**Enactment of Scientific Inquiry: Observation of Two Cases at Different Grade Levels in China
Mainland**

Lei Wang^{1*}, Ronghui Zhang¹, David Clarke², Weizhen Wang¹

¹ *College of Chemistry, Beijing Normal University, Beijing 100875, China*

² *Melbourne Graduate School of Education, University of Melbourne, Victoria, 3053, Australia*

Corresponding author E-mail : wangleibnu@126.com

Abstract

Enactment of scientific inquiry in classroom has attracted a great attention of science educators around the world. In this study, we examined two competent teachers' (one grade 9 chemistry teacher and one grade 4 science teacher) enactment of scientific inquiry in selected teaching units

to reveal the characteristics of enacted inquiry at different grade levels by analyzing lesson sequence videos. **The coding schemes for enacted inquiry consist of ontological properties and instruction practices.** Pre-topic and Post-topic teacher interviews and the two teachers' responses to a questionnaire **were** adopted to identify the factors influencing teacher's enactment. The results indicate that both the two case teachers' enactment involved a range of inquiry activities. The enacted inquiry at 4th-grade level covered all the inquiry elements, tending to engage students in the whole procedure of inquiry. The 9th-grade chemistry class placed emphasis on the elements "making plans" to solve problems in authentic context. Important factors influencing the enactment include teacher's understanding about scientific inquiry, textbooks, assessment, students and resource. **Implications for inquiry enactment, instruction improvement has been provided.**

Keywords: Scientific Inquiry, Enactment, Factors, **Observation, Ontological Properties, Instruction Practice**

Backgrounds

Chinese Ministry of Education initiated a new round of general education reform nationwide at the beginning of 2000. Within one year, the new science curriculum standards for Grades 1 through 9 were released by MOE (Ministry of Education [MOE], 2001). The mission of this science education curriculum reform was to shift the emphasis from transfer of knowledge in the classroom to development of students' scientific literacy with inquiry-based teaching (Liu, Liang & Liu, 2012). As required by the reform document, integrated science curriculum was carried out at elementary level all over the country, while most provinces adopted separated science subjects at middle school and high school levels including chemistry, physics, biology and geography.

Similar to the situation all over the world, scientific inquiry has been a key aspect in the basic education reform in China. In the *Science Curriculum Standard for Grade 3-6* (Ministry of Education [MOE], 2001a) and *Chemistry Curriculum Standard for Middle School* (Ministry of Education [MOE], 2001b) , scientific inquiry is articulated as both a learning method and a learning goal, which indicates its important role in basic science education. As the reform was initiated at the national level, science teachers began to implement inquiry-based teaching in science classrooms (Wang, 2010). Consequently, researchers become interested in the question how scientific inquiry is implemented in classrooms, especially the characteristics of the situation at different grade levels.

A few studies have examined how teachers enacted inquiry in the classrooms. The instrument DiISC (*Discourse in Inquiry Science Classrooms*) was developed to measure teachers' use of

instructional strategies in their classrooms that support oral and written discourse, and academic language development embedded in inquiry according to learning principles (Arizona State University, 2008). The DiISC has five scales in relation to five sets of instructional strategies. The scales are *Inquiry*, *Oral Discourse*, *Writing*, *Academic Language Development* and *Learning Principles*. Fu, Zhou, & Zheng (2007) investigated the frequencies and time length of inquiry using middle school and high school teacher questionnaires. Zhou, Li, & Zheng (2005) found that teacher's belief, teacher's subject knowledge and the ability to respond to class situation, assessment system, instruction time, school leader or coordinator make an influence on inquiry-based teaching by tracking and interviewing one 9th-grade chemistry teacher and another physics teacher.

While the above studies provided insight into the classroom practices in terms of scientific inquiry, few reported studies focused on the interaction between teacher and students in inquiry classroom. Moreover, few studies put sight into the features of inquiry classroom at different grade levels. Given the importance and emphasis of scientific inquiry in curriculum standards, this study explored the inquiry classroom at different grade levels to reveal their features and to identify the factors influencing teacher's enactment of scientific inquiry. As such, we intended to answer the following two research questions: (a) What are the characteristics of the enacted inquiry at different grade levels, especially at elementary grade and middle school? (b) Which factors influence teacher's enactment of scientific inquiry?

Theoretical Framework

Scientific Inquiry

A key aim of science teaching reform efforts has been to engage students in the epistemological aspects of science authentically. This aim is behind the considerable attention recently dedicated to inquiry and nature of science instruction. (Ford & Wargo, 2007).

The *National Science Education Standards* (NRC, 1996) claimed that all students should develop abilities necessary to do scientific inquiry, and understanding about science inquiry. Elements of inquiry in the standards were involved in the following text:

Inquiry is a multi-faceted activity that involves making observations, posing questions, examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.

(NRC, 1996, p. 23)

Inquiry is often framed as consisting of both process skills and understandings about the nature of science (e.g., NRC, 1996). Process skills include designing investigations, collecting, and analyzing data. Understandings about the nature of science consist of aspects of the philosophy and sociology of science, such as the tentative nature of theory or the role of creativity in experimentation. Together, the process skills and understandings are intended to provide an accessible, authentic image of how scientists engage in their practices of studying the

natural world (Breslyn& McGinis, 2012).

The above views on science inquiry are rooted in early science education literature. According to Schwab (1962), “teaching science as inquiry” consists of two separate, identifiable parts: “teaching by inquiry” and “science as inquiry.” These are best viewed as the process and the product of what might occur in a science classroom. Teaching by inquiry involves the means by which students gain knowledge. It includes the development of inquiry skills, such as the abilities (a) to identify and define a problem, (b) to formulate a hypothesis, (c) to design an experiment, (d) to collect and analyze data, and (e) to interpret data and to draw meaningful conclusions. Science as inquiry extends the image of science beyond that of a collection of facts, to include viewing science as a method by which facts are obtained (Eltinge & Roberts, 1993). In this study, we focused on the process skills of scientific inquiry **because our interest was on classroom inquiry activities to reveal the features of enacted inquiry.**

Curriculum Enactment

This present study adopts an enactment framework instead of fidelity of implementation. Fidelity of implementation expects classroom teaching to follow step-by-step procedures and instructions from curriculum standards. On the other hand, the enactment assumes that textbook development and classroom instruction are creative and reflective processes. For enactment, it is not necessary or even impossible to demonstrate strict fidelity to the materials in order to be judged consistent with the intent of reform documents (i.e., curriculum standards). Instead, variations in enactments that meet student learning needs are considered reflective of reform and

consistent with the intent of the materials (Schneider, Krajcik, & Blumenfeld, 2005; McDonald & Songer, 2008).

As for the factors influencing classroom inquiry enactment, a previous research has found that the most critical factor influencing a prospective teacher's intentions and abilities to teach science as inquiry is the prospective teacher's complex set of personal beliefs about teaching and views of science, wherein a prospective teacher's personal view of teaching science as inquiry is comprised of his or her knowledge of scientific inquiry and of inquiry-based pedagogy and his or her beliefs of teaching and learning (Crawford, 2007). In a study of exemplary secondary science teachers (Breslyn & McGinnis, 2012), the discipline (biology, chemistry, earth science, and physics) in which a teacher taught was found to be a major factor on teachers' conceptions and enactment of inquiry. Two other contextual features of the classroom influencing enactment were curriculums and student abilities.

One of the reasons for the lack of inquiry in the science classroom is textbook portrayals of science as a collection of facts rather than as a process of inquiry (Eltinge & Roberts, 1993). Germann et al (1996) conducted a study to determine the degree to which the major high school biology laboratory manuals have portrayed inquiry. The results of the study indicated that the examined nine popular manuals seldom provided opportunities for students to pose a question to be investigated; formulate a hypothesis to be tested; predict experimental results; design observation, measurement, and experimental procedures; work according to their own design; or formulate a new question or apply an experimental technique based on the investigation they performed.

Teachers' use of textbooks can also have an effect on student learning (Eltinge & Roberts,

1993). For example, Forbes and Davis (2010) found that pre-service elementary teachers frequently added or substituted new elements into the curriculum materials they used, and suggested that future research on pre-service teachers' use of curriculum materials should also characterize how these lessons with added elements actually play out in elementary classrooms.

