of the course involved lesson design and practice. In the 7th -9th week, each group of pre-service teachers chose their lesson topic and collaboratively designed a hypothesis-based inquiry lesson. For more effective lesson to children, the pre-service teachers practiced the lesson procedure beforehand to reduce any anticipated errors. After their trial, they discussed and revised their lesson to enhance the feasibility and efficiency of lesson. In the 10-13 week, they teach their lessons to a mixed class of Grades 4, 5, and 6 students in the gifted science classes. This class is a type of voluntary students' club based on extra science learning curricular once a week. The last two weeks (14-15th week) there was reflective discussion among the pre-service teachers and the teacher educator (researcher). They also wrote reflection reports individually and had group discussions on their difficulties. Finally they shared their reflection through whole class discussion. All discussions were audio taped and transcribed for data analysis.

Here is the summary of three lessons that the pre-service teachers conducted. In all three lessons, students were asked to construct their hypotheses, design experiments, and verify their hypothesis.

Lesson 1. Snow man's coat

Students would figure out how they could keep ice bars longer without melting. The students observed ice cream bars for 10 minutes in three conditions; leaving it in the air, fanning it, and wrapping it with cloth. For the third condition, children tested it with different kinds of cloth and changes in the numbers of wrapping.

Lesson 2: Paper spinner and hoop plane

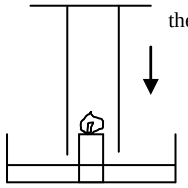
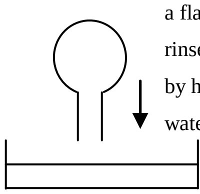
There were two separate activities; 1) paper spinner and 2) plane with hoops. The students made their own hypotheses of what makes the objects fly longer. Students tested the variables of length of wings and the number hoops.

Lesson 3: Candle flame and rising water

Students asked find out under what condition and why the water level goes up higher after candle flames are off inside of cylinder. Children came up with variables of candle numbers and length to verify their hypothesis.

Among three lessons, we will exhibit the details and cases from lesson #3 more frequently than the rest two lessons. That is not because there were more difficulties or stories found in this particular lesson but it would be more plausible to discuss the issues of hypothesis-based inquiry teaching when the readers understand the sequence of the whole lesson process (see Table 1). Therefore, we attempt to introduce more episodes from the lesson #3.

Table 1. The sequence of lesson #3, '*the Candle flame and rising water'*

Process	Activities	video clips
Introduction	➢ A video clip of burning candle and covered by a cylindrical glass ➢ Children observe and discuss why the water is rising after the candle went off.	
Hypothesis making	➢ Children in four groups make hypothesis on under what condition water will go inside more. ➢ Children presented their hypothesis to the whole class. They explained their ideas based on oxygen consumption.	
Testing	➢ Children design their experiments with variables and constants based on their hypothesis and conduct test.	
Data interpretation	➢ Children collect data and examine if their hypothesis was right. They make conclusions	
Presentation	➢ Children represent their results and conclusion to the whole class.	
Ending video	➢ Teacher show another video clip of rising water inside flask, but with no candle flame involved. ➢ Teacher explains that the main reason of water level rising was heat (temperature change) not oxygen consumption.	

Data collection and analysis

In order to understand the depth of problems and difficulties of hypothesis-based teaching, there was a need for us to understand the pre-service teachers' lived experiences, stories, and reflection on and in their actions. For this purpose, we employed qualitative approach for data collection and analysis which allowed us to reach more detailed, descriptive, and approachable understandings of the pre-service teachers' dilemmas and difficulties of teaching. We employed video-recording of classes and pre-service teachers' written reports to understand their classroom teaching. We also collected data from their reflective writings and audio-recording of group discussions on their interactions with children.

In data analysis, the researchers modified and employed the process of open coding, axial coding and selective coding originally suggested by Glaser and Strauss (Flick, 2006). When suggested by Glaser and Strauss, this process of coding was intended to develop grounded theories from research texts (Flick, 2006); however, our purpose to adopt this process was not to create a new theory but to search for integrated themes and relationships among research data so that we could explain the phenomena of hypothesis-verification teaching in science classrooms. For that purpose, we found the process of coding fruitful to enhance the coherence of interpretation and thematization of data in our study.

