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THESIS

ENHANCING THAI ELEMENTARY TEACHERS' UNDERSTANDING OF NATURE OF SCIENCE AND TEACHING PRACTICE REFLECTING NATURE OF SCIENCE THROUGH COLLABORATIVE ACTION RESEARCH

LADAPA SUTTAKUN

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This interpretative case study examined elementary teachers' understandings of nature of science (NOS) as well as their ability to explicitly teach NOS through collaborative action research (CAR). It involved three Thai elementary teachers, who taught science at different grade levels in a government public school. Initially, the teachers' understandings of NOS and how they taught NOS in the classroom were explored using a questionnaire, individual semi-structured interviews and extended classroom observations, and then analyzed using content analysis. A workshop was then held to introduce the teachers to contemporary views of NOS before they attempted to translate particular aspects of NOS into classroom practice. To promote collaborative and reflective discourse, the researcher and teachers met regularly and engaged together in CAR. The researcher facilitated group meetings and provided advice and support to help the teachers learn about NOS and how to introduce NOS in their classrooms. A variety of qualitative data collection methods including teacher interviews, classroom observations, group discussions during CAR, teacher journal entries, the researcher's field notes and a collection of other relevant materials were used to examine how CAR supported the teachers' learning about teaching NOS. The data were analyzed using a constant comparative method.

The findings indicated that none of the teachers came into the study with complete understandings of NOS or methods for teaching NOS. None of them explicitly taught NOS in the classroom although they claimed to do so. However, two of the teachers implemented an implicit approach to teaching NOS through engaging students in hands-on or inquiry-based activities. The results of the study indicated that participation in CAR afforded varied supports to the teachers learning to teach NOS. Discussions and activities during collaborative group meetings provided teachers with opportunities that affirmed their tacit understandings of NOS, challenged their problematic understandings of NOS, and helped them reinterpret what is meant by teaching NOS effectively. Involvement in the CAR process also helped the teachers decide what NOS aspects are attainable by students, helped them see possible ways to translate those NOS aspects into classroom practice, and promoted their reflection on their efforts with NOS instruction.

This study found that significant components of Bell and Gilbert's (1994) model of teacher development were intrinsic to the CAR process, specifically personal development, social development, and professional development. It also suggested that the teachers needed continued support to develop pedagogical content knowledge (PCK) for teaching NOS.

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Student's signature Thesis Advisor's signature

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CHAPTER I

INTRODUCTION

This introductory chapter begins by describing the background information and significance of the study. A result of the educational reform in Thailand and the importance of the Nature of Science (NOS) for science education development are much more meaningful issues to consider in both a worldwide and Thai context. After that the problems in teaching and learning science and the rationale of the study lead to the purposes and the research questions. This chapter also presents the summary of the methodological framework, delimitation of the study and the operational definition of terms. Finally, an outline of the forthcoming chapters will be summarized in the last section.

Background of the Research Study

The current educational reform in Thailand is a result from the Asian economic crisis in 1997. This crisis caused the Thai government to realize the need for a change of formulating educational policy and a plan to help all Thai people to succeed in a knowledge-based society, to enhance the people's quality of life and to develop human resources, especially in science and technology, to compete with others in the age of globalization (Office of the National Education Commission [ONEC], 2002). The challenging guidelines for development of education which were mandated by the 1997 Constitution of the Kingdom of Thailand and which appeared in the eighth National Economic and Social Development Plan (1997-2002) (National Economic and Social Development Board [NESDB], 2002). These two documents were promulgated in the enactment of a national education law in 1999, the 1999 National Education Act (ONEC, 2004).

After the enactment of the 1999 National Education Act (ONEC, 1999), education in Thailand was driven into a period of reform. Teaching and learning reform is regarded as the heart of the educational reform, aiming to change learning processes from the traditional passive mode to a more student-centered mode (Atagi, 2002; ONEC, 2005). As a result, all students are viewed as being capable of learning and self-development at their own pace instead of being knowledge receivers (ONEC, 1999). In addition to education reform, all educational stakeholders, including teachers, schools, parents and communities were asked to play new roles in order to achieve the requirements of the educational reform. Schools, for example, are seen as more responsible for developing their own curricula, which should be appropriate for their students and various contexts. Teachers are encouraged to carry out research to improve their own teaching practices, with the aim of improving students' learning.

Science education reform in Thailand is based on the 1999 National Education Act which provides educational guidelines, for example, the teaching and learning process, science curriculum, the assessment of student's outcomes and the science teacher professional development (Boonklurb, 2001). The ultimate goal of science education is to develop a scientifically and technologically literate society. This scientific society would demonstrate rational and systematic thinking, learning through the scientific process, and the use and application of science in daily life. Therefore, all Thai citizens should be able to understand scientific process as a way to gain scientific knowledge, know scientific concepts, have decision-making skills and practice scientific and rational thinking (The Institute for the Promotion of Teaching Science and Technology [IPST], 2003; ONEC, 2001). Many teaching and learning approaches are presented by IPST in the teachers' teaching manual (for example, inquiry learning approach, hands-on and minds-on learning activities and cooperative learning) in order to achieve the aims of science education (IPST, 2003)

With regards to teaching and learning science at the elementary level, the teaching and learning process still emphasizes lecturing, reading, writing and memorizing content more than the development of scientific process skills (ONEC, 2001, Soydhurum, 2001; Promkatkeaw, 2007). Most elementary school teachers who teach science do not have a science teaching degree and lack an understanding of scientific process skills (Soydhurum, 2001). They also do not have enough time to develop their science teaching skills and techniques because of the high workloads at their schools (ONEC, 2001; Soydhurum, 2001). Insufficient knowledge of science content and NOS, and a lack of teaching skills, have resulted in a lack of confidence and negative attitudes towards science and the teaching of science among teachers (Akerson and Hanuscin, 2007; Tairab, 2001; ONEC, 2001; Soydhurum, 2001).

Rationale for the Study

The Importance of Nature of Science for Science Education in Thailand

The main goal of science education in many countries, including Thailand, is to produce scientifically literate learners and citizens. Science educators and researchers have agreed that an adequate understanding of NOS is an important component of scientific literacy that students are expected to learn. Scientifically literate individuals should have an acceptable understanding of NOS (AAAS, 1990; NRC, 1996; Abd-El-Khalick and Lederman 2000; IPST, 2002).

The concise description of NOS is often debated in science education. The NOS representation is as dynamic as the knowledge and enterprise of science itself. Through general outline, Lederman (1992) has defined the phrase NOS as, “The epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge”. However, science educators and researchers have defined NOS in many ways such as, “What science is, how it works, the epistemological and ontological foundations of science, how scientists function as a social group and how society influences and reacts to scientific endeavors” (Clough and Olson, 2008).

According to the National Science Curriculum Standards (IPST, 2003), understanding of NOS is an important aim of teaching and learning science. Moreover, NOS and technology has been specified as a science content standard, namely Sub-strand 8: Nature of Science and Technology. As specified by the IPST, NOS has three main aspects: (1) scientific inquiry to develop scientific knowledge,

(2) the limitations of science and (3) the interrelationship between science, technology, society and environment (IPST, 2003). This sub-strand aims to encourage students to do scientific inquiry in order to gain scientific knowledge, process skills and attitudes. In the process of teaching and learning, NOS should be integrated into other scientific topics in every grade level (IPST, 2002).

Teaching science while including the conceptions of NOS enhances students' learning of science content, understanding of science, awareness of moral and ethical values, decision making and instructional delivery (Driver, Leach, Millar, and Scott, 1996; McComas, Almazroa, and Clough., 1998). Students are empowered to have a scientific thinking process and make decisions about the situations they face, including application of basic scientific knowledge within their daily life (Hand, Prain, Lawrence, and Yore, 1999; Colburn. 2004). Moreover, teaching science in a manner that reflects the conceptions of NOS also enhances teachers' changing views of teaching and learning science. Teachers would be most likely to make more use of inquiry-based or constructivist approaches in teaching science (Lederman, 1998; McComas *et al.*, 1998).

Mistakes in teaching science appear to affect students' attitudes toward science and learning in science classes, for example, using 'cookbooks' (or laboratory manuals that are state all steps of the activity) in laboratory activities can convey mistaken notions about the scientific process. An additional mistake was most of the textbooks teachers use emphasize the products of science more than how the knowledge was developed (Clough and Olson, 2004). Research examining professional development that enhances teachers' attentions to, and implementations of, accurate and effective teaching about NOS is greatly needed (Clough and Olson, 2008).

Although NOS has been seen as an important content standard in the national science curriculum and is specified in the science teacher standards, many studies in Thailand report that both students and teachers have inadequate understanding of the conception of NOS (Vangnurat, 1999; Srivinet, 2000; Vadeesirisuk, 2001;

Promkatkeaw, 2007; Yutakom and Chaiso, 2007). It is reasoned that these findings relate to the 'newness' of this sub-strand (Promkatkeaw, 2007). In other words, teachers might not be sufficiently prepared to deal with this sub-strand in their classrooms. Limpanont (2004) found that most of teachers teach the conceptions of NOS by lecturing and doing experiments following the textbooks. The teacher taught the conceptions of NOS because it was the objective of the science curriculum rather than to be aware of the importance of teaching it. Additionally, teachers' lack of scientific content knowledge, understanding the conceptions of NOS and ability to use scientific language affect their teaching about NOS (Yutakom and Chaiso, 2007).

From the pilot study using a questionnaire followed by semi-structured interviews with twenty eight Thai elementary science teachers, it was found that the teachers had limited conceptions of NOS in 3 aspects: the acquisition of scientific knowledge, the nature of scientific knowledge and the relationship between science and society. More than half of the teachers did not know what NOS is about and how to teach it. Some teachers had misunderstood that teaching about the nature and/or scientific process is teaching NOS. These teachers seem to appreciate teaching science by lecturing, demonstrating and group work respectively. These findings seem to infer that the elementary teachers need support about NOS (Suttakun, in press).

It is commonly accepted that teachers play an important role in developing students' understandings of NOS (AAAS, 1990; NRC, 1996; Lederman, 1999; Driver *et al*., 1996; IPST, 2002). Teachers who lack an understanding of NOS might let students perceive science as a difficult and uninteresting subject, leading to unwillingness to learn science (ONEC, 2001). Thus, it is important to foster an adequate understanding of NOS among teachers, especially elementary teachers, to enable them to help students to develop an understanding of NOS (Abd-El-Khalick and Lederman, 2000; Wang, 2001; Akerson and Hanuscin, 2007; IPST, 2003). To achieve this, teachers need supports that will help them to understand NOS and allow them to integrate the conceptions of NOS into their teaching practices (Yutakom and Chaiso, 2007).