Methods

Conceptualization of the Current Study

Scientific Inquiry in Chinese Curriculum Standards. The *Science Curriculum Standard for Grades 3-6* (Ministry of Education, 2001) states that “Scientific inquiry is the core of science learning. Inquiry is both a learning goal and a learning method.” In the standard, scientific inquiry is described as one of the curriculum goals, with the other two goals being attitude & views and scientific knowledge. Scientific inquiry activities are specified as the following elements: asking question, making hypothesis, making plan, conducting observation and experiment& making artifacts, collecting information, drawing conclusion, and communicating.

The *Chemistry Curriculum Standard for Grade 9* (Ministry of Education, 2001) states that “scientific inquiry is not only an important method of learning but also major content”. In the standard, scientific inquiry is presented as one of the five main content topics, with the other four topics being chemistry substances in life time, the structure of substance, chemical reactions, and chemistry & society. The standard states that Chemistry curriculum aims to promote student understanding of scientific inquiry processes and methods, and to foster students' competence in scientific inquiry. It **articulates** scientific inquiry procedures to be composed of the following

eight elements: asking question, making hypothesis, making plan, conducting experiment, collecting data, drawing conclusion, reflecting, and communicating.

It is evident that inquiry activities identified in the two standards are quite similar. Both the two standards claim that only one or several activities of scientific inquiry (that is, elements of inquiry) may be involved in classroom teaching during a certain time. However, the 7 or 8 inquiry elements are too many to make detailed analysis about enactment, and some of them are overlapped with each other. To keep the clarity of the current study, considering the common properties of the elements, we combine “conducting observation and experiment& making artifacts” with “collecting information” to be “collecting evidence” for elementary grade level, and integrate “conducting experiments” with “collecting data” to be “collecting evidence” for middle school grade level. Although “Communicating” (both elementary and middle school levels) is an important inquiry element, it doesn’t show up as an independent inquiry activity **in this study** because communication always permeates in all other inquiry elements. A similar situation also applies to the element “reflecting”. Table 1 shows the specific activities of scientific inquiry in the two standards and **the inquiry activities included in this study**.

Table 1

Scientific Inquiry Activities

Science Standard (Grade 3-6)	Chemistry Standard (Grade 9)	Inquiry Activities included in this study
asking question	asking question	asking question
making hypothesis	making hypothesis	making hypothesis
making plan	making plan	making plan
conducting observations and experiments & making artifacts	conducting experiment	collecting evidence

collecting information	collecting evidence	
drawing conclusion	drawing conclusion	drawing conclusion
communicating	reflecting	-
-	communicating	-

Coding Scheme for Enacted Inquiry. To address the first research question, the coding scheme for each inquiry activity mainly involves two parts called *Ontological Properties* and *Instructional Practice*. Figure 1 shows the structure of the coding scheme. “Ontological properties” refers to the types of question, hypothesis, plan, evidence and conclusion, number of them in one inquiry activity, and quality evaluation. For instance, the scientific questions proposed in class could be classified as the following categories: (1) relation question, that will lead to exploring the relationship of two objects; (2) explanation question, that will lead to seeking the explanation for specific phenomena; (3) description questions, that directs to just describing objects or phenomena; (4) evaluation question, that will lead to evaluate something; (5) designing question, that will direct to make design. Quality evaluation refers to evaluating the quality of questions, plans, etc. With regard to scientific question, quality evaluation indicates evaluating whether they are testable. Plan, hypothesis and so on sometimes get involved in the problem about number of them in one activity. “Instructional Practice” is related to the stimulation and scaffolding provided by teacher, and the subject of the activity.

Figure 1 Structure of Coding Scheme for Enacted Inquiry

Examine the factors that influence the enactment. The current study adopts a natural approach to explore the factors influencing the enactment by placing the emphasis on teachers' delivery of the topic and the **materials** used to plan the topic instruction. **The second author conducted a 30min-long pre-topic teacher interview before start of the topic unit teaching, and a 0min-long pre-topic teacher interview after each teacher finish their topic unit teaching. The protocols of interviews have been shown in the appendix at the end of this article.** Pre-topic interview focused on teacher's understanding of the topic, how the teacher decided what to teach, decisions about how to teach the topic. Post-topic interview included how well teacher achieved the instructional goals, the extent to which assessment influence the **planning and implementation of teaching**. The teacher questionnaire was administered to investigate the instructional objectives and the extent to which the student meet the learning goals. Teachers completed the questionnaire after each lesson of the topic. This part just provides qualitative evidence to claims about the factors.

Cases Introduction

To reveal the characteristics of enacted scientific inquiry at different grade levels and identify the factors influencing the enactment, the methods we employed combine a naturalistic approach (Wu & Krajcik, 2006). Two competent teachers were purposefully selected.

Ms. CAI, Grade 4 Science teacher, taught for 1.5 years Biology and Science, in a newly-established top-tier elementary-middle school in Beijing. She received her M.A. degree in Biological Education, with a certification in middle school (Biology).

Ms. LIU, Grade 9 Chemistry teacher, had more than 10 years of teaching experience in Chemistry, has taught 9th grade chemistry for 3 years in a top-tier middle school in Beijing. She held a certification in Grades 9-12 (Chemistry).

Data Collection

The data collected for each case included 4 class periods of videos in specific topic units (Air of grade 4, and Acids and Bases of grade 9), teaching planning materials, students' worksheets, and assessment materials. The second **author** made pre-topic and post-topic interviews with each teacher. As described in previous section, the two teachers completed the questionnaire which aimed to investigate their understanding of **subject content, planning of teaching, understanding of students learning and the assessment to be used**. Data for grade 9 were collected in March 2011, while data for grade 4 were collected in December 2011.

The two exemplary teachers in this study were from Beijing city. Similar to most other areas in China that are under the same direction of new standards, science curricula of general education in Beijing consist of three parts: integrated science in Grades 3-6, traditional separated

science subjects (Physics, Chemistry, Biology, Geography) in Grades 7-9, and traditional separated subjects in senior high schools (Grades 10-12) . Junior high school students are required to take Chemistry subject for one year in Grade 9.

Teaching Topics

The Air topic in Grade 4 and the Acids & Bases topic in Grade 9 are focuses of this study, since they both belong to Physical Science so that we can avoid the evident difference of disciplines. Table 2 is an overview of the Air Unit (4S refers to Grade 4; L01 refers to the 1st lesson) by the lesson sequence as well as the lessons included in this study. Table 3 is an overview of the Acids & Bases Unit by the lesson sequence as well as the lessons included in this study. Each lesson period lasts about 40 minutes in Beijing. There are 36 and 40 students in Ms.CAI's class and Ms.LIU's class.

Table 2

Overview of the Air Unit (Grade 4)

Lesson Number	Content	Whether or Not Included in This Study
4S-L01	Composition of Air in the life	YES
4S-L02	What is Oxygen	YES
4S-L03	What is Carbon Dioxide	YES
4S-L04	Combustion	YES

Table 3

Overview of Acids & Bases Unit (Grade 9)

Lesson Number	Content	Whether or Not Included in This Study
9S-L01	Electrolyte (1)	NO
9S-L02	Electrolyte (2)	NO
9S-L03	Indicators for Acids & Bases	YES
9S-L04	Properties of Sulfuric Acid	YES
9S-L05	Properties of Acids	YES
9S-L06	Properties of Bases	NO
9S-L07	Neutralization Reaction	YES

Data Analysis

To examine the classroom practice, several steps were taken. First, a detailed summary of each videotape was prepared, which included the teacher's and students' activities and conversations. Second, we coded the episodes on the videotapes that involved scientific inquiry activities using the coding scheme described previously with the software *Nvivo 8*. **The durations of the episodes are not identical because they depend on the length of each inquiry activity.** In relation to the second research question, the interview transcripts and teachers' responses to the questionnaire were repeatedly checked to find out the factors influencing teacher's enactment.

Reliability

Two science education graduates (**the second and fourth authors**) observed and coded the science lessons and chemistry lessons. *Nvivo 8* was used to record the coding and make comparison between the two coder's coding, and it calculated Kappa coefficient for each coding

category to be the parameter of consistency. The final percentage of the inter-rater agreement ranged from 0.71 to 0.80.

Results

Scientific Inquiry Enacted in Science Classrooms

We identified the inquiry activity episodes involving inquiry activities in the filmed four lessons of each **teacher**, and coded them according to the **coding scheme** to get the frequencies for each inquiry activity and the frequencies of the activities that include the corresponding subcategories of the inquiry activity. In what follows, we'll present the frequencies along with the specific **coding scheme** of each inquiry activity.