For open coding, we individually cross-checked lesson plans, video clips of their lessons, and their reflections to look into the frequent ideas and concerns emerged. Through the audio data of their discussion, we could understand why their action occurred certain ways during teaching. Since each pre-service teacher was working closely with one group of children, their observation on children's learning behaviors was very descriptive and reflective. This process also helped us understand the pre-service teachers' experiences which were unrecognized by us. For axial coding, the researchers, after the first step of coding, gathered to discuss interpretation, themes, and concerns related to the data. During this step, we attempted to find out integrated, coherent themes and concerns of hypothesis-based teaching. For the selective coding, the researchers selected some episodes from lessons and discussions which distinctively exhibited the concerns and difficulties of teaching hypothesis-based inquiry. Then we discussed the details of pre-service teachers' experiences, decision-making scenes, and actions in the episodes to re-examine the themes and the contexts of the episodes. By following these steps, we could analyze and conclude the integrated themes of the difficulties and concerns of hypothesis-based inquiry in classroom teaching.

RESEARCH FINDINGS

In this study, we found several pedagogical and instructional difficulties of teaching hypothesis-based inquiry in science classrooms. We especially examined three stages of the teaching of scientific investigation; 1) hypothesis construction, 2) experimental design and test, and 3) data interpretation.

Lack of understanding of hypothesis

Good hypotheses require children's tentative and testable explanation or solution to the given problem in order for them to develop an investigative process. However, the pre-service teachers show uncertain understandings of hypothesis during their teaching practice. They asked children to predict the result of given problems as hypothesis making. Children wrote down what would happen without why it would happen, that is, a tentative explanation to the prediction. In this case, children's hypothesis is only a simple prediction, not hypothesis. In the first lesson led by the first pre-service teacher group, children were asked to predict in which way they could keep ice bars the longest without melting among three options (fanning, leaving with no interruption, and wrapping with cloth). For instance, children's hypothesis was "when we fan on it, it will melt the fastest". In the second lesson, children were asked to make hypothesis filling in the blank on the sentence suggested by the pre-service teachers, "when the wings are _______, paper sinners will fall down slowly". Among four groups of children, three groups made a hypothesis that "the longer the wings are, the slowly the paper spinners will fall down." And one group said "when the wings have an appropriate length, the spinner will fall down slowly" with no related explanation. Children's hypothesis making seemed a bit more appropriate in lesson 3 in terms of explanation. In lesson 3, the third group of pre-service teachers guided children to come up with possible reasons for their prediction. Here are the details of children's hypothesis making process in the lesson 3 (Episode #1).

Episode #1

Two pre-service teachers (Tae and Kang) were team teaching in this lesson. Tae taught the first half and Kang taught the second half. The rest of the pre-service teachers in the group one were helping children's group activity. In the beginning of the lesson, Tae showed a video clip of covering a burning candle with a measuring cylinder. Children observed that the candle flames went off and the water level inside the cylinder rose. The pre-service teacher asked a few questions to guide children's hypothesis making. Tae asked,

Classroom dialogue #1

Tae (teacher): Why do you think the water level has gone up inside the cylinder? Could you write down your thinking and present it to the class?

Student group 1: We thought it is because the air disappears because of the candle flame and the water was replacing the space of the air.

Tae: Ok , good work. What about next group?

Student group 2: It is because Oxygen will be consumed and there will be empty space. The water went into the cylinder to fill the space.

Tae: Ok, next group, are you ready? Ok, tell us your thought.

Student group 3: There is difference of air pressure inside the cylinder. And, Oxygen disappears and the water is sucked in to replace the space.

…

Group 4: Oxygen disappears so the water goes in to fill the space.

Tae: Ok, good work, guys. Now I am going to ask you to think of how you can make the level of water higher.

Later, Tae asked children to make hypotheses, suggesting the sentence of 'when_____, the

> water level goes up higher, because_____'. Three groups of students said that 'the more candles are inside, the higher water level will be because they will consume more oxygen'. One group (group 3) presented a different condition. It was "the longer the candles are, the more water will go inside because carbon dioxide is heavier that the air and can extinguish the flame. In this case, the flames can stay longer". From the previously dialogue that they suggested above, we could only assume that they also had the idea of oxygen consumption to explain for the difference of air pressure (see dialogue #1).