There are many teaching approaches for encouraging the understanding of NOS. Generally, the two important teaching approaches that help learners to develop understandings of NOS involve engaging them in scientific inquiry activities that use an implicit or an explicit approach. However, to promote teachers' understandings of NOS through professional development, literature suggests that an explicit-reflective approach that embeds NOS instruction in the context of science content is more effective than an implicit approach which assumes that learners' constructed understandings of NOS are a natural consequence of engaging in inquiries (Abd-El-Khalick and Lederman, 2000; Akerson, Abd-El-Khalick and Lederman, 2000). There are a variety of teaching and learning models based on this idea; for example, the explicit and reflective activity-based approach (Akerson *et al*., 2000; Akerson, Morrison, and McDuffie, 2006), explicit and reflective inquiry-oriented instruction (Bianchini and Colborn, 2000; Khishfe and Abd-El-Khalick, 2002), and the use of controversial issues, scientific stories or scientific history (Yip, 2006; Lin and Chan, 2002).

Rationale for Teacher Professional Development through Collaborative Action Research

According to the 1999 National Education Act, professional teacher development is an important factor for achieving educational reform in Thailand. However, there are some problems with conventional professional teacher development in Thailand. Pitiyanuwat (2000) noted that teacher professional development is fragmented and unsystematic; it does not involve all teachers, does not serve teachers' needs and over emphasizes theory. Fry (2002) suggested that there should be an alternative mode of teacher professional development in Thailand. In addition, Yutakom and Chaiso (2007) proposed that encouraging teachers to conduct classroom action research for improving their own teaching practices is a potential strategy for teacher professional development.

After Thailand's educational reform and the release of the Act, the trend for professional development has focused on having a teacher-centered approach process, in which the teachers construct their own knowledge of teaching and develop instructional units by themselves. Moreover, in accordance with the requirements of the Act (section 30), teachers have been encouraged to develop their proficiency in teaching science by doing classroom-based action research (ONEC, 1999; Yutakom and Chaiso, 2007).

However, several studies in the Thai context have reported that most elementary teachers lack knowledge about action research and the skills for conducting classroom-based action research (Inchan, 2003; Saenphet, 2004; Kompukdee, 2007). Further, teachers do not have confidence to conduct classroom research (Phengdi, 2006); therefore, minimal classroom action research has been conducted by elementary teachers, especially in the subject area of science (Inchan, 2003; Saenphet, 2004). Moreover, most classroom research conducted by elementary teachers is presented in the form of one-paged, informal reports (Inchan, 2003; Saenphet, 2004). Nevertheless, many professional development programs were continually developed and designed to encourage teachers to understand and be able to conduct classroom action research (Yutakom and Chaiso, 2007).

In education, action research is an ongoing process of systematic study that is conducted by the teachers who wish to examine their own teaching and students' learning. There are various methods for conducting action research for the purpose of improving classroom practice, such as descriptive reporting, purposeful conversation, collegial sharing and critical reflection (Loucks-Horsley, Styles, and Hewson, 1998). The practice of action research includes five key elements: (1) the teachers contribute to or formulate their own questions, and collect data by themselves; (2) teachers use an action research cycle, for example, PAOR cycle model including planning, acting, observing and reflecting; (3) teachers participate with a variety sources of knowledge; (4) teachers work collaboratively; and (5) teachers learn from research which is documented and shared (Loucks-Horsley *et al.*, 1998; Cox-Petersen , 2001; Capobiance, 2007).

Over the years, many claims have been made about the benefits of teachers engaging in research of their own practices. For example, it has been asserted that doing self-study research helps teachers to become more flexible and open to new ideas (Feldman, Paugh and Mills, 2007). Furthermore, conducting action research makes teachers more aware of their own practices (Tabachnick and Zeichner, 1999) and increases their confidence and competency in their teaching practices (van Zee, Lay, and Roberts, 2003). Through action research, teachers are encouraged to conduct systematic inquiry to answer questions about student learning, instructional strategies and social dynamics (Cox- Petersen, 2001). Additionally, action research helps teachers, through collaborative work, to share ideas, gain the benefits of one another's teaching experiences and engage in common studies to enrich their subject knowledge (Loucks-Horsley *et al*., 1998).

Many related studies expose that action research and/or collaborative action research is an effective approach for teacher professional development (Loucks-Horsley *et al*., 1998; van Zee *et al*., 2003; Yutakom and Chaiso, 2007).Collaborative action research entails teachers joining together to examine and take action in response to different issues and concerns related to their practices (Feldman, 1996). In other words, the teachers and researchers come together to solve problems, create change and accomplish some shared goals regarding teaching and student learning in science (Capobianco, 2007). Collaborative action research not only enhances teachers' content and pedagogical knowledge (Feldman, 1996; Capobianco, 2007), but also gives teachers the opportunity to explore their own teaching practices and to make decisions to promote effective change (Erickson and Christman, 1996; Cox-Petersen, 2001; Guo and Chang, 2004). In Thailand's context, studies have found that collaborative action research is helpful not only for improving the teacher's knowledge and ability to conduct classroom action research, but also increasing their confidence as well (Sittisomboon, 2003; Phengdi, 2006).

As mentioned in Thailand's *National Science Curriculum Standards* (IPST, 2003), NOS is an important learning outcome that students must understand in order for them to be able to participate in and contribute to a scientifically knowledge-based society. This curricular requirement urges Thai science teachers themselves to have informed understandings of NOS, appreciate the importance of teaching NOS to students, and is able to teach NOS effectively (Lederman, 1992, 1999). As NOS is quite new to many Thai science teachers (Promkatkeaw, Forret, and Moreland, 2007; Yutakom and Chaiso, 2007; Buaraphan, 2009), particularly those who teach at elementary levels, this study primarily aims to enhance Thai elementary science teachers' understanding of NOS and their ability to teach NOS effectively. To achieve this aim, collaborative action research, which emphasizes the teachers' reflection on teaching practice and their collaboration, is used as a means to teacher development. The use of collaborative action research for teacher development is also highlighted in the National Education Act (ONEC, 1999). The study focuses on whether and how collaborative action research can support the participant teachers learning about NOS. Findings of the study could provide implications to teacher professional development regarding NOS in Thailand and elsewhere.

Purposes of the Research

As this study aims to enhance Thai elementary science teachers' understandings of NOS and their ability to teach NOS effectively through collaborative action research, it has two main purposes. The first one is instructional in terms that the study can provide results that are relevant to how NOS can and should be taught in Thai elementary science classrooms and what kinds of challenges Thai elementary science teachers would encounter in teaching NOS. The second purpose involves the process of teacher development in Thailand in terms that the study can suggest how collaborative action research can be used and organized to enhance Thai elementary science teachers' understandings of NOS and their ability to teach NOS effectively. This result of the study can provide implications to the use of collaborative action research as a mean to teacher development in other domains in additional to NOS.

Research Questions

Two research questions guide this study:

1. What are Thai elementary teachers' initial understandings of NOS and teaching practices that reflect NOS?

    1.1 What are the elementary teachers' understandings of NOS?

    1.2 Do the elementary teachers' practices reflect NOS?

2. How does collaborative action research support Thai elementary teachers as they learn how to explicitly teach about NOS?

    2.1 How does collaborative action research influence the elementary teachers' understanding of NOS?

    2.2 How does this collaborative action research project influence the elementary teachers' practice of teaching NOS?

Methodological Framework of the Study

The interpretive methodology is employed as a theoretical framework of this study for investigating the change of teachers' understandings and practices about NOS. In order to obtain details to determine how the elementary teachers understand NOS and how they learn to teach NOS through conducting collaborative action research; the interpretive case study is used as the research method. Case study can support the investigations by gaining insight into, discovery of, and interpretation of specific phenomena (Merriam, 1998). Data was collected from multiple sources, including individual interviews, classroom observations, group discussions and a collection of materials to obtain qualitative data with minimized attempt to manipulate the research setting (Lincoln and Guba, 1985). The data was initially evaluated through a within-case analysis and then followed by a cross-case analysis. The results were reported in individual cases and followed by common findings across the three cases. A detailed account of the methodology is provided in Chapter III.

Delimitation of the Study

This research is an interpretive case study that aims to enhance the elementary teachers' understandings of NOS and teaching reflecting NOS through collaborative action research. This research study is conducted at a public elementary school under the Lamphun Education Service Area Office, in the 2009 academic year. Three elementary teachers who teach science subjects in grades 1, 3 and 4 are the participants in all two phases of this study. The three teachers work together by conducting collaborative action research to improve their understandings of and teaching practices reflecting NOS.

Operational Definition of Terms

Understanding of the Nature of Science

Understanding the nature of science means the ability to describe ideas and give examples about NOS, which is guided by the National Science Curriculum Standards (IPST, 2002), including three domains: 1) Scientific knowledge acquisition; 2) Nature of scientific knowledge and 3) Interrelationship among science, technology, society and environment. These three domains are elaborated into seven aspects of NOS including: there is no single and stepwise process of scientific method in doing science; science is based on evidence; science is subject to change; scientific knowledge is constructed from both observation and inference; creativity and imagination are important in science; human subjectivity; and lastly social and culture milieus have influence on, and be influenced, by science. The understanding of NOS can be examined using a number of methods including a questionnaire, individual interviews, discourse in workshops and group meetings, and science teaching practice.

Teaching Practice Reflecting the Nature of Science

Teaching practice reflecting the nature of science means the variety of learning science experiences or activities in which the teacher intentionally integrates the three aspects of NOS (scientific knowledge acquisition; nature of scientific knowledge and interrelationship among science, technology, society and environment). Teachers can help students develop their conceptions of NOS through the use of discussion, guided reflection, and specific questioning in the context of activities, investigations and historical. It is an explicit approach to teaching NOS which, for example, the students do scientific inquiry and engage in discussion about NOS aimed to make a connection between the inquiry being conducted and relevant aspects of NOS. The teaching practices which reflect NOS are examined using classroom observations, interviews, lesson plans and writing reflections.

Collaborative Action Research

Collaborative action research refers to as a collective activity in which participant teachers, a science educator, and the researcher join together to seek ways to integrate NOS into the participant teachers' instruction. In the collaborative action research of this study, the participant teachers, with facilitation by a science educator and researcher, come together to identify difficulty related to teaching NOS, share ideas related to NOS as well as ways to effectively integrate NOS into instruction, and reflect on implemented instruction with a view to further improvement. The collaborative action research is conducted as a regular activity in which all conversations among the participant teachers, a science educator, and the researcher are recorded for examinations.