Ms. CAI

At the beginning of the first lesson in the unit, Ms.CAI (Grade 4 teacher) posed several questions to direct students review what scientific inquiry is: how do scientists work? What steps constitute scientists' research process? Through a short story about Galileo's research on falling objects, she illustrated that the process of inquiry includes posing question through observation, formulating hypothesis, collecting evidence by conducting experiment or looking for information, drawing conclusion through evidence analysis.

Throughout the unit, the five inquiry activities were carried out, and the two activities "asking questions" and "drawing conclusions" occurred the most frequently (Table 4).

Table 4 Frequencies of each inquiry activity in Grade 4 Unit

	Number of Inquiry Activity Episodes			
Inquiry Activity	4S-L01	4S-L02	4S-L03	4S-L04
Asking Question	7	6	9	5
Making Hypothesis	3	2	1	1
Making Plan	6	2	4	3
Collecting Evidence	3	6	5	3
Drawing Conclusion	5	8	7	4

Asking Question. *The ontological properties of Asking Question consist of type of question, and quality of question. The instructional practice includes subject of posing question (who propose question) and teaching practice.* Table 5 displays the specific coding categories of each aspect and the frequencies of all the categories in each lesson. In this Unit, most of the research questions were formulated by Ms.CAI, such as: what is air like according to your observation (4S-L01, description), what method can be used to collect air (4S-L01, design), how to prove that whether the bottle is fully filled with the CO₂ collected (4S-L03, design), why did the left candle extinguished while the other right candle did not (4S- L03, explanation), whether is it good to have more and more oxygen(4S-L02, evaluation). The types of these sample questions are demonstrated in the parentheses.

Table 5

Frequency of Asking Question in Grade 4 Classrooms

Aspects	Categories	4S-L01	4S-L02	4S-L03	4S-L04
Type of question	Relation Question	0	0	0	0
	Explanation Question	2	0	2	1
	Questions directed to description or observation	2	4	3	0
	Questions directed to evaluation	0	1	0	0
	Questions directed to design	3	1	3	4
Quality of Question	Teacher guided students to evaluate the questions	1	0	0	0
Who propose question	Teacher	6	6	8	5
	Student	1	0	1	0
Teaching Practice	Teacher encouraged more than 3 students to propose question	1	0	1	0
	Teacher stimulated students to ask question	1	0	1	0

Nevertheless, Ms.CAI also provided students opportunities to ask scientific question. Segment 1 shown in the following is taken from the first lesson (4S-L01) of the unit[In all the segments, the symbol “T” refers to the teacher, “S” refers to students of the whole class, “S+Arabic numeral” refers to a certain student.]. Teacher asked “what research questions can you formulate on the basis of your observation” so as to initiate students asking questions. Students tend to **pose** questions on “why” mostly, for instance, “why do we need air”. Then, the teacher tried to stimulate students to evaluate these questions proposed by the students, but clearly they had no idea about the criteria for the investigable questions. In the third lesson (4S-L03), students had one more opportunity to raise questions as shown in segment 2. Most questions students asked were assigned to the types of “explanation” and “prediction”. Some questions **were** related to the

composition and preparation of substance, while relation questions involved (e.g. what's the difference between CO₂ and O₂?). It's evident that Ms. CAI stimulated students to formulate questions in a similar manner in segment 1 and 2, and encouraged more than 3 students to formulate question in segment 1.

Segment 1

T: On the basis of your observation, what questions can you propose?

S: [students expressed their questions one by one] Why can't we see and touch the air?

Why is the air odorless? How is the air formulated? How does the air occupy space? Is air invisible at any time? Why is air soluble in water? What constitute the air? Why can't we live without air? Can we touch the air?

T: Now, can you identify which question is investigable and the most basic question?

(Students had no idea about this, keep silent.)

T: "What is the composition of the air" is the most basic question. Long time ago, people viewed air as consisted of only one gas. Here we will come to the composition of air.

Segment 2

T: When we conduct science investigation, after observation we need to propose research questions. In regard to carbon dioxide, can you pose investigable questions?

S: Why do people breathe out CO₂? What's the difference between CO₂ and O₂? Why CO₂ make people faint? How is the carbon dioxide formulated? **What will happen for the concentrated carbon dioxide?** What's the constituent of carbon dioxide?

Making Hypothesis. The ontological aspects of hypothesis include type, number and representation of hypothesis. *Type of hypothesis* involves two main categories, that is, *hypothesis on explanation* and *Predicting phenomena*. *Number of hypothesis* refers to the number of hypothesis in each inquiry activity which is identified as “making hypothesis”. *Representation of hypothesis* includes written language and oral communication. The instructional aspects include the subject of the activity and teaching practice. Table 6 shows the coding framework of making hypothesis and the frequencies of the categories in each lesson.

Throughout the unit, Ms. CAI provided students opportunity to formulate hypothesis by raising questions such as “What will happen to the candle” “Why did the candle extinguish”. Corresponding to these questions, the type of hypothesis involved explanation and prediction. Segment 3 from lesson 4S-L01 showed that Ms. CAI motivated students to make hypotheses about what would happen to the burning candle if it is covered with a glass bottle. The teacher made a talk with students to help them formulate the hypothesis whether “keep on burning” or “extinguished”, then asked students to write down the hypothesis on the worksheet (Figure 2) which was developed to support student learning.

Table 6

Frequencies of Making Hypothesis in Grade 4 Class

Aspects	Categories	4S-L01	4S-L02	4S-L03	4S-L04
Type of hypothesis	Hypothesis on explanation	1	0	0	1
	Predicting phenomena	2	2	1	0
Number of hypothesis in one activity	1 hypothesis	2	1	0	0
	2 hypotheses	0	0	1	0
	3 or more hypotheses	1	1	0	1
Representation of hypothesis	Written language on worksheet	3	1	0	1
	Communicate in verbal language	3	2	1	1
Who makes hypothesis	Teacher	1	0	0	0
	Student	3	2	1	1
Teaching Practice	Teacher provides scaffold for making hypothesis	2	0	1	0
	Teacher stimulates students to formulate hypothesis.	1	2	0	1

Segment 3

T: (holding a glass bottle) There is air inside, right? Now, if the burning candle is covered, what will occur on the candle? Read the first table [figure 2], write down your guess or hypotheses in the first column of the table. Make a guess at the possible phenomena. We call the left candle as No.1, and the right one as No.2. What will happen to the burning No.1 candle without treatment? Keep on burning. Then if we cover No.2 with a bottle, what will happen?

S: Extinguished

T: Okay, write down your hypotheses.

After the inquiry activity “making hypothesis” shown in segment 3, Ms.CAI carried out the experiment to treat the two candles, directed students to observe that No.2 candle extinguished in a while. Subsequently, the class came to another “making hypothesis” shown in segment 4 which is assigned to be explanation. Ms.CAI stimulated students to making hypotheses on the reason why the candle burned out. Ms.CAI required students to fill their hypotheses in the worksheet (Figure 2), after that, she asked the students who raised their hands to communicate their opinion and organized a discussion. In this activity, more than one hypothesis were involved, teacher encouraged more than one student to communicate their claims.

Segment 4

T : Why did the candle flame go out? Do you have any assumption? Write down your hypothesis on your worksheet. If you finish it, and want to share your opinion, please raise your hand.

[After students finished the work, the discussion started]

T: Finished? Okay, share your hypotheses with us.

S1: Because fire needs air to keep on burning, while fire consumed air. When covered with the bottle, there is no air getting into the bottle, the fire extinguished because it's short of air. The candle outside can get air continuously, thus it keeps on

burning.

T: Your hypothesis is long. Can you summarize it in a sentence?

S1: If there is no air, the fire can't stay lit.

T: Because there is no air. OK, what's your opinion?

S2: Maybe air is consisted of more than one kind of gas, while only part of the gas support combustion.

T: You mean, do you think there is air in the bottle?

S2: yes, there is. But there is no combustion-supporting air.

T: It's also a good hypothesis. Think about how to prove it.

S3: I agree with S2. Ms.CAI collected a bottle of air, when it covered the candle, there is air. But it's possible that only oxygen in the air support combustion, there is air but no oxygen.

T: We know there is combustion-supporting gas. Just now, we said that air is combustion-supporting, but now is there air in this bottle?

S: Yes, there is.

T: Who agree? [all students raised hands]

T: Who hold the opinion that there is no air left inside the bottle? [none of students raised hand]

a

b

Figure 2 A student's worksheet in lesson 4S-L01 : (a) a scanning copy ; (b) a translated reproduction

Making Plan. The ontological aspects of making plan involve quality of plans, number of plans and evaluating plan. The instructional practices of making plan include the subject of the activity and teaching practice. Across this unit, Ms.CAI provided opportunities for student to making plans, and she also designed plans.