From the examples above, there are difficulties in the pre-service teachers' teaching of hypothesis making. Firstly, they understood a simple prediction as hypothesis. In 1esson 1 & 2, the suggested format of hypothesis making was only to predict what will happen under certain conditions. The pre-service teachers did not ask children to think about explanations or reasons for their predicted result. This process of simple prediction could not provide children with an opportunity to collect and interpret data to explain why certain results happened. Secondly, the pre-service teachers were not able to guide children to construct a hypothesis which children could design an experiment to test their hypothesis. In the lesson 3, the pre-service teachers did not realize that the hypothesis that children constructed was not testable with the materials and situation that they provided to children. That is, there was no way to measure and justify the oxygen consumption in their experimental materials and equipments. We will explain the details of this notion in the following section.

Unfocused roles of testing

To justify a hypothesis, there requires fair tests. The conditions of fair test are designing the variables and constants. Controlling variables and constants can attain the fairness of test, however, they need to test their explanation given in the hypothesis, not the part of their prediction on result. The pre-service teachers did not have sufficient understandings of this connection between hypothesis and test. The lack of understanding led children's work not fruitful. For example, in the episode #1 above, children's test with the different numbers of candles could prove that their prediction was right, however, could not verify their explanation true. Here are more details of the scene.

Episode #2

After children made their hypothesis such as 'the more candles- the higher water level- because of oxygen consumption' in the groups of 1, 2, and 4 and 'the longer candles- the higher water level- because carbon dioxide is heavier than the air' in the group 3, the teacher asked children to deign experiments to test their hypotheses. Children set up their tests based on variables and constants and started testing their hypothesis out. In their testing, what students actually observed was that the water level went higher when there were more candles. In other words, their test seemingly confirmed that their hypothesis was true. Children concluded their work in which the data from the experiment showed that their hypothesis was right.

During children's experiments, Kang took over the second part of the lesson. She asked children to present their result and conclusion.

Classroom dialogue #2

Kang: Let's hear about the last group's conclusion.

Boy 1: We thought that when there are more candles, the more water will go inside because when the candles are burning, carbon dioxide will come out and the density of carbon dioxide is bigger than oxygen and any other gas inside of cylinder so there will be some empty space and the water will be sucked in to replace the space.

Boy 2: Therefore, we tried to test cases with 1, 2, 3, and 4 candles. We made the same the amount of water [in the petridish], the size of cylinder, the length of the candles, and the time we cover the cylinder. It did not go well, .. we could not do the case of 4 candles. The level of water was 5 cm for 1 candle, 6 cm for 2 candles, 7 cm for 3 candles. We did not have time for 4 candles.

Kang: So in the beginning you thought that because of the combustion, Carbon dioxide will come out, and the density is bigger so there will be some empty space. That's why the water will be sucked in.

Boy 1&2: Yes.

Kang: Then, if carbon dioxide is more dense, there would be empty space? (She gestures)

Boy 1: That's because the density of carbon dioxide is bigger…

Kang: What do you mean by the density is bigger?

Boy 1: the molecules are gathering..

Kang: So it means they are very tightly together? That's why there will be empty space?

Boy1: The space inside the cylinder is the same and if the density of the gas becomes bigger, then there will be some space created.

Kang: …ok, good. Thank you.

….

Kang: To sum up your hypothesis and conclusion, most of you thought that the candles are using oxygen and the water goes inside to replace the empty space. So you designed your test and carried it out. However, think about what you observe on the video in the beginning. If it is because of oxygen consumption, the candle flame is continuously consuming oxygen, the water would go up gradually. However, on the video, you saw the water was suddenly going up very high after the flame was off.

A child: because of heat.

> Kang: Then, we thought it was related to oxygen.. let's watch one video clip to think about other reason.

> During their presentations, Kang realized that children were getting wrong ideas that the water level goes up because oxygen is consumed and water is replacing the space of oxygen. She attempted to teach children the "correct" knowledge of the phenomenon. She showed a video clip which her group prepared beforehand. The video clip showed a demonstration of which a teacher rinses a round flask with hot water and put it upside down on a petridish filled with water. There was neither candle nor flame involved in the demonstration so there should be no activities of combustion and oxygen consumption. So by showing this video clip, the pre-service teachers attempted to explain the relationship between water rising and heat (temperature). However, without any discussion on children's experiment and conclusion compared to the video clip, the lesson was ended.