Outline of the Chapters

This dissertation is divided into six chapters. This introductory chapter discusses the background of the education reform in Thailand after facing an economic crisis and the current situation of science education reform after the enactment of the 1999 National Education Act which provides educational guidelines. In order to achieve the aim and objective of science education, understanding NOS is regarded as an important component to produce scientifically literate learners. It is important to support teachers in understanding NOS and teaching reflecting NOS. Collaborative action research is considered as an effective strategy to help teachers to develop their knowledge and teaching practice. This research study aims to understand whether and how participation in collaborative action research can foster teachers' understandings of NOS, and enhance elementary teachers' abilities to reflect on NOS as they teach science. Chapter 2 offers a review of the literature, the theoretical perspectives and research findings relevant to this study. Chapter 3 discusses the research methodology applied in this study. I begin with a discussion of the research design, issues around the data analysis and the trustworthiness of the study. This is followed by information about the context of the study, data collection procedures and analysis of the data. The findings of each case and a discussion of the research findings by cross case are presented in Chapter 4 and 5 respectively. Finally, Chapter 6 concludes and discusses the research findings and presents the implications for both practice and research in the future.

CHAPTER II

LITERATURE REVIEW

Introduction

The review of literature in this chapter is divided into three main sections; science education in Thailand, the Nature of Science (NOS) and professional development. These three sections are identified as the theoretical framework of this study. This chapter begins by reviewing literature on science education in Thailand to provide important details of science educational reform efforts and the context of science education in Thailand, especially at the elementary level, that is the focus of this study. The second section of the chapter discusses relevant literature about NOS. Encouraging teachers' understandings of NOS and teaching practices reflecting of it are regarded as aims of this study; therefore, the second section of this chapter will describe NOS as it applies to each aspect of this study.

Although definitions and elements of NOS have been considered widely by science educators, for the purposes of this study, the important conceptions of NOS will be identified. The values of NOS are indicated as the rationale for this study. The subsection on teaching and learning NOS reviews learning theories and teaching approaches for NOS. Factors that influence the translation of the NOS knowledge into teaching practice, especially by elementary teachers, are also described in this subsection. Research that attempts to improve teachers' understandings and teaching of NOS is described in the last subsection dealing with NOS.

The last section of this chapter reviews important issues related to teacher professional development, especially for in-service teachers. The general characteristics of successful teacher development models and action research as an effective professional development are reviewed as the rationale or principle guiding this research study. The collaborative action research is described in the last part of this section as a method for studying teacher learning.

Science Education in Thailand

Regarding the effects of the economic crisis, the political system of Thailand has been driven to change, and this has had a significant impact on the educational system. According to the over-centralized, bureaucratic and inefficient nature of the Thai educational system, several key problems have to be solved urgently. For example, there have been inadequate efforts to enhance good teaching and teacher learning. Moreover, the problem of traditional pedagogy that emphasizes rote learning is of central importance for educational reform in Thailand (Fry, 2002).

The 1999 National Education Act

Education in Thailand entered into a period of educational reform after promulgation of the 1999 National Education Act (ONEC, 1999). An effort to reform education is driven by the changing economic landscape of Thailand which demands that employees have a higher level of knowledge and skills. The citizens are increasingly expected to be life-long, autonomous and self-regulated learners that have the ability to adapt readily to a changing world (Pillay, 2002).

The 1999 National Education Act is composed of nine chapters that contain these general provisions: objectives and principles, educational rights and duties, the educational system, national education guidelines, educational administration and management, educational standards and quality assurance, teachers, faculty, staff, and educational personnel, resources and investment for education, and educational technologies (ONEC, 1999).

Chapter 4 of the Act (Section 22-30) mentions the educational guidelines for supporting the teaching and learning system based on a student-centered approach (ONEC, 1999). Section 22 recommends that, “All learners are regarded as being most important and that they are capable of learning and self-development”. Therefore, teaching and learning processes shall aim “To enable the learners to develop themselves at their own pace and to the best of their potential”. In Section 24, the Act has guidelines about the organization of the learning process. The educational institutions are expected to provide substance and arrange activities in line with the learners’ interests and aptitudes regarding individual differences, and provide training in thinking process and application of knowledge in solving problems. The instructors should teach by integrating subjects and activities in their instruction and allow the learners to gain knowledge from authentic experiences in order to promote thinking, practical skills and life long learning. Moreover, the instructors are expected to create the appropriate learning environment, instructional media and facilities for learning at all times and in all places (ONEC, 1999). These guidelines support a new learning approach that is student-centered.

Regarding professional development, Chapter 7 of the Act (Section 52-57) (ONEC, 1999) states that the status and quality of teachers should be improved. It includes guidelines “To enhance the teaching profession, raise welfare for teachers, attract good and capable individuals to be teachers, and upgrade current working teachers”. Moreover, to develop suitable learning for students and to develop teachers’ professional knowledge and skills, Section 30 specifies that, “Educational institutions shall encourage instructors to carry out research for developing suitable learning for students” and Section 24 recommends that instructors should use the benefits from research as part of the students’ learning process.

Science Education Reform in Thailand

According to the Act and the impact of science and technology on society, science education in Thailand has been driven to reform to try to enhance citizens' capabilities in economic development, international competitiveness and happy coexistence in a global community (IPST, 2003). The IPST which is under the authority of the Thai Ministry of Education plays a major role in science, mathematics and computer education in Thailand. It also has the responsibility for establishing, revising and updating the National Science Curriculum Standards as a guide for all schools to help them to develop their own curriculum. Moreover, it has an important role in conducting and promoting research and development in science including teaching and learning approaches, to develop the science teacher standards for teacher performance assessment and to promote professional development in science and technology instruction according to the national education guidelines within the Act (IPST, 2002).

The National Science Curriculum Standards

Science is a principle subject group consisting of eight subject areas in the 2001 Basic Education Curriculum. The National Science Curriculum Standard is set up by IPST following section 27 of the Act as a core curriculum for the learners at all levels. In doing so, the components and contents of this core curriculum are formed, moving from simple to more complex content for different grades. The National Science Curriculum Standard provides the science standards for learning at the basic level and at different levels, the core content for levels and grades, the expected learning outcomes and content for each grade for successive periods from grade 1 to grade 12 (IPST, 2002). In developing a school-based curriculum, the educational institutions have to construct a curriculum based not only on the core curriculum, but also on the contexts, needs, local wisdom and the attributes of desirable members of their community.

There are eight science content standards in the Basic Science Curriculum Standard: (1) Living Things and Living Processes; (2) Life and Environment; (3) Matter and Properties; (4) Forces and Motion; (5) Energy; (6) Processes that Shape the Earth; (7) Astronomy and Space; and (8) The Nature of Science and Technology. To organize the learning process, the Sub-strand 8 (Nature of Science and Technology) is integrated within other Sub-strands. Sub-strand 8, which deals with the concepts of NOS that states, “Students are expected to use the scientific process and scientific minds when investigating, solving problems, knowing that most natural phenomena have definite patterns explainable and verifiable within the limitations of data and instrumentation during the period of investigation, and understand that science, technology, society and environment are interrelated" (IPST, 2002).

Science Teaching and Learning Process

Within the teaching and learning process, although the 1999 National Education Act of Thailand (ONEC, 1999) does not specify student- centered learning as the only new approach for teaching and learning reform, many Thai science educators agree that this approach is the central teaching and learning approach based on constructivist learning theory. It is suitable for educational institutes to use as a guideline for organizing the learning process (Pillay, 2002). According to the Act, the science teaching and learning processes should emphasize providing substance and activities that address learners' interests and aptitudes, and support learners' thinking processes and problem solving in their authentic experiences. The learning of science should be a developmental process that enables the learner to discover and learn independently and acquire proper knowledge, process skills and a positive attitude. Moreover, teachers are expected to use a variety of methods and manage the learning environment to facilitate the learner to learn at all times and in all places (IPST, 2003).

The IPST has supported teachers' use of a variety of teaching methods for science teaching by recommending the important aspects for qualitative science teaching in the teaching manual. The IPST has recommended using an inquiry-based teaching and learning process, problem solving process, hands-on/minds-on activities and cooperative learning in teaching and learning science. Although IPST has emphasized incorporating the inquiry approach in teaching and learning science, there are limitations such as class sizes, a lack of science equipment and a shortfall of competent teachers. The system of entrance examinations to higher education is also a major hindrance of effective teaching and the learning process. The teachers teach science by paying attention to content more than process. On the other hand, students learn science by rote memorization to pass examinations (Boonklurb, 2001).

Science Teacher Professional Development

Chapter 7 of the National Education Act B.E. 2542 (1999) outlines the issues related to the professional development of teachers, Faculty of Education staff and other educational personnel. For implementing the Act in science teacher professional development, there are various approaches that support in-service teacher development including enrolling in teacher education programs, training courses or workshops, distance learning and mentoring by outstanding teachers. Very little work has been done in planning, developing and delivering in-service training in new teaching and learning methods (Pillay, 2002). The only major in-service training in new teaching and learning approaches for classroom teachers has been done through workshops. A few of the workshops have been conducted by the IPST and by the Thai Ministry of Education (MOE). This is a serious concern for several reasons: many of these teachers have not had any training since they graduated some 20 or more years ago and certainly no training in new teaching and learning methods (Pillay, 2002); less than 5% of all in-service teachers in each school are allowed to enroll in regular teacher development programs (OBEC, 2004); there is no system for the development of in-service teachers; training courses do not serve teachers' needs; and there is an emphasis on theory rather than on practice (Pitiyanuwat, 2000) . In order to solve these problems and promote effective professional development, the Office of the Education Council (OEC) has introduced school-based training (SBT) as an effective and sustainable method for in-service teacher development. The teachers and schools have been enabled to develop their own teacher professional development based on their own contexts (OEC, 2004). Teachers have been found to have continuous self-development through studies, training and participation in seminars or study tours together with conducting research for constant improvement of their work (ONEC, 2002).

The trend of professional development in Thailand after the education reform and the release of the Act have focused on teachers constructing teaching knowledge and the development of their instructional units. In-service teachers are required to do classroom action research to improve their ability to teach science (Yutakom and

Chaiso, 2007) which is outlined in Section 30 of the Act. This section of the Act indicates that teachers should be encouraged by educational institutions to carry out research for developing suitable learning for students at different levels of education.

Teaching and Learning Science in Elementary Schools of Thailand

Prior to the education reform, teaching and learning science at the elementary level was based on the Curriculum B.E. 2503. The Thai Ministry of Education integrated science and social studies within a subject of life experience. Teaching and learning science placed emphasis on the content of science; therefore, the students did not conduct experiments. The teachers taught science by lecturing rather than by guiding and the students doing (ONEC, 2001).