Segment 5 in what follows was taken from lesson 4S-L03. In this segment, Ms.CAI motivated students to design experiment to collect carbon dioxide, and allowed several students to communicate their plans. Thus, more than 1 plan was involved to get carbon dioxide, most of students' plans were feasible, but incomplete with a lack of apparatus elements. Ms. CAI suggested to get carbon dioxide from air, and guided students to evaluate this plan. Finally, teacher proposed two feasible and complete plans-one for laboratory, and the other for family experiments. Both students and teacher made plans, and the process involved evaluating the

plans.

Table 7

Frequency of Making Plan in Grade 4 Classrooms

Aspects	Categories	4S-L01	4S-L02	4S-L03	4S-L04
Quality of the plans made by students	Infeasible	0	0	1	1
	Feasible but not intact	1	1	2	0
	Intact but not Feasible	1	0	0	1
	Intact and Feasible	3	1	2	2
Numbers of plans	Only one Plan	4	1	2	1
	2 Plans	2	0	2	1
	3 or more plans	0	1	1	1
Evaluating plans	Teacher guide students to evaluate plan	2	1	3	2
Who make the plan	Teacher	3	1	3	1
	Students	3	1	3	2
Teaching practice	Teacher encourages 2 students to communicate	1	0	2	0
	Teacher encourages more than 2 students to communicate	2	1	1	2

Segment 5

S1: Sometimes there is bubble in cola, and it tastes stimulating. That is carbon dioxide.

T: You mean, there is CO₂ in cola.

S2: I don't agree with her. CO₂ was pressed into cola with high pressure. Because, CO₂ will dissolve in water when there is high pressure.

T: Her opinion is that we could get CO₂ from cola, is it right? So, it's okay.

S3: We can blow up a balloon with mouth.

T: Excellent. The gas we breathe out also contain CO₂. We also know there is CO₂ in the air.

S: Yes.

T: Is the percentage of CO₂ in air high or low?

S: low.

T: If we see air as a round plate, nitrogen occupies the largest area, oxygen takes the second large area, while the rest gases only have a percentage of 1%. These gases include water vapor, rare gas, and CO₂. That means, whether the percentage of CO₂ is high or low?

S: low.

T: Scientists found that the percentage of CO₂ is 0.03% -0.04%. Thus, it's hard to collect CO₂ from the air. [Then, teacher introduced the methods to prepare CO₂ including the materials and apparatus used.]

Collecting Evidence. Table 8 presents the categories and frequencies of *collecting evidence*.

The ontological aspects of *Collecting Evidence* involve type of evidence and quality of evidence. The *type of evidence* includes the following categories: (a) Describing phenomena; (b) Generalizing phenomena; (c) Extra information. The *instructional practice* involves the subject and the approach to collecting evidence, and teaching practice. The *teaching practice* focuses on teacher's stimulation and guidance to students. In relation to the types of evidence, Ms.CAI's class mainly involved "Describing phenomena" throughout the topic unit, while "Generalizing evidence" and "Extra information" just occurred in 4S-L02. Furthermore, Ms.CAI guided students to evaluate whether the evidence match the hypothesis in each lesson of the unit. Teacher's demonstration, extra information and videos were predominantly the approach to collecting evidence. Besides, teacher stimulated students to collect evidence in 4S-L01 and 4S-L04, and frequently directed students to observe and record the phenomena.

Table 8

Frequency of Collecting Evidence in Grade 4 Class

Aspects	Categories	4S-L01	4S-L02	4S-L03	4S-L04
Type of evidence	Describing phenomena	3	1	5	3
	Generalizing phenomena	0	3	0	0
	Extra information	0	2	0	0
Quality of evidence	Teacher guides students to evaluate whether the evidence match the hypothesis	1	1	1	1
The subject and the approach to collecting evidence	Teacher guides student watching videos	0	4	1	0
	Teacher adds extra information	0	2	4	0
	Teacher does experiments demonstrating to students	3	0	0	2
	Student gets evidence from previous experiment	0	0	0	1

	Students' hands-on experiment in groups	0	0	0	0
Teaching practice	Teacher stimulates students to collect evidence	1	0	0	1
	Teacher directs students to observe and record phenomena	3	4	4	2

For instance, when investigating combustion condition (4S-L04, Segment 6), Ms.CAI stimulated students to seek evidence from previous experiments in this unit to prove oxygen is a necessary criterion. With the guidance of teacher, students described the process and phenomena of those experiments, which is assigned to be “describing phenomena”. After the first student (S1) provided his evidence to the question, teacher directed students to evaluate the fitness between hypotheses and evidence.

Segment 6

T: How can we prove that oxygen is necessary for combustion? Think about the experiments we carried out previously.

S1: When the burning stick was placed on the top of a bottle filled with carbon dioxide, it burned out.

T: We found the stick burned out in the bottle full of carbon dioxide, when we did experiment to test carbon dioxide. This just indicates that carbon dioxide can't support burning, but it doesn't suggest that oxygen is necessary.

S2: We did an experiment, lit up the candle, and covered it with a bottle.

T: That experiment suggest, when we lit up two candles, covered one of them with a

bottle, we found, which candle extinguished?

S: The one covered.

T: Yes.

S2: No oxygen left.

T: It extinguished because there was no oxygen left. That means we proved combustion needs oxygen.

In lesson 4S-L02, Ms. CAI used video to demonstrate the experiment: put a lit candle into the bottle filled with oxygen, and asked students to record the phenomena. Then teacher summarized the different phenomena of burning in oxygen, nitrogen and air, which was assigned to be *generalizing phenomena*. In lesson 4S-L03, after the discussion about the method to confirm whether the bottle is full of carbon dioxide, teacher conducted the experiment and demonstrated the process to the students. She led students to pay attention to the phenomena, and told students to write down “the burning sticks extinguished” in the worksheet.

Drawing Conclusion. The aspects and categories of *Drawing conclusion*, and frequency of each category are shown in Table 9. The ontological aspects include *type of conclusion*, *approach to drawing conclusion*, *fitness between evidence and conclusion*. *Type of conclusion* involves the following categories: (a) Explanation, which means that the conclusion is to answer “why” question; (b) Relation, the conclusion is to identify relation between some objects; (c) Inference, which refers to further inference based on evidence. *Approach to drawing conclusion*

includes: (a) observation, drawing conclusion by directly observing single phenomena; (b) generalization, generalizing series of phenomena or experiments; (c) phenomena-based reasoning, reasoning the conclusion by combination of knowledge and phenomena; (d) comparison, comparing different phenomena to answer the question like “which one is better”.

Table 9

Frequency of Drawing Conclusion in Grade 4 Class

Aspects	Categories	4S-L01	4S-L02	4S-L03	4S-L04
Type of conclusion	Explanation	1	0	1	0
	Relation	0	0	0	1
	Inference	4	8	6	3
Approach to drawing conclusion	Observation	2	5	3	0
	Generalization	0	2	0	1
	Phenomena-based reasoning	3	1	4	3
	Comparison	0	0	0	0
Fitness between evidence and conclusion	Teacher as subject	1	0	0	0
	Students as subject	1	0	0	0
Who draws conclusion	Teacher	3	7	5	3
	Students	2	1	2	1
Teaching practice	Teacher encourages more than 2 students to communicate the conclusion	2	0	2	0
	Stimulating	2	2	2	0
	Directing to record	0	5	3	0
	Summarizing	3	2	2	4

As shown in Segment 7(in lesson 4S-L01) below, Ms.CAI motivated students to draw conclusions on properties of nitrogen by asking “What is nitrogen like through your observation of air? Why can you draw the conclusion, or why can’t?”. The conclusions on color, odor of nitrogen, were assigned **to be inference for the type of conclusions, and observation for approach to drawing conclusions**. Ms.CAI encouraged more than 2 students to communicate their conclusions.

Segment 7

S1: I see nothing (in the air), it’s proved that this gas is colorless, and no reflection of light, because only when object reflects light we can see it.

T: good

S2: I don’t agree with him. Although other gases in air only have a proportion of 1%, but they might react with nitrogen and make nitrogen colorless.

T: You mean that if chemical reaction occurred, we might not see the matter. Okay, the nitrogen we are talking about does not react with other matter.

S3: We can’t identify whether it is soluble in water.

T: you mean, we can figure out what is nitrogen like through observing the air. That is because—what is the proportion of nitrogen in the air?