In this episode, the pre-service teachers did not understand what children's tests proved was only the prediction part (the more candle, the higher water level), not the explanation part (because of oxygen consumption) which is more essential to hypothesis-verification process. The collected data and results were not sufficient to explain if the reason for the rising level of water was oxygen consumption or something else (e.g., heat or air temperature). The independent variable (the numbers of candles) and dependant variable (water levels) are enough to prove the prediction, but unsatisfactory to explain the reason. From this episode, we raise some concerns of understanding and scaffolding the relevance of tests in children's investigating process. With the given experimental situation (materials, equipment, etc.), it was impossible to justify the tentative explanation of oxygen consumption, therefore, re-examining the hypothesis on oxygen consumption was a necessary step that the teacher needed to take. However, the pre-service teachers could not know how to intervene and scaffold the process of hypothesis making and designing a test when children's hypothesis was not justifiable and their experimental design could not test their hypothesis. Without realizing the importance of testing for the explanation of hypothesis, the pre-service teacher asked children to process their test. The teacher did not attempt to explain that their hypothesis could not be right by exploring other conditions. Nor did they ask children to reexamine their hypothesis and develop alternatives before their experimental design.

In hypothesis-based investigation, designing valid tests is a critical process to verify hypothesis. The variables on tests need to be designed to examine tentative explanations that investigators presuppose. Even though the pre-service teachers in the lesson 3 encouraged children to come up with temporary explanations, there was no deep understanding in which test needed to be set up for the explanation, not the result of prediction. They did not realize that the variables in children's experimental design, e.g., the number or length of candles could not justify the hypothesis as a whole (prediction and explanation). As a hypothesis which is eventually proved as wrong can also lead sufficient scientific thinking and knowledge through testing, we do not say that it is meaningless to have hypotheses which cannot be justified by test in the first place. However, without appropriate pedagogical scaffolding, the process of problem solving through hypothesis-verification would be unfruitful and result in perplexing understandings of the role of hypothesis and test. A hypothesis needs to be proved right or wrong through vital testing, and if it is still doubtable or proved wrong, then, there should be more ideas, discussion, and tests to generate alternative and eventually truthful explanations. However, the test design in this episode was not fulfilling the purpose. The design of variables needs to be sufficient to support or refute the explanatory part of hypothesis, not the prediction of final result. Without understanding this connection, the pre-service teachers' approach to hypothesis-verification approach got challenged to attain its purpose.

Lack of skills of data analysis and discussion

In the process of verifying hypothesis, data collection and interpretation are critical to collect the evidence of scientific explanation. This process is situated in the classroom environment because children's interactions with the learning environments are emerging non-linearly. The data collected and interpreted by children are rather unpredictable in classrooms and pre-service teachers seemed not prepared to scaffold the process of reaching the conclusion. However, in all three lessons, the data interpretation and analysis was not taken as important part of knowledge construction. The following episode shows the lack of understanding of the importance of data analysis in teachers' approach.

Episode # 3

The children in the group 3 collected their data from the variables on the length of candles. Their results showed when the length of candle was 5, 8, 11, 14, and 17, the level of water was 6.1cm, 6.5cm, 5.2cm, 5.4cm, and 5.2cm respectively. When they presented their result that there was not found some pattern or much difference of water level among different lengths of candle.

Classroom dialogue #3

Boy 2: To conclude, differently from our hypothesis, when the length of candle is not too long, not too short, but proper, the level of water is the highest. That[the length of candle] was 8 centimeters.

Kang: So you thought in the beginning that when the candle was longer, water would go up more. Why did you think that way?

Boy 1: errr… eh….

Boy 2: Because if the candle is longer, it will take loner carbon dioxide reaches the flame.. and the water also goes up gradually and it will take longer time to reach the flame…

Kang: so you thought the short candle will go off early because carbon dioxide reaches it first so only little water goes in?

Boy 2: yes.

Kang: but I see your results, notice that longer candles did not have more water in. The highest water level was when it was 8cm, then.

Boy 2: Yes.

Kang: ok…

The teacher moved on to the next step without any discussion on this notion.

It is likely that when the candle is shorter, the water level goes up higher. According to this, the children's findings could lead a meaningful discussion on their test results and interpretation. The teacher did not know how to respond to children's results and how to open a discussion for children to think about reasons for which their result was different from their hypothesis. For most of times of children's presentation, the pre-service teacher repeated children's conclusion without further discussion, only moving forward to the next step of the lesson. No critical perspectives and questions were generated during the data presentation and conclusion. This concern appeared in other lessons.