After the establishment of the IPST, there was new emphasis placed on empowering students to understand the scientific process by conducting experiments. In doing so, and in accordance with the Basic Education B.E. 2521 (Adjusted B.E. 2533), IPST set goals for teaching science at the elementary level to enhance students' thinking, practicing, and problem solving skills. Moreover, the IPST indicated that students should be able to use the scientific process in order to develop their own life skills. However, science remained integrated within the life experience subject and the curriculum continued to emphasize content, principles and theories of science that were not linked together and not related to real life. This neither enhanced students' thinking nor supported students to achieve in the scientific process (ONEC, 2001). Teaching and learning science at the elementary level continued to emphasize lecturing, reading, writing and memorizing content more than the development of scientific process skills (ONEC, 2001; Soydhurum, 2001).

After the passing of the Act and the reform of science education, the whole system of science education was changed including teaching and learning science at the elementary level (Grade 1-6). The new science curriculum, the National Science Curriculum Standards, which supports the goals of scientific literacy, mentions only core scientific concepts and places more emphasis on the inquiry approach.

Additionally, schools are expected to develop their own science curriculum based on their localities and communities and to engage in teaching and learning science according to their own contexts (ONEC, 2001). However, the Report of the Thai Education Condition 2549/2550 (Chiengkui, 2007) found that most school-based curriculum development paid more attention to content rather than process and did not emphasize authentic instruction. Additionally to these reports, Thai teachers have no confidence to develop and use the curriculum because they lacked experience and felt uncomfortable with its originality. With regards to science instruction, some teachers rarely change their teaching behavior; they still taught by lecture following the books and they seldom used a variety of teaching methods in their instruction. The report also pointed out that most elementary school teachers who teach science have no degree in teaching science and lack an understanding of scientific process skills. These teachers also do not have enough time to develop their science teaching skills and techniques because of the high workloads at their schools (ONEC, 2001; Soydhurum, 2001; Chiengkui, 2007). This educational situation seems to look similar to the international finding that insufficient knowledge of science content and NOS, and a lack of teaching skills, has resulted in a lack of confidence and negative attitudes towards science and the teaching of science among teachers (ONEC, 2001; Akerson and Hanuscin, 2007).

Nature of Science

Understanding NOS has been an important component of scientific literacy and an ultimate goal of science education in many countries for a long time (AAAS, 1990; NRC, 1996; Abd-El-Khalick and Lederman 2000; Wang, 2001; IPST, 2002). Misconceptions and/or inadequate conceptions about what science is, how it works, how scientists go about doing their work, and the relationship of science in our everyday lives are still pervasive in our science classrooms. Therefore, helping students develop adequate understandings of NOS is an important objective for science education.

What does the term 'Nature of Science' mean?

Other than a tentative definition that includes characteristics of science, there is no absolute definition for 'nature of science' that fully describes all scientific knowledge and enterprises (Schwartz and Lederman, 2002) and there is always likely to be an active debate at the philosophical level about what such a definition should include (McComas *et. al*., 1998). Consequently, in many NOS studies, one will see 'Nature of Science' instead of the more stylistically appropriate 'the Nature of Science'. Using ‘Nature of Science’ implicitly implies that there is no one single agreed upon definition (Lederman, Abd-El-Khalick, Bell, and Schwartz, 2002; Schwart Schwartz, Lederman, and Crawford, 2004). There are, however, many definitions and elements for NOS that have been considered by science educators.

To answer the question “What is nature of science?” it might help to consider the familiar question, “What is science?” There are three common answers to this question: Science is a 1) Body of Knowledge, 2) Method/Inquiry, and 3) Way of Knowing. By these three characteristics, nature of science generally refers to 'the characteristics of scientific knowledge that are derived from how the knowledge is developed (i.e., scientific inquiry)' (Lederman, 2006). Nature of science is concerned with how actual science is done and how scientists go about doing their work. However, there are many considerations about the definitions and characteristics of NOS.

Lederman (1992) has defined the phrase NOS encompassing the field of epistemology. It is, “The epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge." Ryder, Leach and Driver (1999: 202) have defined NOS in another aspect by emphasizing on the social studies of science as, “The one who understands about the social practices and organization of science and how scientists collect, interpret and use data to guide further research." The ‘nature of science’ also refers to, “The values and underlying assumptions that are intrinsic to scientific knowledge, including the influences and limitations that result from science as a human endeavor” (Schwartz, Lederman, and

Crawford, 2004: 611). Therefore, the phrase NOS is often used by science educators to refer in many issues such as, "What science is, how it works, the epistemological and ontological foundations of science, how scientists function as a social group and how society influences and reacts to scientific endeavors" (Clough and Olson, 2008: 144).

McComas *et al.* (1998) provide a good overall description of the NOS in the following paragraph:

> The nature of science is a fertile hybrid arena which blends aspects of various social studies of science including the history, sociology and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors (McComas *et al.*, 1998: 4).

The definitions and perspectives for NOS have continuously changed among historians, philosophers and sociologists of science and education through the years. Changes of perspectives on NOS are reflected in the ways the science education community has attempted to define NOS over the past 100 years. In the early 1900's, NOS was defined in terms which increased the emphasis on the 'scientific method'. In the 1960's, the NOS objectives were concentrated on inquiry and science process skills. By the 1970's, the NOS was apparently defined; it had been included as a critical component of scientific literacy. In that era NOS was defined in terms of characteristics of scientific knowledge, for example, being tentative, public, replicable, probabilistic, humanistic, unique, holistic and empirical. By the 1980's, many additional characteristics of NOS started to appear in definitions of NOS; such as, the theory-laden nature of observation, the role of human creativity in developing scientific explanations, the social structure of scientific organization and the role of social discourse in validating scientific claims (Abd-El-Khalick and Lederman, 2000).

More recently, many science education documents have delineated the basic components that underlie an adequate understanding of NOS. For example, Science for All Americans (AAAS, 1990) has emphasized teaching three elements of NOS: the scientific world view, scientific methods of inquiry and the nature of the scientific enterprise. First, in explaining the scientific world view, students should understand that scientific knowledge is both stable and subject to change. Science investigations generally work the same way in different places, but the results of similar scientific investigations seldom show exactly the same thing, because of different methods or situations. Second, in their study of scientific inquiry, students should understand that scientific investigations may take many different forms, including observing and using tools, collecting specimens for analysis and doing experiments. The scientists' explanations come partly from what they observe and partly from what they think. Third, in teaching about the scientific enterprise, four aspects should be exposed: its social structure, its discipline and institutional identification, its ethics and the role of scientists in public affairs.

Common aspects of nature of science

In addition to these arguments and disagreements that are waged by historians and philosophers of science, the question of whether these issues are of any real importance to students' studying, especially in the elementary level is also a matter of debate. According to McComas *et al*. (1998), advocacy for students' understandings of science and its nature is not a new concept in education. It was seen as an important goal for students' learning science 100 years ago. While it was not called NOS, scientific method and processes were previously viewed as goals worth pursuing in science education (McComas *et al.*, 1998). However, even though there is no firm agreement to exactly what aspects should be taught for elementary students, the key aspects of NOS that are appropriate for inclusion in the K-12 science curriculum have begun to emerge from a review by science educators of the extensive literature in the history and philosophy of science.

Aikenhead and Ryan, (1992: 477) stated, “The aspects of the nature of science that are considered to be important objectives of science education include understanding the nature, production and validation of scientific knowledge; the internal and external sociology of science; and the people and processes of science."

Brickhouse, Dagher, Letts and Shipman (2000:340) believe, “What is included as nature of science content draws upon an extensive literature in science studies that include philosophy, sociology and history. Thus, what is emphasized in nature of science content can vary considerably."

McComas (2004) suggested a concise set of nine key ideas which provides a list of objectives for elementary teachers, to shape their instruction in science:

(1) Science demands and relies on empirical evidence;

(2) Knowledge production in science includes many common features and shared habits of mind; however, there is no single step-by-step scientific method by which all science is done;

(3) Scientific knowledge is tentative but durable (This means that science cannot *prove* anything but scientific conclusions are still valuable and long lasting because of the way in which they are developed but mistakes will be discovered and corrected as part of the process);

(4) Laws and theories are related but there are distinct kinds of scientific knowledge. Hypotheses are special, but a general, kind of scientific knowledge;

(5) Science is a highly creative endeavor;

(6) Science has a subjective element (Ideas and observations in science are 'theory-laden'; this bias potentially plays both positive and negative roles in scientific investigation);

(7) There are historical, cultural and social influences on the practice and direction of science;

(8) Science and technology impact each other, but they are not the same; and

(9) Science and its methods cannot answer all questions. (In other words, there are limits on the kinds of questions that can be asked of science)

Furthermore, Abd-El-Khalick and Lederman (2000) suggested the seven aspects of NOS that are non-controversial and accessible to K-12 students and which are also considered to be relevant to their daily lives. It is at a certain level of generality that connections between students' knowledge about science and the decisions they make regarding scientific claims are visible (Abd-El-Khalick, Bell, and Lederman, 1998). The seven aspects of NOS that they believe are important for K-12 students, and all citizens, to understand and appreciate are:

> …that scientific knowledge is tentative (subject to change); empirically-based (based on and/or derived from observations of the natural world); subjective (theory-laden); partly the product of human inference, imagination and creativity (involves the invention of explanation); and socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the function of, and relationships between scientific theory and laws. (Abd-El-Khalick, Bell, and Lederman, 1998: 418)

Furthermore, these core aspects are identified and described according to the aforementioned reform documents. In addition, Lederman *et al*. (2002) proposed that each of these NOS aspects should be construed in the context of K-12 science education rather than the context of educating graduate students in philosophy or history of science and these aspects could be approached at different levels of depth and complexity depending on the background and grade level of students. Therefore, each aspect of NOS will be discussed in detail by dealing with students' learning context.

The Evidence-based Nature of Scientific Knowledge

Scientific knowledge, that aims to explain about natural phenomena, is at least partially based on observations of the natural world, and 'sooner or later, the validity of scientific claims is settled by referring to observations of phenomena' (AAAS, 1990). Eventually, the validity of scientific claims is established by referring to observations of phenomena. Consequently, scientists give more attention to acquire accurate data. Such evidence is obtained by observations and measurements taken in situations that range from natural settings to completely managed ones (such as the laboratory) (AAAS, 1990). To make their observations, scientists use their own senses and instruments that enhance those senses. Scientists observe passively, make collections and actively probe the world. In some situations, scientists can control conditions consciously and precisely to obtain their evidence. Nevertheless, scientists do not have direct access to most natural phenomena such as impractical or directly observable conditions (e.g. studying stars, in people or in distinction animals). In such cases, observations of nature are always filtered through our perceptual apparatus and/or intricate instrumentation, interpreted from within elaborate theoretical frameworks, and almost always mediated by a host of assumptions that underlie the functioning of scientific instruments (Lederman *et al*., 2002).