S: a large amount

T: yes, so we could draw conclusions on the color and odor of nitrogen by observing

air.

For the type of conclusion, the conclusions in lesson 4S-L03, such as “carbon dioxide is colorless and odorless” “carbon dioxide doesn’t support burning, and also nonflammable” “carbon dioxide is heavier than air”, were originated from the phenomena, thus they were assigned to be inference in regard to the types of conclusion. In lesson 4S-L01, with teacher’s guidance, students **drew the** conclusion that part of the air was consumed by the burning candle, and the other part of air left in the bottle, which was direct to answer teacher’s question “why did the water get into the bottle”. Such a conclusion was assigned to be explanation. Teacher summarized the three conditions of combustion, which **revealed** the relation among them, thus this conclusion was assigned to be relation.

With regard to *approach to conclusions, observation, generalization and phenomena-based reasoning* were involved to draw conclusions in Ms.CAI’s class. In lesson 4S-L02, Ms.CAI generalized the phenomena of different matter burning in oxygen to conclude that oxygen can support burning and make the flammable thing burn more vigorously, **thus this conclusion is assigned to be generalization**. In lesson 4S-L03, Ms.CAI concluded that carbon dioxide is heavier than air through the reasoning on the experiments phenomena, but not just observation or generalizing, **so it is assigned to be phenomena-based reasoning**.

Summary. Ms.CAI placed emphasis on all the five inquiry activities in an explicit way to **show students how to do inquiry** and make students experience the inquiry process. She often used the words “make a guess”, “how to improve”, and “what conclusions you can draw” to engage students in the inquiry activities. In addition, worksheets were developed to help student make inscriptions for inquiry.

We also found that Ms. CAI divided the whole inquiry task (e.g. composition of air) symbolized by research questions teacher proposed into several sequenced inquiry activities. This manner is helpful to involve students in the inquiry process and advocate primary students to understand inquiry. Thus, we could conclude that classroom performance reflected that Ms.CAI viewed scientific inquiry itself as learning content. However, students were guided in most inquiry activities, for example, teacher expressed the conclusion clearly and then reminded students to write down.

Ms. LIU

Throughout the unit, Ms. LIU's class involved four of the five inquiry activities including asking question, making plan, collecting evidence and drawing conclusion. Table 10 shows the frequencies of inquiry activities in each lesson. What follows below will discuss the features of each enacted inquiry activity by coding the episodes with the categories of each aspect for the four activities, and summarize the overall features of Ms. LIU's enactment of scientific inquiry.

Table 10

Frequencies of inquiry activities in Grade 9 Class

Inquiry Activities	9S-L03	9S-L04	9S-L05	9S-L07
Asking question	2	2	1	1
Making hypothesis	0	0	0	0
Making plan	1	1	1	1
Collecting evidence	1	3	2	1
Drawing conclusion	2	4	3	1

The coding framework of each inquiry activity for Ms. LIU's grade 9 class is mainly the same to that of Ms.CAI's grade 4 class, so as to **uncover** the characteristics of enacted inquiry at different grade levels. As such, the specific meaning of the categories will not be repeatedly introduced in this part.

Asking Question. In this unit, all the research questions were posed by Ms. LIU, and most of them were questions directed to design (Table 11). Ms. LIU raised questions such as “how can we identify the acidity of soil”(9S-L03), “We could buy concentrated sulfuric acid from agent store , but dilute sulfuric acid is needed in lab, how do we make the concentrated into dilute sulfuric acid” (9S-L04), “Thinking from the theoretical perspective, how do you prove whether the liquid brought from home contain acid” (9S-L05), “How can we prove that hydrochloric acid reacts with sodium hydroxide” (9S-L07). The activities initiated by these questions were to design investigations, they are coded as *Question directed to design*. The only *Relation question* “Does all the acids have the same degree of acidity, all the alkaline have the same alkalinity” was involved in lesson 9S-L03. The question “we can observe, how is concentrated sulfuric acid like” in lesson 9S-L04 belong to the *Question directed to description or observation* were observed.

Besides, the proposed questions served as the driving question in lesson 9S-L03, 9S-L05 and 9S-L07. That is, the whole lesson was organized around each of the questions. This is different from the situation of Ms.CAI's class in which many questions were involved in a lesson.

Table 11

Frequency of Asking Question in Grade 9 Class

Aspects	Categories	9S-L03	9S-L04	9S-L05	9S-L07
Types of proposed question	Relation Question	1	0	0	0
	Explanation Question	0	0	0	0
	Question directed to description or observation	0	1	0	0
	Question directed to evaluation	0	0	0	0
	Question directed to design	1	1	1	1
Quality of Question	Teacher guides students to evaluate the questions	0	0	0	0
Who propose question	Teacher	2	2	1	1
	Student	0	0	0	0
Teaching Practice	Teacher stimulates students to ask question	0	0	0	0
	Teacher encourages more than 3 students to propose question	0	0	0	0

Making Hypothesis. There was no explicit *making hypothesis* across the four lessons. That is, teacher did not stimulate students to make hypothesis. However, in the process of making plans, hypothesis might be implicitly permeated in student's thinking. For instance, in the lesson 9S-L05, Ms. Liu asked students to bring some liquids which may contain acid to classroom from home. When a student choosing the liquid, it might involve "making hypothesis" about which one is acidic. In addition, when the students designing plans to prove whether the liquid contain acid, hypotheses were also involved implicitly, for instance, they may thought that if there was acid, the liquid would turn red when adding litmus, or bubbles will arise in the solution when active metal was added to the liquid".

Making Plan. Table 12 displays the coding categories and frequencies of making plan in this unit. It indicates that “making plan” was involved in each lesson.

Table 12

Frequency of Making Plans in Grade 9 Class

Aspects	Categories	9S-L03	9S-L04	9S-L05	9S-L07
Quality of the plans made by student	Infeasible	0	0	0	0
	Feasible but not intact	0	0	0	1
	Intact but not feasible	0	0	0	0
	Intact and feasible	1	1	1	0
Number of plans	Only 1 plan	1	1	0	0
	2 Plans	0	0	0	0
	3 or more plans	0	0	1	1
Evaluating plans	Teacher guide students to evaluate plans	0	0	1	1
Who make the plan	Teacher	1	1	0	0
	Students	0	0	1	1
Teaching practice	Teacher encourages 2 students to communicate	0	0	0	0
	Teacher encourages more than 2 students to communicate	0	0	1	1

In lesson 9S-L03, Ms. LIU required students to bring some flowers, vegetables or fruits to the class which would be used to produce acid-base indicator. After introduction to what acid-

base indicator is, Ms. LIU told students the subsequent activity was to make acid-base indicator and to do experiments to observe the color of acid and base when litmus or phenolphthalein was added. Apparatus and operation steps were also introduced by Ms. Liu in the statement of the activities,. That is, teacher constructed the plan for this experiment. However, students have the freedom to choose the materials, such as rose, apple, red cabbage, and so on.

According to Ms. LIU's response in the questionnaire, lesson 9S-L03 was aimed to provide experimental foundation for learning properties of acid and base, and to apply the concepts that were taught previously to daily life context. To some extent, this orientation could explain why not students but the teacher made plans in this lesson.

In lesson 9S-L04, Ms. LIU led students to think about how to make concentrated sulfuric acid into dilute sulfuric acid. First, the teacher and students discussed the two ways - adding water to sulfuric acid or adding sulfuric acid to water. Ms. LIU used a video to demonstrate the phenomenon that concentrated sulfuric acid was splashed out when water was added to it. Ms. LIU guided students to explain the cause of the phenomena with a common phenomenon in daily life. Finally, it came to the correct manner for diluting sulfuric acid (Segment 8). The whole process was progressed in the dialogue of teacher and students, but the plan was made by teacher.

Segment 8

T: If you are a teacher who prepares agents for chemistry class, you will face such a problem: chemicals agent stores just sell concentrated sulfuric acid, but the laboratory needs dilute sulfuric acid. How can we make the concentrated sulfuric acid into dilute sulfuric acid?

T: How many manners for diluting?

S: Two

T: Add water to acid, or add acid to water. In regard to concentrated sulfuric acid, which one is suitable?

S: Add acid to water.

T: Let's watch a video (the video showed when adding water to concentrated sulfuric acid, and the acid was splashed out). What phenomenon is similar to this one?