Episode # 4

The following excerpt is from the second lesson on paper spinner.

Classroom dialogue #4

Boy A (team 2): We made paper spinner with 1, 3, 5, 7, and 9 centimeters wings… And our result is our hypothesis is right when the wings are below 5 centimeters, but it is wrong when wings were7 and 9 centimeters.

Hwang: Ok, the flying time was increasing till 5 centimeters and then it decreased from 7 centimeters. Ok, give them hands. Next group.

Boy B (team 3): We tried 6, 7, 8, 9, and 10 centimeters and for accuracy, we tested three times each. With 6 centimeters, the flying time was 1.2 seconds, 7 centimeters, 1.5 seconds, 8 centimeters 1 second, 9 centimeters 0.9 second, and 10 centimeters for 0.8 second. So it was matched with our hypothesis. The finding is when the wings are not short, not long, but 7 centimeters which is just proper length, the flying time is the longest.

…

Hwang: uhhhh.. 7 centimeters… so this team had a different hypothesis and different result. Ok, give them hands. Next team!

Other two groups presented their conclusion in similar patterns. The lesson ended without analyzing why their hypothesis (prediction in this case) could become wrong when the length of wing reached beyond certain points and what they could interpret from the data.

In this episode, the results showed a certain pattern in the ratio between wings and body where the flying time was not increasing any more when the increase of wing length reached at a certain point. Even though this point varied among groups due to the materials and ratios of wing and body, their results showed their hypothesis could be right only until the point. All groups showed this similar pattern in their graphs, however, the teacher did not ask children to think about why this could happen.

The pre-service teachers did not show much effort in interpreting and analyzing data. If the pre-service teachers had asked children to discuss reasons why the levels of water could be different from what they expected (episode #3), why the spinner with longer wings could fly longer, or what would be the similar patterns among groups' results (episode #4), it could have been more scientific explanation and reasoning skills generated and developed through the process. However, there were not enough awareness and scaffolding to fulfill the aspect of investigative inquiry learning.

DISCUSSION

Based on the findings in this study, we highlight the difficulties of teaching hypothesis-based inquiry in the dimensions of the nature of hypothesis, fairness of test, skills of data analysis and communication. Firstly, there needs a sufficient understanding of the nature of hypothesis in order to conduct effective teaching of hypothesis-based inquiry. If there is one sentence, one observation, one single inference about a single concrete object with no testable explanation involved in hypothesis making, the statement is not sufficient to become a hypothesis (Quinn & George, 1975). Because the preservice teachers in this study could not understand the distinction between simple prediction and hypothesis, the process of hypothesis-verification became a simple observation on the test result, not being able to test and understand scientific explanation in the process. Constructing hypothesis is a foundational stage to cohere the entire process of hypothesis-based inquiry. Seen in the Episode #1, without understanding the difference between simple prediction and hypothesis, inquiry process is not sufficient to develop students' inquiring about the phenomena and solving problems in scientific manners. For example, to verify 'their hypothesis, the more candles, the higher water level because of oxygen consumption,' children set up their test with varying the number of candles. However, in this case, the hypothesis was not sufficient to explain the phenomenon and not testable in the given situation. There could have been a discussion on the oxygen consumption was not the main reason for water level rising by showing earlier the video clip which was shown in the end of lesson. This shows that the pre-service teachers had the proper scientific content knowledge for the lesson, however, they did not have the sufficient understanding of hypothesis constructing process. It is critical to construct hypothesis testable and explanatory of the given problems. To enhance higher level of thinking and reasoning, teachers need to understand and practice the nature of hypothesis in their teaching.

Secondly, there should be more understanding of the purpose of test and what is fair test in scientific investigation. Studies explain that hypothesis leads us to decide what to be observed (as well as how, when and where) or which variables are likely to be significant to justify hypotheses (e.g., Wenham, 1993). This draws our attention to the coherent link between hypothesis and following test. Without the connection between hypothesis and test, the process of verification became disjointed work with irrelevant data and explanation to certain phenomena. The test is not a straightforward observation on what is happening during experiment. This also means variables and constants in the test must be connected to the explanation given in the hypothesis. If we intend to enhance the value of fair test, the variables and constants should be controlled in the connection to what needs to be observed and tested. For example, their test in candle and water lesson could verify only the part of prediction (the more candle, the higher water level), not the explanation part (because of the oxygen consumption). That is, a test is not only to get the final result which is predicted but also to be able to examine if the tentative explanation is right or wrong.