The Tentative Nature of Scientific Knowledge

Scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations. This knowledge, including facts, theories and laws, is subject to change. Scientific claims could be changed based on gaining new evidence, scientists have made possible claims through advances in thinking and technology, and as extant evidence is reinterpreted in the light of new theoretical advances, changes in cultural and social values, or shifts in the directions of established research programs. Tentativeness in science does not happen solely from the fact that scientific knowledge is inferential, creative, and socially and culturally embedded (Lederman *et al*., 2002). Therefore, all other aspects of NOS provide rationale for the tentativeness of scientific knowledge. The Science for All Americans (AAAS, 1996) proposes this characteristic of scientific knowledge as follows:

> …Change in knowledge is inevitable because new observations may challenge prevailing theories. No matter how well one theory explains a set of observations, it is possible that another theory may fit just as well or better, or may fit a still wider range of observations. In science, the testing and improving and occasional discarding of theories, whether new or old, go on all

the time. Scientists assume that even if there is no way to secure complete and absolute truth, increasingly accurate approximations can be made to account for the world and how it works.

On the one hand, scientific knowledge is durable and not easily changed. Although scientists reject the notion of reaching the absolute truth and accept some uncertainty as part of nature, most scientific knowledge is durable. The modification of ideas is the norm in science as powerful constructs tend to survive and grow more precise and to become widely accepted (AAAS, 1996).

Scientific Theories and Laws

The notion about theory and law is one of the most alternative conceptions held by teachers and students. They believe that a theory could become a law when it has been supported by a great deal of scientific evidence. In fact, theories and laws are different kinds of scientific knowledge which are created by scientists to interpret and describe phenomena. They both have substantial supporting evidence and one does not become the other (Lederman *et al.*, 2002). Furthermore, hypotheses in science may lead to either theories or laws with the accumulation of substantial supporting evidence and acceptance in the scientific community. Theories are as legitimate a product of science as laws. Laws describe relationships, observed or perceived, of phenomena in nature. On the other hand, theories are inferred explanations of natural phenomena and mechanisms for relationships among natural phenomena (Schwartz *et al*., 2004). More important, theories have a major role in generating research problems and guiding future investigations. Scientific theories are often based on a set of assumptions or axioms and posit the existence of non-observable entities. Thus, theories cannot be directly tested. Only indirect evidence can be used to support theories and establish their validity. In general, laws are descriptive statements of relationships among observable phenomena. For instance, Boyle's law, which relates the pressure of a gas to its volume at a constant temperature, is a case in point. Theories, by contrast, are inferred explanations for observable phenomena or regularities in those phenomena. For example, the kinetic molecular theory serves to explain Boyle's law. Students often (a) hold a simplistic, hierarchical view of the relationship between theories and laws whereby theories become laws depending on the availability of supporting evidence; and (b) believe that laws have a higher status than theories (Lederman *et al.*, 2002).

Methods to Do Science

One of the most widely held misconceptions about doing science is the notion that there is a single and step-wise way to do the scientific method. Although common features in the practice of science, like logical reasoning and careful data collection, are part of all good science, there is no universal set of steps that begin with 'defining the problem,' extend to 'forming a hypothesis', 'testing the hypothesis,' and finish with 'making conclusions' and 'reporting results.' Such a stepwise method has been portrayed to the students for a long time and this is one of the most common myths found in both teachers and students (McComas, 2004). Moreover, these steps may be effective as a research tool, but there should be no implication in classroom discussions that all scientists use such steps as a universal method and follow when they do science (McComas *et al*., 1998). Scientists apply various methods in doing research. It is true that scientists observe, compare, measure, test, speculate, hypothesize, create ideas and conceptual tools, and construct theories and explanations. However, there is no single sequence of activities that will unerringly lead them to functional or valid solutions or answers, let alone certain or true knowledge (Lederman *et al.*, 2002).

Many science lessons may start with asking the questions that lead to investigations and experiments for seeking conclusions. However, the teacher still needs to emphasize that there are many different routes to discover scientific knowledge (Schwartz *et al.*, 2004). Teachers should reflect that science in different disciplines implement investigations in different ways. Astronomers cannot manipulate nor do the experiment with the objects in the sky so the way they investigate the natural phenomena is different from that of the chemists who easily control levels of various compounds in their laboratories and monitor the effects of changing the quantity or quality of the compounds in a system. The methods used by scientists are dependent on circumstances and scientists are not compelled to use the traditional scientific method. Relating to other NOS aspects, imagination and creativity are important factors that let the scientists investigate and think in different ways, and these different types of investigations to provide different information and evidence are responsible to the tentative characteristic of scientific knowledge (Schwartz *et al.*, 2004).

Observation, Inference, and Theoretical Entities in Science

To explain about the natural phenomena, scientists make many observations and then attempt to explain what they observe. Lederman *et al.* (2000) proposed, “An understanding of the crucial distinction between observation and inference is a precursor to making sense of a multitude of inferential and theoretical entities and terms that inhabit the worlds of science. Examples of such entities include atoms, molecular orbital, species, genes, photons, magnetic fields and gravitational forces." Schwartz *et al.* (2004) proposed the difference between observation and inference as following:

> …Observations are gathered through human senses or extensions of those senses. Inferences are interpretations of those observations. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.

Students should be able to distinguish between observation and inference. Scientists observe the natural phenomena by making descriptive statements about the phenomena which are directly accessible to their senses or extensions of their senses. For example, objects released above ground level tend to fall to the ground. By contrast, to make inferences, scientists make interpretations from observed evidence. For example, objects tend to fall to the ground because of gravity. The notion of gravity is inferential in the sense that it can be accessed and/or measured only through its manifestations or effects, such as the perturbations in predicted planetary orbits due to interplanetary attractions, and the bending of light coming from the stars as their rays pass through the sun's gravitational field (Lederman *et al*., 2002).

Imagination and Creativity

Although science is reliant on the empirical evidence, the development of scientific knowledge not only involves making observations of the natural world, human imagination and creativity also play an important role for generating scientific knowledge. Imagination is a source of innovation. Scientists use imagination, along with logic and prior knowledge, to generate new scientific knowledge. Science involves the invention of explanations and theoretical entities, which requires a great deal of creativity on the part of scientists. For instance, this aspect of science, coupled with its inferential nature, entails that scientific entities such as atoms and species are functional theoretical models rather than faithful copies of reality (Lederman *et al*., 2002). Therefore, scientists do not only work with data and well-developed theories. Creativity and imagination is needed not only for constructing theories, but for hypothesis formation also (Martin, 1997). Often, scientists have only tentative hypotheses about the way things may be. Such hypotheses are widely used in science for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of data. In fact, the process of formulating and testing hypotheses is one of the core activities of scientists. To be useful, a hypothesis should suggest what evidence would support it and what evidence would refute it (AAAS, 1996). Therefore, scientific concepts do not emerge automatically from data or from any amount of analysis alone. For inventing hypotheses or theories, the imagination is used by scientists to figure out how the world works and how they can put reality to test, like writing poetry, composing music or designing skyscrapers (AAAS, 1996).

The Subjectivity and Theory-Laden Nature of Scientific Knowledge

As you know scientific knowledge is empirically based, scientists try to be open-minded and apply mechanisms such as peer review and data triangulation to improve objectivity. On the other hand, personal beliefs, values, intuition, judgment, creativity, opportunity and psychology all play a role in scientific activities. Additionally, science and scientists are influenced by the society, culture and discipline in which they are embedded or educated (Chen, 2006). All scientists' background factors (e.g., theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences and expectations) form a mindset that affects the problems scientists investigate and how they conduct their investigations, what they observe (and do not observe), and how they interpret their observations. This (sometimes collective) individuality or mindset accounts for the role of theory in the production of scientific knowledge (Lederman *et al*., 2002). Contrary to common belief, science never starts with neutral observations (Popper, 1992). Observations (and investigations) are always motivated and guided by, and acquire meaning in reference to questions or problems, which are derived from certain theoretical perspectives (Lederman *et al*., 2002). This is also echoed by Chalmers (1999) who writes, "What observers see, the subjective experiences that they undergo, when viewing an object or scene is not determined solely by the images on their retinas but depends also on the experience, knowledge and expectations of the observer."

The Social and Cultural Embeddedness of Scientific Knowledge

Science is a human endeavor and is influenced by the society and culture in which it is practiced. The values of the culture determine what and how science is conducted, interpreted, accepted and utilized. Science, it follows, affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy and religion (Lederman *et al*., 2002). A good example of the effect of politics and religion on science is illustrated by the story of Galileo. Galileo supported the Copernican System which stated that the sun, and not the earth, was the centre of the universe. Because this belief was contradictory to the prevailing religious beliefs, Galileo was called to appear before the Inquisition in Rome in 1633. He was charged with heresy and was placed under house arrest where he remained until his death in 1642. Pope John Paul (II) eventually pardoned Galileo, some 400 years after the fact. It is important to teach students, however, that not all cultural influences are negative (Allchin, 2004). Charles Darwin, for another example, was steeped in Victorian ideas about the competition that existed in society. These ideas, in turn, helped to shape his thinking on the concepts of natural selection (Allchin, 2004).

At last but not least, however, these core aspects interdependent. Schwartz *et al*. (2004) proposed, “None of these aspects can be considered apart from the others. For example, tentativeness of scientific knowledge stems from the creation of that knowledge through empirical observation and inference. Each of these acts is influenced by the culture and society in which the science is practiced as well as by the theoretical framework and personal subjectivity of the scientist. As new data is considered and existing data reconsidered, inferences (again made within a particular context) may lead to changes in existing scientific knowledge."

According to the National Science Curriculum Standard of Thailand, although the IPST does not provide a specific definition of NOS, it has specified three main elements concerning NOS. These elements work together, are in consensus with the common aspects previously mentioned above and are important for teaching and learning science. The three main elements of NOS included in scientific inquiry are defined as the development of scientific knowledge, the limitations of science, and the interrelationship between science, technology, society and the environment. These three elements are defined as follows:

1) Scientific inquiry is the development of scientific knowledge. Scientific knowledge has been gained by human attempts to use scientific processes in scientific inquiry and to solve problems by observing, investigating, researching and systematically gathering data. Therefore, the body of scientific knowledge is increasingly being constructed and continuously being transformed.

2) The limitations of science; scientific knowledge can be explained and verified. Science should be used as a reference in debates when new data and

evidence are discovered. Sometimes, there will be contradictions in the interpretation of the same data because scientists may interpret data in different ways and with different ideas, and as a result, scientific knowledge is subject to change.