S: Water boiling

T: When adding water to a pot filled with hot oil, water will spill out. The difference between oil and water includes density and boiling point. When the oil is hot, even if it is not boiling, the water is boiled and would spill out with oil. We can use this example to explain the phenomenon in the video. Heat is released when concentrated sulfuric acid is dissolving in water, and it is at the lower phase. Water at the upper phase, boiled by the heat, and splashed out with concentrated sulfuric acid. And we just mentioned, what property does concentrated sulfuric acid demonstrate?

S: Corrosivity.

T: Hygroscopicity, strong oxidizability, and corrosivity. If it is splashed out, it will be dangerous.

In the lessons 9S-L05 and 9S-L07, students played as the subject to make plans, and more than 1 plan were designed to answer the research questions. Most of the plans designed by students were feasible, some were not intact enough. Ms. LIU guided students to evaluate or revise plans. Segment 9 is taken from lesson 9S-L05 in which students made plans. Ms. LIU raised the question “The acids in laboratory usually include hydrochloric acid and sulfuric acid, but there are many acids **in daily life**. You have brought many liquids such as vinegar, lemon juice, and detergent. Now, please think about, how to prove that the liquid you brought contains acid(s)?” to engage students in making plans. Ms. LIU required the students to write down the key words of their plans on the worksheet (Figure 3). What’s important to know is that students have studied properties of sulfuric acid in classroom before, and studied properties of hydrochloric acid on their own, thus they developed plans independently at first before discussing with their group members.

a

初三化学实验探究：如何证明你从家里带来液体中含有酸呢？
实验方案及原理：

实验方案	实验依据	实验现象
放入石蕊	酸：变红	变红
NaOH滴入酚酞，加酸	中和反应	红→无
放铁片	置换反应出H ₂	有气泡产生
pH试纸	遇酸变色	试纸变色
铁锈	金属氧化物与酸反应	红棕色消失

实验小结：依据以上实验，你能总结出酸有哪些通性：

1. 指示剂
2. 与活泼金属反应：金属 + 酸 → 盐 + 氢气
3. 与金属氧化物反应：金属氧化物 + 酸 → 水 + 盐
4. 与碱反应：碱 + 酸 → 水 + 盐
5. 与盐反应：盐 + 酸 → 新盐 + 新酸

b

Inquiry with experiments: How do you prove that the liquid you brought contains acid(s)?

Plans and Principles:

Plans of Experiments	Rationales of the Plans	Phenomena Observed
Add litmus	Acid turn red	Turn red
Add Phenolphthalein to NaOH, then add Acid	Neutralization reaction	Red → colourless
Add iron sheet	Displacement reaction occur, so H ₂ is released	Bubbles arose
pH test strips	The colour change when the strip encounters acid	The test strip' colour changed
Add iron rust	Metallic oxide reacts with acid	The reddish brown colour faded

To summarize: On the basis of the above experiments, the general properties of acids include:

1. Indicator
2. Reaction with active metal, Metal + Acid → Salt + Hydrogen
3. Reaction with metallic oxide, Metallic Oxide + Acid → Water + Salt
4. Reaction with base, Base + Acid → Water + Salt
5. Reaction with salt, Salt + Acid → new Salt + new Acid

Figure 3 A student’s worksheet for inquiry in lesson 9S-L05 : (a) a scanning copy ; (b) a reproduction

In lesson 9S-L07, students discussed in groups to make plans on how to prove whether hydrochloric acid reacts with sodium hydroxide solution. After that, students reported their plans to the teacher and the class (see segment 9). Some plans were feasible but not intact, teacher led students to make evaluation and modification on the plans.

Segment 9

T: Who wants to share your plans or your groups' plans?

S1: First, add hydrochloric acid to sodium hydroxide solution. Then add phenolphthalein after a moment.

T: Why, please illustrate your experiments' rationales.

S1: Phenolphthalein is an acid-base indicator. It will become red in sodium hydroxide solution. If sodium hydroxide reacts with hydrochloric acid, because the amount of sodium hydroxide is small, so there will be none left, so phenolphthalein will be colorless.

T: He means that the reaction is at the first phase, will the mixed solution change the color? It's ok, but is there any default in this plan?

S1: Add excessive amount of sodium hydroxide.

T: For example, the amount of sodium hydroxide should be small or excessive. The sequence for adding agents. Who can help to modify it?

S2: First, add sodium hydroxide; Second, add phenolphthalein; Third, hydrochloric acid.

Collecting Evidence. The coding categories and frequencies of each activity *Collecting Evidence* in this unit are demonstrated in Table 13. collecting evidence were all involved across all the four lessons, all of them belong to the type “*Describing phenomena*”. Students’ group work of hands-on experiment was adopted in three of the four lessons. Videos and teachers’ demonstration were also used as the approach to collecting evidence. Ms.LIU didn’t stimulate students themselves to collect evidence for hypothesis, but frequently directed students to observe and record the phenomena. The evaluation about whether the evidence matched the hypothesis didn’t occur explicitly.

Table 13

Frequencies of Collecting Evidence in Grade 9 Class

Aspects	Categories	9S-L03	9S-L04	9S-L05	9S-L07
Type of evidence	Generalizing phenomena	0	0	0	0
	Describing phenomena	1	3	2	1
	Extra information	0	0	0	0
Quality of evidence	Teacher guides students to evaluate whether the evidence match the hypothesis	0	0	0	0
The subject and approach to collecting evidence	Teacher guides student watching video	0	2	0	0
	Teacher adds other information	0	0	0	0
	Teacher does experiments demonstrating to student	0	1	1	0
	Student gets evidence from previous experiment	0	0	0	0
	Students' experiments in groups	1	0	1	1
Teaching practice	Teacher stimulates students to collect evidence	0	0	0	0
	Teacher directs students to observe and record phenomena	0	3	1	1

Ms. LIU placed an emphasis on students' group work of hands-on experiments. The work was always organized after plans were adequately designed by teacher or students. When student groups were carrying out experiments, Ms. Liu reminded them to make experiment records, gave advice for their experiments, and supervised the progress of their experiments.

When investigating properties of sulfuric acid in lesson 9S-L04, Ms. LIU used videos to

demonstrate dehydration and hygroscopicity of concentrated sulfuric acid. Teacher led students to make observation and understand dehydration and hygroscopicity. Ms. LIU did an experiment to show the reaction of Barium Chloride and dilute sulfuric acid, and then introduced the reaction to students through describing the phenomena. This activity is also assigned to be *describing phenomena*.

Throughout the four lessons, Ms. LIU always directed students to observe and record the experiments phenomena. When teacher's demonstration or video of experiments were adopted, Ms. LIU guided students to observe the phenomena. In the case of students' group work on hands-on experiments, Ms. LIU required students to make record on their worksheets. Students were always asked to report their experiments, phenomena and conclusions. Segment 10 shows an example of student groups' oral report in lesson 9S-L07 .in which they demonstrated their experiments to the class which was used to prove whether hydrochloric acid reacted with sodium hydroxide in the solution

Segment 10

(Students demonstrated the tubes used to do experiments, and illustrated their groups' experiments)

S1 (group 1): This is the first plan. First, we added a lot of hydrochloric acid and phenolphthalein, the formed solution was colorless. Second, sodium hydroxide solution was added, maybe because it's a big amount, it shows deep red.

S2 (group 1): This is conducted according to the second plan. Sodium hydroxide solution was added first, then phenolphthalein, and hydrochloric acid last. The solution was red at

the beginning and changed into colorless in the end.

T: Is there somebody using pH papers?

S3(group 2): this pH paper was used to test the solution after reaction, that is the one in which no color change occurred. The solution is deep red.

T: What's the pH value?

S3:The value is between 1-2.

S3: This is the first one, the solution is red after reaction.

S4(group 3): Our group adopted experimental comparison. This is the mixed solution of litmus and hydrochloric acid, it is red. This is the mixed solution of litmus and sodium hydrochloride solution, it is blue. When hydrochloric acid was mixed with sodium hydrochloride solution, it's purple.

S5(group 4): We tested the temperature in the reaction process. 20 ml hydrochloric acid and sodium hydrochloride solution, it was 20°C before reaction, 30°C after the reaction.

Drawing Conclusion. The categories and frequencies of each aspect are shown in the following Table 14. All the four lessons included the activity drawing conclusion. All of the conclusions belong to the type “Inference”. The approaches to drawing conclusion involved observation, generalization, phenomena-based reasoning and comparison. Both teacher and students played as the subject to draw conclusion. The teacher stimulated students to formulate conclusions, directed them to record conclusions, and summarized the conclusions.