Thirdly, teachers also need to know how to make their decision on how and when to guide/scaffold children's actions in inquiry process. Data collecting and interpretation based on evidence is the essential component of scientific investigation and reasoning, however, the connected examination between primary data and the statement of results has been often ignored in the process of scientific reasoning (Kanari & Millar, 2004). In each group discussion in this study, the pre-service teachers showed their discomfort on how much intervention they could carry out during inquiry teaching. One asked such question: *"Is it ok to give them answers at the end when they could not find the right answers? Is it ok to say* *this is not right when they suggested their own answers? Because in inquiry, it is more important to learn the process so even though they could not find the right answer, they must have learned a lot during the process".* Their beliefs in which inquiry values process rather than products and inquiry should be student-centered not teacher-centered are strongly embedded in their minds, however, in real teaching practice, they felt comfortable, encountering the cases of which children are getting wrong concepts after their experiments. In the lesson 3, if the pre-service teacher had intervened children's work at the stage of hypothesis construction or if he has shown the video clip with no candles involved and developed some discussion around the heat and oxygen consumption, the process of investigation would have been more meaningful and truthful to enhance children's scientific thinking and explanation. Given that the development of teachers' understandings of inquiry can be developed through practical experiences and understanding (Crawford, 2007), theoretical modeling of inquiry teaching is not enough for pre-service teachers develop the knowledge and skills of inquiry teaching. Therefore, we believe that the pre-service teachers' pedagogical management and skills will improve over time, yet, it is only possible through the reiteration and critical reflection on their practice of hypothesis-based inquiry in classrooms.

This difficulty also raises a pedagogical concern about enhancing children's appropriate communication skills during data collection and analysis for more effective meaningful investigative inquiry. The pre-service teachers expressed their difficulties in mentoring children's behaviors of reaching a conclusion during group discussion. The lack of children's communication and discussion skills was obviously noticed by the preservice teachers. They said, *"children in my group did not discuss collaboratively in conclusion. They were enthusiastic about activities, but after that, they did not want to discuss to draw a conclusion".* The observed children were selecting what they wanted and even distorting the data. Even though the preservice teachers were trying to encourage the students to get engaged in discussion or making a conclusion, the process did not seem successful. Socio-cultural aspects of learning as fundamental nature of scientific knowledge development need to be taken into account to enhance children's scientific attitudes in inquiry learning. Since their decision making process is often negotiated in authoritative and dialogic discourse among themselves (Scott, & Mortimer, & Aguiar, 2006), the value of sharing plural theoretical accounts as collectives in groups needs to be undertaken to enhance the abilities of data analysis, conclusion, and scientific argumentation (Duschl & Osborne, 2002; Kelly, Crawford, & Green, 2001).

CONCLUDING REMARKS

Hypothesis-verification process is beneficial to enhance children's scientific minds and problem-solving skills. Being engaged in the process, children learn how to make hypotheses, design their experiments to test their hypothesis, and reach conclusions. However, to make the process fruitful and valid, more systemic and disciplined instruction is required to develop children's reasoning and skills of evidence-based scientific explanation. Teachers' understanding and decision making on how to intervene or guide children's work would be challenging without sufficient understandings of the nature of hypothesis and the roles of test. The process of hypothesis-verification is not simply 'predicting what' but 'explaining why' on given problems. In this process of explaining and verifying, there are more scientific knowledge, thinking and reasoning skills involved to solve the problem. To aim for the development of higher level of scientific thinking and problem solving, this study suggested that teachers' appropriate guidance on children's actions based on their understandings of hypothesis, test, and analysis would be essential. And yet, this study still remains some issues of children's cognitive levels and the levels of scientific thinking skills in elementary classrooms. Distinguishing simple prediction from hypothesis in elementary levels might be argued as an unnecessary challenge for teachers as well as children, which requires critical discussion among science educators and researchers. Teachers' tactful pedagogical decision making is also required when they employ the approach of hypothesis-based inquiry teaching in classrooms. For this approach has been discussed and implemented as a critical method to enhance scientific thinking and reasoning, there needs to be more thorough consideration on how we conduct this approach not to be another cookbook-based practical work but to be a meaningful action to evoke children to seek for evidence to claim for their ideas.

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