3) The interrelationships among science, technology, society and the environment are represented in two groups of statements: (1) science and society - everybody in every part of the world can participate in science, so science is the result of the collective knowledge of humans. The communication and publication of scientific data for analytical and critical thinking increases scientific knowledge, and affects society and the environment. Research and use of scientific knowledge must be within the limitations of moral principles and ethics which are accepted by society and help to maintain the environment. (2) science and technology - scientific knowledge is an important foundation of technological development, whereas, technology is the process of developing and improving products by using scientific knowledge while cooperating with other disciplines, skills, experiences and the imagination and creativity of humans. Technology relates to resources, processes and management systems, so it must be used to benefit society and the environment (IPST, 2002).

Therefore, the descriptions of these common aspects of NOS are important for this study to focus and be embedded in. Their importance is not only their accessibility for students at all levels and relevance to their daily lives, but also as the guide for designing and developing the professional development program of this study.

Nature of Science in Science Education

The Role and Importance of Nature of Science in Science Education

An explicit understanding of NOS has long been considered as a linchpin component of scientific literacy and an important learning objective in the science curriculum (AAAS, 1993; NRC, 1996). A scientifically literate person should develop an understanding of the concepts, principals, theories and processes of science. Additionally, they should understand how science works, and have an awareness of the complex relationships between science, technology and society (Abd-El-Khalick and BouJaoude, 1997; Clough and Olson, 2004) Understanding how scientific knowledge is developed and knowing the relationship between theory and evidence may enable students to evaluate scientific claims thoughtfully, rather than responding with uncritical agreements or refusals (Hogan, 2000). Moreover, understanding how scientific knowledge has changed over time enables students to understand how their own scientific knowledge develops (Solomon, Duveen and McCarthym, 1992).

Teaching and learning science in the past required only the student acquire scientific facts. Although the facts, concepts, laws, theories and models of science are the basic forms of scientific knowledge, what is required for understanding science is the ability to integrate the components of the body of science knowledge, for the purpose of applying them to events, making predictions and establishing relationships between ideas (NRC, 1996). Additionally, Fouad Abd-El-Khalick claimed that science educators teach science as if it is the trusted means for determining truth. He stated that science instruction presumes that 'science is completely rational, objective, procedural, authoritative and free of cultural influence' (as cited in Chamberlain, 2004). He maintains that educators need to develop an approach to teach science that is more authentic to NOS. This would mean that 'science is not just evidence, but intuition. It is not just procedure, but creativity. Its conclusions are not set in stone, but ever-changing and open to question as part of a dynamic social enterprise' (Chamberlain, 2004). Therefore, understanding about science is not only understanding what scientific knowledge is, but also understanding NOS as what characterizes and constitutes of scientific knowledge.

Teaching NOS as one goal of science teaching was suggested by many science educators. For example Driver, Leach, Millar and Scott (1996) offered five arguments that illustrate why understanding NOS is important and necessary for scientific literacy. Their arguments were as follows:

1. Utilitarian: understanding the NOS is necessary to make sense of science and manage the technological objects and processes in everyday life.

2. Democratic: understanding the NOS is necessary for informed decision-making on socio-scientific issues.

3. Cultural: understanding the NOS is necessary to appreciate the value of science as part of contemporary culture.

4. Moral: understanding the NOS helps develop an understanding of the norms of the scientific community that embody moral commitments that are of general value to society.

5. Science learning: understanding the NOS facilitates the learning of science subject matter.

An additional suggestion offered by McComas *et al*. (1998) argues that a better understanding of what science is, the scientific community, and how science works will enhance students' learning of science content, understanding of science as a human endeavor and increased interest in science and science classes. The knowledge of the NOS also promotes better social decision making and improves instructional delivery. Students who possess an adequate conception of NOS will have an understanding of the scientific enterprise beyond the content knowledge it produces. They will begin to recognize the implications of science as a culturally based social endeavor and they will understand how the processes of science can still be defined and affected by human creativity and subjectivity (Lederman, 1999; Bell, Lederman and Abd-El-Khalick, 2000). Bell *et al.* (2000) found that students who read about the life and work of a scientist, or engaged in a case study about the development of a milestone advancement in scientific understanding, might develop awareness of issues such as the influence of scientists' personal knowledge, motivations, and commitments; their social, cultural, and professional contexts; existing theories; and prior research on the production and revision of scientific knowledge. Moreover, teaching science in a manner that reflects the conceptions of NOS not only enhances students understanding of science but can also influence teachers' instructional approaches. The teachers who engage in teaching about NOS have been found to make more use of inquiry-based or constructivist approaches in teaching science (Lederman, 1998; McComas *et al.,* 1998).

In the Thai science educational context, the teaching and learning of NOS has been considered as an important element of scientific literacy. The Institute for Promoting of Teaching Science and Technology (IPST) which established the National Science Curriculum standard explicitly recommends an understanding of NOS as an aim and objective of science instruction (IPST, 2002).

In Thailand, teaching and learning of science is based on the aims and objectives for the learners. There are at least six objectives for science education that is related to NOS:

1. To understand the scope, limitations and nature of science
2. To provide skills for discovery and creation in science and technology
3. To develop the thinking process, imagination, ability to solve problems, data management, communication skills and ability to solve problems, data management, and ability to make decisions
4. To be aware of relationships between science, technology, humans and the environment in terms of influence and impact on one another
5. To utilize knowledge and understanding of science and technology for the benefit of society and daily life
6. To bestow the scientific mind, moral and ethical sense of responsibility and proper values so that science and technology will be used constructively (IPST, 2002: 4).

Moreover, NOS is also recommended as an important standard for science teachers in Thailand. The Standards for Thai science teachers, which was set up by IPST, aims to enhance teaching ability that supports the development of students' scientific knowledge, thinking skills, learning process, attitudes, moral principles, ethics and values according to the National Science Curriculum Standard (IPST, 2002). The IPST endorses ten science teacher standards that comprise three important aspects, teachers’ knowledge, behaviors and abilities. The first standard is The Nature of Science and Technology which requires the teacher to:

- understand the nature of science and technology in its content and knowledge according to curriculum;
- understand ideas about the inquiry process and the problem-solving process;
- be able to use knowledge and understanding in generating learning experiences with meaningful science content for learners (IPST, 2002:18).

According to the Thai science teacher standards, teachers are required to have an adequate understanding of NOS and have abilities to teach NOS for promoting the students’ understanding NOS through inquiry process.

Assessing Views of Nature of Science

Research about student and teacher understandings of NOS has received increased interest in the international science education community. Lederman (1992: 332) presented a comprehensive review of the research on nature of science that dealt with:

a) Assessment of student conceptions of the nature of science;
b) Development, use and assessment of a curriculum designed to improve student conceptions of the nature of science;
c) Assessment of, and attempts to improve, teachers’ conceptions of the nature of science; and
d) Identifications of the relationship among teachers’ conceptions, classroom practice and students’ conceptions.

Early research about NOS was quite descriptive and simply tried to assess students’ conceptions of the scientific enterprise. These studies indicated that students typically do not acquire adequate conceptions of NOS and suggested this could be the result of a lack of curricular attention paid to NOS. Hence, significant research effort was directed toward designing, implementing and testing curricula that could convey accurate conceptions of NOS. The researchers also began to realize the role of teachers as the intermediaries of the curriculum. Teachers cannot be expected to teach what they do not understand and many studies showed that teachers possessed inadequate conceptions of NOS. Lederman (1992) noted that research concerned with improving teachers’ conceptions of NOS was guided by the assumption that teachers’ conceptions directly transferred into their classroom practices. This suggested that improvement of teachers’ NOS views could promote more effective NOS instructions in the classroom. As such, Lederman’s fourth line research related to NOS attempted to elucidate the relationship between teachers’ conceptions of NOS and their classroom practices.

Many related research on NOS have consistently shown that both students and teachers possess 'inadequate' or 'naïve' understandings of NOS. These misunderstandings are not consistent with contemporary ideas about NOS (Duschl, 1990; Lederman, 1992; Abd-El-Khalick and Lederman 2000; Wang, 2001). Views of NOS are assessed and divided into two main groups as what follow.

Traditional and Contemporary Views of Nature of Science

Science education has identified the distinctions between traditional and contemporary or constructivist views of NOS (Clough, 1997; Haidar, 1999). The traditional view emerges from two philosophical perspectives, the realist view and the empiricist or positivist view (Hung, 1997; Wang, 2001). The realist view likely refers to real entities or to present real images of the world that is more accurate than our commonsense (Hung, 1997). Regarding the development of scientific knowledge, empiricism claims that 'the power of senses as collecting apparatus in acquisition of knowledge', and 'experience from using senses as the only source of knowledge' (Hung, 1997: 261). Moreover, both of the two perspectives acquired not only the present real image of the world but also can be described in absolute terms, such as 'true', 'proven', 'confirmed', 'right', and 'correct' (Wang, 2001). Similarly, Haidar

(1999: 807) argued about the development of scientific knowledge in this traditional view, “Describing the universe as a great machine that performs the work for which it was called into existence. It suggests that we can observe, know and predict the inner workings of the universe from an objective vantage position."

The opposing contemporary or constructivist view of science has its underpinnings in two other philosophical perspectives, instrumentalism and constructivism (Hung, 1997; Wang, 2001). Instrumentalism considers scientific theories and explanations as apparatus for understanding the world or 'instruments for ordering perceptions' (Munby, 1983:150; Hung, 1997:213). It can be argued that scientific models are only instruments for scientific explanations which may not represent reality (Hung, 1997). Haidar (1999: 808) also writes, “Contemporary work in physics and philosophy of science has challenged fundamental beliefs of the traditional view and has provided enough ground to establish what is known today as the constructivist view." Constructivism proposes that 'knowledge is not discovered, but that it is a human construction (and is always subjective)' (Wang, 2001: 10). The constructivist view of science understands the world in different ways, for example, we can no longer observe, know and predict the universe objectively. Our observations are theory laden, or in other words, what we observe is influenced by the theories we carry. Haidar (1999) reviewed the examples of the differences between the basic beliefs underpinning ‘Traditional and Contemporary’ views of science as showing in Table 2.1 as follows.

Table 2.1 The Differences between the Basic Beliefs Underpinning Traditional and Contemporary' Views of Science

Traditional View	Contemporary View
- Science is merely a means of revealing the natural laws of God that regulate a clockwork universe.	- Science is viewed as a set of socially negotiated understandings of the universe.
- The only way to gain scientific knowledge is through the application of the induction method. Scientists are objective and free from illusion and myths of the past.	- Knowledge is accepted as viable by the scientific community. There are other ways to gain scientific knowledge, not an absolute scientific method.
- Scientific knowledge is absolute and devoid of creativity and human imagination.	- Scientists are influenced by prior knowledge, social factors and other influences. Scientific knowledge is intuitive.