Table 14

Frequency of Drawing Conclusions in Grade 9 Class

Aspects	Categories	9S-L03	9S-L04	9S-L05	9S-L07
Type of conclusion	Explanation	0	0	0	0
	Relation	0	0	0	0
	Inference	2	4	3	1
Approach to drawing conclusion	Observation	1	1	0	0
	Generalization	0	1	1	0
	Phenomena-based Reasoning	0	3	1	0
	Comparison	1	0	1	1
Fitness between evidence and conclusion	Teacher as subject	0	0	0	0
	Students as subject	0	0	0	0
Who draws the conclusion	Teacher	1	3	3	1
	Students	1	1	0	0
Teaching practices	Teacher encourages more than 2 students to communicate the conclusion	0	0	0	0
	Stimulating	0	1	0	0
	Directing to record	1	1	1	0
	Summarizing	2	2	2	1

In lesson 9S-L01, students reported the color of litmus and phenolphthalein in hydrochloric acid, sodium chloride solution and sodium hydroxide solution according to their observation in group work. Ms. LIU generalized and reorganized the conclusion that students had reported as the colour of litmus and phenolphthalein in acidic, basic and neutral solution. In this episode, the

conclusion was drawn from the **approach** of observation, and coded as inference for the aspect type of conclusion.

After students reported on the experiment of making acid-base indicator in 9S-L01, Ms. LIU motivated students to draw conclusions by asking “According to your reports, let’s make a summary. Which material is suitable to be used to make indicators in family? ”. The conclusions corresponding to this question are drawn from comparison, and coded as inference.

Overall, Ms. LIU placed an emphasis on generalization of conclusions and always summarized the conclusions. Consequently, most of the conclusions were assigned to be “summarizing” for teaching practices and inference from the teacher (as shown in Table 14). Segment 11 was taken from the lesson 9S-L05 in which teacher summarized students’ reports on experiments of testing the acidity of some liquids brought from home to formulate conclusions.

Segment 11

T: According to your reports on the phenomena, considering the acidity, which one has the strongest acidity?

S: The detergent, and lemon juice.

T: Considering the phenomena, which phenomena was the most evident? Which agent? For example, the bubbles in acid were very obviously visible.

S: pH test strips

T: pH test strips, litmus. These methods resulted in obvious phenomena.

T: From laboratory to life in society, we can find that, although the acids are not the same, but the phenomena in our experiments were similar. Why?

T: Different kinds of acids have some common properties because they can ionize to release H^+ in water.

Summary. The enacted scientific inquiry in Ms. LIU's class, was much more like problem-solving in authentic context. First, Ms. LIU usually set an authentic context to motivate the class and promote the progress of teaching activities. For example, at the beginning of lesson 9S-L07, to identify adulterated wine using the principle of neutralization reaction was demonstrated to students through TV show. Afterwards, students were engaged in designing plans to prove whether hydrochloric acid react with sodium hydroxide solution. Then Ms. LIU guided students to learn the types of neutralization reaction, and to summarize the method for proving neutralization reaction. The class returned to the context of wine identification through the video of introducing rationales of the identification process.

Second, most of the research questions proposed by teachers were directed to design plans, this is also evidence for the feature of problem-solving. Overall, the inquiry in grade-9 case placed more emphasis on inquiry teaching or learning rather than learning inquiry. The scientific inquiry was aimed to understand science ideas and apply science ideas in authentic contexts. In other words, Ms. LIU's class emphasized the inquiry skill "making plans", and dedicated to cultivate students' ability to **plan investigations** to solve the problems.

Factors Influencing Enactment of Scientific Inquiry

Teachers' understanding about inquiry. Through pre- and post-topic interviews with the two teachers and their responses to the questionnaire, we find that teachers' understanding of scientific inquiry is an important factor influencing the enactment of scientific inquiry, because their understanding can account for part of their enacted inquiry. In the questionnaire, there was a question "What was the main thing you wanted students to learn from today's lesson? Why do you think it is important for students to learn this?" Ms. CAI (Grade 4 Science teacher) answered this question after Lesson 3S-L01 as follows:

Students already had some common sense about air when reading science books in their rest time. Some students even knew the components of air. Thus, in addition to teaching them scientific knowledge "air consists of nitrogen, oxygen, carbon dioxide, water steam", I think teacher also needs to help students realize that scientific knowledge is not definite as what is written in the textbooks, but it is the patterns and rules which were generalized through constant investigations.

The reason is that students should not just remember the conclusions when they study science, the most important thing for students is to understand how scientific conclusions are formed. On the basis of students' interest in science, I expect them to investigate scientific phenomena actively in future.

The interviews with Ms. LIU (Chemistry teacher, Grade 9) indicate that she focused on the systematic structure of chemistry knowledge, and students' ability to apply chemistry knowledge to solve authentic problems, and their ability to design and conduct hands-on experiments. Her

response to the same question in the questionnaire (9S-L07) was quite different from the answers of Ms. CAI:

- 1. the method used to prove neutralization reaction*
- 2. the method used to confirm the reaction with no obviously visible change*
- 3. Explain the application of neutralization reaction in life and society*

The reason is that these will provide foundation for neutralization titration, and promote students to apply chemistry knowledge and theories in community and society.

Other factors including textbooks, assessment, students and resources. The 9th-Grade teacher Ms. LIU said: “National curriculum standard, guideline of high school entrance exam and textbook are the main materials which help me decide what to teach. I pay attention to the recommended inquiry tasks in the chemistry curriculum standard. Textbook is the most fundamental materials, because the province-responsible high school entrance exam is closely related to the textbook. We usually focus on the specific content in the textbook and integrate some exam item to them. I pay more attention to experiments in the textbook, that is, inquiry tasks. With regard to experiments, sometimes I try to transform the teacher’s demonstrations into students’ group work, or make some change and improvement on the experiment in textbook. Ms. LIU gave such a response to the question “how do you decide how to teach this topic”: It depends on two aspects. The first one is the limitation of the content in the textbook, some are easy to design activities, some are difficult to be organized by activities. The second is about

students diversity, students in a class may have several distinct features from students in another class. Although the main instruction activity is the same, I will make a little bit change in different class.

The 4th- Grade teacher Ms. CAI described what to teach to the researcher (second author) according to the subtitles of the unit of the textbook. Other reference materials for her include the manual book for teachers, and some other teachers' planning on the topic which can be found for the internet. Furthermore, resource limitations such as shortage of apparatus also influence classroom enactment of scientific inquiry. For instance, in regard to "collecting evidence", all of the experiments in the case of grade 4 were organized as teacher's demonstration rather than students group work.

Conclusions and Discussion

Characteristics of Enacted Inquiry at Different Grade Levels

In regard to the ontological properties of inquiry activities, the two cases covered kinds of questions, hypotheses, plans, evidence, and conclusions. Both grade 9 and grade 4 cases involved “questions directed to design”, however, it is devoid of “Explanation Question” and “Question directed to evaluation” in grade 9, and less than “Questions directed to description or observation ”in grade 4. According to the hierarchical categories of research questions used by Hasson and Yarden (2012), “Explanation Question” and “Question directed to evaluation” can be assigned to higher order questions.

With respect to making hypothesis, the teacher in grade 4 case provided opportunities for students to make hypotheses with different representation forms. For the activity “making plan”, both the two case teachers allowed students to make more than one plan, and directed them to evaluate the plans. With respect to collecting evidence, the grade 9 teacher gave students opportunities to conduct experiments in groups. Both the two case teachers included the two types of evidence-describing phenomena and generalizing phenomena. In terms of drawing conclusion, both grade 9 and grade 4 cases covered different methods to draw conclusions, and most of the conclusions belonged to “inference”.

The present study finds that the 9th grade case lacked the opportunity for inquiry activity “Making hypothesis”, and gave students less opportunity to posing research questions. However, the study also reveals that the 9th grade chemistry class placed emphasis on engaging students in making design and conducting experiments to solve authentic problems, students are expected to

use their knowledge in this process, students' knowledge and conceptual understanding could be expanded. This can be a supplementary to Breslyn & McGinis (2012)'s findings about chemistry teaching:

the chemistry teachers in this study tended to enact inquiry with an emphasis on content knowledge, they are less likely to enact items measured with the PII(The PII assesses the degree to which teachers engage their students in inquiry as defined by the National Research Council's Abilities Necessary to Do Inquiry). In this case, chemistry teachers were less likely than biology teachers to allow students a choice of questions to investigate, support students' use of questioning and discuss the use of hypotheses.

This study indicates that it is possible and important for teachers to involve different kinds of inquiry activities which belong to different categories of the ontological properties in classrooms in a topic unit or in a longer-term instruction. It shows a meaningful enactment of scientific inquiry by specifying it into such variant and abundant activities for students. What is important is that teachers need to lead students to evaluate quality of questions, fitness between hypothesis, evidence and conclusions, so that students would acquire critical thinking to do inquiry. Banchi, H. and Bell, R. (2008) suggested that there are four levels of inquiry-based learning in science education: confirmation inquiry, structured inquiry, guided inquiry and open inquiry. At the beginning of a new science subject curriculum, guided inquiry is necessary to show students how to do inquiry, just like the two cases in this study. As students progress on learning content knowledge and inquiry skills, open inquiry needs to be provided to them.

For the instructional practices in the enacted inquiry, the two case teachers set good

example to other teachers when enacting inquiry or conducting inquiry-based teaching. The behaviors such as stimulating students to actively pose research questions and engage in other inquiry activities, providing scaffolding for students especially for the early-year students and the difficult part of inquiry activities like making plans for older students, asking student to record and report their questions, hypothesis, experiments phenomena and the conclusions, could be used to promote development of students' understanding about scientific inquiry and abilities to do inquiry. Requiring them to write down their opinions and encouraging more than 3 students to express their opinions are valuable to engage students in inquiry activities especially for the situation that there are about 40 students in a class.

Furthermore, both the national science standard for elementary school and chemistry standard for 9th grade (MOE, 2001) call for scientific inquiry with similar identification of process skills. This study indicates that the scientific inquiry at elementary levels is to make students experience and understand the process of inquiry. As grade level increase to middle school, the focus will be to develop students' ability to do certain inquiry activities but not cover all the inquiry elements, just like the case of Ms.LIU.

Moreover, this study shed light on the research method for the enactment of scientific inquiry. The coding schemes for the enacted inquiry include important aspects of each inquiry element, such as types of the activities, approaches to the activities, subject who initiates the activity, and teaching practices. These aspects provided multi-faceted perspectives for each inquiry activity, which may contribute to describing teacher's interpretation and enactment in classroom.

Factors Influencing Enactment

This study evidences that teacher's understanding about scientific inquiry, textbooks,

assessment materials, students and resources are the major factors that influence enactment of scientific inquiry. Findings from this study have implications for curriculum developers and teacher educators in science education. Curriculum developers should make the inquiry embedded in curriculum materials in a more explicit way giving an emphasis on the inquiry activity elements. To promote instruction improvement, teacher educators need to pay more attention to teacher's understanding on scientific inquiry reflected by their instruction practices. Furthermore, assessment materials that contain items to assess students' ability to do inquiry will be helpful to promoting instruction.

Appendix: Interview Protocols and Questionnaire**(a) Pre-topic Interview Protocol**

1. Tell me something about the topic.
2. How do you decide what to teach?
3. Which resources, such as documents or websites, did you refer to in planning this topic?
4. What are your main objectives in teaching this topic? What do you hope that your students will learn about this topic?
5. How do you decide how to teach the topic? What activities have you chosen for the teaching of this topic?
6. What do you think are the challenges for the students to learn about this topic?

(b) Post-topic Interview Protocol

1. To what extent have you achieved your instructional goals for this unit?
2. How can you tell how well you have achieved your instructional goals for this unit?
3. To what extent did assessment of any type influence the planning and the teaching of this unit? And how does it affect any other aspects of teaching beside this topic?
4. What were the key decisions you made during the teaching of this unit?

(c) The Teacher Questionnaire for Each Lesson

1. Please describe the subject matter content of today's lesson.

2. What was the main thing you wanted students to learn from today's lesson? Why do you think it is important for students to learn this?
3. To what extent did the students meet your learning goals? How do you know?
4. Please describe what did not go according to plan.

References

- Arizona State University. (2008). Discourse in Inquiry Science Classrooms (DiISC): Reference Manual. Retrieved from <http://digitalcommons.unl.edu/teachlearnfacpub/121/>
- Banchi, H. and Bell, R. (2008) The Many Levels of Inquiry. The Learning Centre of the NSTA. Retrieved from http://learningcenter.nsta.org/files/sc0810_26.pdf.
- Breslyn, W., & McGinnis, J. R. (2012). A Comparison of Exemplary Biology, Chemistry, Earth Science, and Physics Teachers' Conceptions and Enactment of Inquiry. *Science Education*, 96, 48 – 77.
- Chinese Ministry of Education. (2001 a). *National Curriculum Standards Series: Science Curriculum Standards for Grade 3-6 (in Chinese)*. Beijing: Beijing Normal University Press.
- Chinese Ministry of Education. (2001 b). *National Chemistry Curriculum Standard for Junior High School (in Chinese)*. Beijing: Beijing Normal University Press.
- Crawford, B.A. (2007). Learning to Teach Science as Inquiry in the Rough and Tumble of Practice. *Journal of Research in Science Teaching*, 44(4), 613–642.
- Eltinge E.M., & Roberts, C.W. (1993). Linguistic Content Analysis: A Method to Measure Science as Inquiry in Textbooks. *Journal of Research in Science Teaching*. 30(1), 65-83.
- Forbes, C.T., & Davis, E.A. (2010). Curriculum Design for Inquiry: Preservice Elementary Teachers' Mobilization and Adaptation of Science Curriculum Materials. *Journal of Research in Science Teaching*, 47(7), 820–839.

- Ford, M.J., & Wargo, B.M. (2007). Routines, Roles, and Responsibilities for Aligning Scientific and Classroom Practices. *Science Education*, 91, 133 – 157.
- Fu, L ., Zhou, S. & Zheng, C. (2007). Investigating the Frequencies and Time Length of Inquiry Activities. *Chemical Education (in Chinese)*, (11): 42-44.
- Gerrmann, P.J., Haskins,S., & Auk, S. (1996). Analysis of Nine High School Biology Laboratory Manuals: Promoting Scientific Inquiry. *Journal of Research in Science Teaching*, 33(5), 475-499.
- Hasson, E. , & Yarden, A. (2012). Separating the Research Question from the Laboratory Techniques: Advancing High-School Biology Teachers’ Ability to Ask Research Questions. *Journal of Research in Science Teaching*, 49(10), 1296–1320.
- Liu, X. , Liang, L., & Liu, E.(2012). Science Education Research in China: Challenges and Promises. *International Journal of Science Education*, 34(13), 1961 – 1970.
- Mcdonald,S., & Songer,N.B. (2008).Enacting Classroom Inquiry: Theorizing Teachers’ Conceptions of Science Teaching. *Science Education*, 92,973 – 993.
- National Research Council (1996). *National Science Education Standards*. Washington, DC: National Academy Press.
- Schneider,R. M., Krajcik,J., & Blumenfeld,P. (2005).Enacting Reform-Based Science Materials: The Range of Teacher Enactments in Reform Classrooms. *Journal of Research in Science Teaching*,42(3), 283–312.
- Schwab, J.J. (1962). The Teaching of Science as Enquiry. In J.J. Schwab & P.F. Brandwein

(Eds.), *The Teaching of Science*. Cambridge: Harvard University Press.

Wang, L. (2010). Progress and Reflection on Chemistry Curriculum Reform (part 1). *Chemical Education (in Chinese)*, (4):15-21.

Wang, L. (2010). Progress and Reflection on Chemistry Curriculum Reform (part 2). *Chemical Education (in Chinese)*, (5):20-24.

Wu, H. & Krajcik, J.S. (2006). Inscriptional Practices in Two Inquiry-Based Classrooms: A Case Study of Seventh Graders' Use of Data Tables and Graphs. *Journal of Research in Science Teaching*, 43(1):63-95.

Zhou, S., Li, T. & Zheng, C (2005). Interpretation on the Teaching Activities of Scientific Inquiry in the Context of New Curriculum. *Teacher Education Research (in Chinese)* (07):65-69.

Minerva Access is the Institutional Repository of The University of Melbourne

Author/s:

Wang, L;Zhang, R;Clarke, D;Wang, W

Title:

Enactment of Scientific Inquiry: Observation of Two Cases at Different Grade Levels in China Mainland

Date:

2014-04-01

Citation:

Wang, L., Zhang, R., Clarke, D. & Wang, W. (2014). Enactment of Scientific Inquiry: Observation of Two Cases at Different Grade Levels in China Mainland. JOURNAL OF SCIENCE EDUCATION AND TECHNOLOGY, 23 (2), pp.280-297. <https://doi.org/10.1007/s10956-013-9486-0>.

Persistent Link:

<http://hdl.handle.net/11343/283096>