Source: Adapted from Haidar (1999: 807-808)

Research that aims to assess teachers' views of NOS has found that, generally, teachers hold a traditional or naïve view regarding aspects of NOS, including the tentative NOS, empirical evidence, human inference, human creativity and imagination (Akerson *et al.*, 2000; Wang, 2001; Khishfe and Abd-El-Khalick, 2002; Akerson and Volrish, 2006; Khishfe and Lederman, 2007), the role of a scientist, the scientific method as a step-by-step process (Haidar, 1999), and scientific theory and law (Haidar, 1999; Akerson *et al.*, 2000). Table 2.1 summarizes the core conceptions of NOS that are associated with traditional and contemporary perspectives.

Table 2.2 The Core Conceptions of NOS Associated with Traditional and Contemporary Perspectives

Aspects of NOS	Traditional View	Contemporary View
Scientific knowledge	- Scientific knowledge corresponds directly to reality. - Scientific knowledge is final, not tentative. - Scientific knowledge is first generated only through observations. - Science is about the facts and could not be influenced by cultures and society.	- Scientific knowledge is our understanding of reality, not reality as it is. - Scientific knowledge is tentative. - Scientific knowledge might also be generated through imagination or creativity. - Of course culture influences the ideas in science.
Scientific theories and laws	- Theories are based directly on observation, where observation is exactly what you see. - Scientists discover theories, because the theories are there in nature. - A theory is a hypothesis that has been proven to be correct. - Scientific models (e.g. the model of the atom and neurological cell) are copies of reality. - Scientists discover scientific laws, because the laws are there in nature.	- Observation is influenced by theories scientists hold. - Scientists invent theories, because theory invention comes from the mind. - A theory is validated by its connection to other theories generally accepted within the scientific community. - Scientific models do not describe reality as it is. They are scientists' ideas. - Scientists invent scientific laws, which describe what nature does.

Table 2.2 (Continued)

Aspects of NOS	Traditional View	Contemporary View
Scientific method	- There is a single method to perform science that is the scientific method. - The scientific method is a step-by-step process. - The use of the scientific method is necessary to discover and validate theories. - An experiment is a sequence of steps performed to prove a proposed theory.	- There is no single method to perform science. There are other methods, e.g. creativity, imagination. - Scientists do not necessarily have to follow sequence of the scientific method. - Scientists use several methods according to circumstances. - An experiment cannot prove a theory or a hypothesis. It just discredits or adds validity to them.
Role and work of a scientist	- A scientist evaluates scientific claims exclusively through empirical evidence. - A scientist is someone who is objective and open minded in all of his acts. - The best scientists are those who follow the steps of the scientific method. - A scientist strives to discover the absolute truth.	- A scientist does not exclusively need to use empirical evidence; he may use imagination or creativity. - A scientist is influenced by many factors, e.g.: previous knowledge, logic and social factors. - The best scientists are those who use any methods that might obtain favorable results. - A scientist works within the scientific community to find the best way to explain part of nature.

Sources: Adapted from Lederman *et al*., (2002) and Haidar (1999: 821)

Sometimes, conceptions of NOS can be categorized into three possible groups: traditional views, contemporary views and a mixture of traditional and contemporary views (Haidar, 1999). Additionally, these conceptions have been characterized using other categorization systems including: misconception/appropriate conceptions of NOS (Tairab, 2001), naïve/informed views of NOS (Akerson *et. al*., 2000, Khishfe and Lederman, 2007), and adequate/inadequate conceptions of NOS (Irez, 2006).

Instruments for Assessing the Teachers' Views of Nature of Science

Most of the instruments used to assess teachers' views and approaches towards NOS assessment over the past 40 years are standardized and rely on traditional paper and pencil instruments. For example, the *Nature of Science Scale (NOSS)* which was developed by Kimball (1968) to determine whether or not science teachers have the same view of science as scientists, *Nature of Science Test (NOST)* which was proposed by Billeh and Hasan (1975) to measure teachers' knowledge of the assumptions and processes of science, and the characteristic of scientific knowledge, and *Views of Science Test (VOST)* which was suggested by Hillis (1975) to measure teachers' understandings about the tentativeness of scientific knowledge (Lederman *et al*., 1998). Because these instruments are composed of forced-choice items, such as agree/disagree, Likert-type scale, or multiple choice, two major criticisms about the instruments' validities emerged (Abd-El-Khalick and Lederman, 2000). The first criticism is related to the assumption that respondents perceive and interpret an instrument's items in a manner similar to that of the developers. Another one is the problem that standardized instruments usually reflect their developers' views and biases regarding NOS. In order to avoid these problems, the strategies to assess teachers' views of NOS in the late 1980s shifted from being more quantitative to more qualitative in nature, utilizing more flexible approaches, such as small group discussion (Solomon, 1991), situated-inquiry interviews (Ryder *et al.*, 1999), reviews of lesson plans and documents, field observations of classrooms and teachers, concept maps, and case studies (Chen, 2006).

One method researchers used to reduce the likelihood of misinterpreting respondents' views was individualized interviews. This allowed respondents to express their own views on issues related to NOS. It also allowed researchers to assess not only the reasons for adopting those positions on certain issues related to NOS, but the respondents' reasons for adopting those positions as well (Abd-El-Khalick and Lederman, 2000). These instruments were developed responding to improve the validity of instruments using open-ended questionnaires combined with individual interview, for example, the Views of Nature of Science Questionnaire (VNOS) (Lederman *et al*., 2002).

The original form of the VNOS questionnaire was developed by Lederman and O'Malley (1990) and consisted of seven open-ended questions. It was used in conjunction with follow-up individual interviews to assess high school students' views of the tentative NOS (Abd-El-Khalick, Lederman, Bell, and Schwartz, 2001). In 1998, the questionnaire was modified twice and the updated form (Form C) uses 10 open-ended questions that challenge the participants to fully express their views in 40-60 minutes (Abd-El-Khalick *et al.*, 2001). Lederman *et al*., (2002: 502) argues, "The VNOS is different in underlying assumptions and form from standardized and convergent instruments," because it aims to elucidate participants' views of NOS and to report the teaching and learning of NOS rather than label the participants' views as adequate or inadequate or sum their understandings into numerical scores.

The VNOS questions assess the participants' views about several aspects of NOS such as whether scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (theory laden), necessarily involves human inference, imagination, and creativity (involves the invention of explanations), necessarily involves a combination of observations and inferences, and is socially and culturally embedded. One additional aspect that has been regarded as closely related to The VNOS also assesses understanding of observation and inference and the relationships between, scientific theories and laws (Lederman, 1999). The significance of these aspects is that when considered together, they cover the description of what NOS is and help reveal a complete image of the participants' understandings about NOS (Irez, 2006).

Teachers' Views of Nature of Science

Research indicates that teachers' views of NOS is generally limited, simplistic, unclear and inadequate for teaching the NOS to support scientific literacy (Lederman *et al.*, 1998; Akerson *et al.*, 2000; Akerson and Abd-El- Khalick, 2003). The teachers' views are not consistent with contemporary conceptions of NOS (Duschl, 1990; Lederman, 1992). Research also suggests that both pre-service and in-service science teachers hold similar views regarding the NOS (Haidar, 1999; Tairab, 2001).

Regarding the process of science, teachers generally seem to have naïve views. They do not have clear understandings of the role of the scientist in creating explanations about the world (Abell and Smith, 1994). They tend to see science as individual work, rather than social or collaborative work and as an objective endeavor with scientists detached from their work (Akerson *et al.*, 2000). For the relationship between science and technology, it has been found that most teachers do not distinguish between science and technology. They describe technology as the application of science to enhance life and view science as a tool to solve problems in our world (Rubba and Harkness, 1993). Tsai's (2002) work indicates that teachers' understandings of NOS are 'nested with' or closely related to their views of learning and teaching, as well as their attitudes toward the capabilities of students to learn science.

Teachers' conceptions of NOS appear to be independent from other investigated variables including teachers' prior science content knowledge, science achievement, and academic achievement (Scharmann, Smith, James, and Jensen, 2005). Moreover, teachers' conceptions of NOS are also not related to other cognitive variables such as logical thinking ability; social personal variables such as locus of control orientation (Scharmann *et al.*, 2005); and personal attributes such as gender (Wood, 1972). In addition, conceptions of NOS are not related to the teachers' teaching level, science subject taught, in-service professional training, field-based teaching experiences and years of teaching experience (Billeh and Hasan, 1975; Abd-El-Khalick and Lederman, 2000).

Research with elementary teachers indicates most teachers have not heard the term ‘nature of science,’ and when they see it in their state frameworks they misinterpret the term as meaning something to do with nature, not as the essence of science itself. These teachers cannot teach about NOS without first improving their own views (Akerson and Abd-El-Khalick, 2003). Informed by the wide range of work within both science education and educational psychology, it can be seen that research into teachers’ understandings of NOS must be broad and multifaceted, and take into account epistemological beliefs, motivations, goals, learning dispositions, knowledge within and beyond the content of NOS, religious beliefs, as well as views of learning and learners.

To date only a limited number of studies have looked at Thai teachers’ conceptions of NOS. Researchers have surveyed teachers’ understandings of NOS by using similar standardized assessment instruments. These studies intended to label the participants’ understanding of NOS as 'adequate' or 'inadequate' or assigned their understandings using numerical scores without elucidating and clarifying further what the teachers understand. There is also some variability and disagreement concerning the findings among researchers (Kingsoda, 1999; Taiyarat, 1999; Meesarphan, 2000; Guanamol, 2000; Srivinet, 2000, Vadeesirisuk, 2001). Researchers have found that, in general, Thai teachers seem to have an adequate understanding of the NOS as confirmed by statistical evidence. However, when focusing on each specific aspect of the NOS, they found that teachers had an inadequate understanding of some aspects, especially the characteristics of scientific knowledge (Promkatkeaw, 2007; Yutakom and Chaiso, 2007). Pholthum (1997) noted that possible reasons for teachers’ lack of understanding of the nature of scientific knowledge might be because they did not learn these aspects in their science content courses or in any science training programs. Teachers are left to construct their own understandings of these ideas through their general experience and their teaching and classroom observations.

Nature of Science in Classroom Teaching Practices

If science teachers are to improve their conceptions about NOS, then it is the teacher educators' role to facilitate this through effective curriculum planning and delivery, including the development of appropriate teaching strategies. Research studies have shown that teachers still hold misconceptions or naïve conceptions of NOS, and therefore have difficulty teaching an appropriate view to students (Akerson *et al.*, 2000). Tsai (2006) explored teachers' scientific epistemological views and their relationships to their instruction as well as students' views and found that teachers who held more positivist views spent more time in teacher-directed activities, while teachers with more constructivist views focused more on students' understandings, inquiry and/or discussion processes. Moreover, his research found that both students and teachers in the classes held similar epistemological views. So it could be indicated that teachers' views of the classroom culture were directly related to the students' views.

Bartholomew, Osborne, and Ratcliffe (2004) believe that most science teachers teach science by focusing on 'what we know' (i.e. scientific facts), rather than "how we know" (i.e. NOS). What NOS should be taught to students and the developmental appropriateness of NOS ideas are crucial decisions that are still being addressed in the science education community.

An important consideration in many reform documents for teaching and learning science is that students are not only expected to learn science content but also acquire scientific attitudes, scientific process skills and discern the complexity of scientific inquiry. Many reform efforts have emphasized the importance of developing images of science that are consistent with current scientific inquiry and the constructivist perspective (AAAS, 1993, Driver *et al.*, 1996, Schwartz *et al.*, 2004).

Underlying the currently advocated pedagogy, the constructivist learning approach, an understanding of NOS and scientific inquiry are recommended as the essence of many standards documents, for example, the National Science Education

Standards. It can be argued that a teacher who lacks adequate conceptions of NOS and scientific inquiry, and a functional understanding of how to teach these valued aspects of science cannot organize the teaching and learning of science according to the several reform efforts (Lederman, 2006).

The NOS and constructivism has been recognized as having a close relationship in many aspects. Matthews (2000) argued, “Constructivism is at its core, as it was with Piaget, an epistemological doctrine; and it is standards coupled with commitments to certain post-positivist, postmodernist, antirealist and instrumentalist views about the nature of science”(p. 165). Moreover, discussions of inquiry cannot be divorced from discussions of constructivism, because inquiry and constructivist teaching approaches seem to share many consensus educational objectives, such as emphasizing students’ construction of concepts and the relationship between student acquisition of concepts and the concepts’ development in the history of science (Abd-El-Khalick, Boujaoude, Duschl, Lederman, Mamlok-Naaman, Niaz, Treagust and Tuan, 2004). In general, constructivism recognizes the learner as the center of knowledge and advocates the role for teachers as facilitators of knowledge construction, rather than as transmitters of information (Hofer and Pintrich, 1997). Inquiry, collaborative learning, discussion and debate, hands-on experiences and private reflections all appear in the development of ‘interactive constructivism.’

Despite numerous attempts to improve students’ views of the scientific endeavor, students have consistently been shown to possess inadequate understandings of several aspects of NOS (Lederman, 1992; Lederman and O’Malley, 1990). Lederman and Lederman (2004: 36) indicated the reason for these problems is twofold. “First, there is much confusion about nature of science (it is often confused with inquiry) and second, there are few research-based resources available to teachers to facilitate the teaching of nature of science.”

Inquiry is a term used in science teaching that refers to a way of questioning, seeking knowledge or information, or finding out about phenomena. The National Science Education Standards’ vision of inquiry includes the processes of science and requires that students combine processes and scientific knowledge as they use scientific reasoning and critical thinking to develop their understandings of science. According to the Standards, Hassard (2004) mentioned that engaging students in inquiry helps them develop:

- An understanding of scientific concepts;
- An appreciation of 'how we know' what we know in science;
- An understanding of the nature of science;
- The skills necessary to become independent inquirers about the natural world;
- The dispositions to use the skills, abilities and attitudes associated with science.

Therefore, the recommendations to improve conceptions of NOS strongly emphasize the use of inquiry in science instruction (AAAS, 1993; NRC, 1996; Schwartz *et al.*, 2004). Using inquiry teaching strategies can serve as an instrument for teachers to learn NOS because these strategies closely resemble how scientists go about their work (Akerson and Hanuscin, 2007). It seems logical that for teachers to have a chance of developing an appropriate understanding of NOS they should participate in scientific inquiries that are similar to what scientists engage in as they do their work. Simply having teachers memorize science content or engage in 'cookbook' activities is not conducive to an implicit understanding of NOS (Akerson and Hanuscin, 2007).

Additionally, for effectively portraying NOS, it is important to consider the difference between teaching NOS and teaching scientific process. More often, teachers assume that their students will come to understand NOS because they have them conduct activities and experiments (Lederman and Abd-El-Khalick, 1998). While NOS and scientific processes do overlap and have interactions together, they are not the same concept. Hipkins, Barker, and Bolstad (2005) have argued that if teachers themselves do not understand the distinction between scientific processes and NOS, then they may truly believe that their students are learning about the NOS as they carry out activities and experiments. This is especially true if these activities and experiments follow what they perceive to be the scientific method. For instance, while learning what observations are and how to make them are important science process skills, the understanding of what guides and limits these observations are part of the NOS domain. Therefore, ‘engaging in inquiry and learning about science process skills are not equivalent to learning about NOS.’ As follows, Abd-El-Khalick *et al*. (1998) considered that scientific processes are activities related to the collection and interpretation of data, and the derivation of conclusions. For example, observing and inferring are scientific processes. On the other hand, NOS refers to the epistemological commitments underlying the activities of science. Consequently, an individual’s understanding that observations are constrained by our perceptual apparatus and are inherently theory-laden is part of that individual’s understanding of NOS. However, it is not important to distinguish the two.

Nature of Science Teaching Approaches

To promote student understanding of NOS, there are a number strategies that have been shown to be effective. These can be categorized into three main groups:

1) Explicit inquiry based teaching approaches;
2) Historical teaching approaches;
3) Constructivist teaching approaches.

Explicit Inquiry Based Teaching Approaches

Some curricula assume that students will develop NOS conceptions aligned with accepted contemporary views simply by participating in inquiry-based activities (Lederman and Abd-El-Khalick, 1998; Schwartz *et al*., 2004). There are two main categories for teaching NOS through inquiry learning activities. An implicit inquiry-based pedagogical approach refers to the absence of specific attention to NOS, similar to the implicit messages within acts of inquiry. Such an approach assumes that even without specifying the aspects of NOS, students would automatically develop better conceptions of NOS as a by-product of engagement in science-based inquiry activities or science process skills instruction (Khishfe and Abd-El-Khalick, 2002; Schwartz *et al*., 2004).

An explicit inquiry-based pedagogical approach, in contrast, refers to providing inquiry-based learning opportunities with the added instructional component of specific knowledge attention to the aspects of NOS. It is widely believed that this approach can help students develop their conceptions of NOS through the use of discussion, guided reflection, and specific questioning in the context of activities, investigations and historical examples (Schwartz *et al*., 2004).

Studies that examine the use of implicit- and explicit-based inquiry approaches to improve learners' NOS conceptions have indicated that an explicit approach with the addition of a reflective component, when combined with classroom support for emphasizing certain aspects of NOS, is more effective than an implicit approach (Akerson *et al*., 2000; Khishfe and Abd-El-Khalick, 2002; Akerson and Abd-El-Khalick, 2003; Scharmann *et al*., 2005; Akerson and Volrich, 2006; Akerson and Hanuscin, 2007; Khishfe and Lederman, 2007). When employing this approach, researchers explicitly introduced the students to certain aspects of NOS and then provided them opportunities to reflect on these aspects. These reflections on NOS aspects can occur within the context of a science-based activity or science content they were learning (Khishfe and Abd-El-Khalick, 2002). Lederman and Lederman (2004) noted that while some students may independently reflect on what they are doing, the best way to ensure reflection for all students is to develop questions, and carefully plan their placement within the activity, to elicit reflective discussion.

There are a variety of NOS instructional strategies, models and activities designed based on this idea of the explicit and reflective approach that have been shown to be effective. For example, an explicit and reflective activity based approach which explicitly teaches the central aspects of NOS by using various activities and encouraging the students' thinking and reflecting upon their views of science (Akerson, Morrison, Lederman and Abd-El-Khalick, 1998; Akerson *et al*., 2000;

McDuffie, 2006). Some research studies use inquiry-based lab activities with reflection to help students to develop their understandings of NOS by allowing lab activities to be more open-ended to engage students in brief reflective discussions explicitly focusing on NOS (Clough, 1998; Tsai, 1999; Colburn, 2004; Schwartz *et al*., 2004). The inquiry-oriented approach is another strategy that explicitly teaches NOS by using inquiry methods such as the learning cycle (Bianchini and Coburn, 2000) and guided inquiry model (Khishfe and Abd-El-Khalick, 2002). Moreover, discussion about some controversial issues such as scientific debate about the applications of science is an effective strategy to explicitly teach NOS (Sadler and Zeidler, 2003; Narguizian, 2004).

Historical Teaching Approaches

The historical teaching approach is one of the most accepted approaches effective for developing an understanding of the NOS. Driver *et al.* (1996) pointed out that explicitly teaching about how scientific knowledge is developed would support students' successful learning in science and contribute to more successful use of scientific knowledge later in life. Many educators, however, use historical stories strictly to teach science content, in a narrow disciplinary mode, without any consideration for using history to teach lessons about NOS (Gauld 1993).

The historical approach suggests that incorporating the history of science into science teaching can augment students' views of NOS. Teaching that includes examples from the history of science is useful for generating discussions about NOS and promoting an understanding of the contextual NOS. Irwin (2000) showed that teaching the concept of the atom and the periodic pattern in atoms of elements via a series of historical episodes helps students understand that human creativity and the power of the imagination are important in the development of scientific knowledge. Allchin (2004) maintained that having students work through historical case studies of error is one of the most direct methods to teach them about the foundations and limitations of scientific knowledge. For example, students can come to understand how science works by investigating incidents of when science did not work and why the scientists of the time thought that it did.

There are a number of teaching and learning strategies that aim to develop the students' understandings of NOS regarding this historical approach. Some examples of these strategies are historical case studies (Gauld, 1993; Dawkins and Glatthorn, 1998; Nelson, Nickels and Beard, 1998; Abd-El-Khalick, 1999; Irwin, 2000), historical vignettes (Roach and Wandersee, 1995, Yip, 2006), historical short stories (Clough and Olson, 2004), history and philosophy of science through models (Justi and Gilbert, 2000; Bloom, 2001) and historical investigative approaches (Lawrenz and Kipnis, 1990; Kipnis, 1998).

Constructivist Teaching Approaches

A constructivist teaching approach is effective to encourage students to understand NOS. Constructivist theory maintains that learners participate in classrooms with their prior knowledge that affects new information received. Therefore, what a student learns emerges from the interactions between what is brought to the learning situation and what is experienced while in it (Wang, 2001). Research indicates that explicitly teaching NOS will not be sufficient to accommodate traditional preconceptions (Abd-El-Khalick and Akerson, 2004). Learning about NOS (like learning scientific knowledge) will not occur through replication but rather through reconstruction (Wang, 2001). Therefore, there are many studies using a constructivist teaching approach to develop students' understandings of NOS. Lin and Chen (2002) proposed that students' understandings about NOS could be enhanced through student-centered historical instruction that provides many activities for students such as discussion about scientists' original debates, project assignments and small group discussions. Some constructivist science educators have advocated the use of a conceptual change model to advance the understanding of NOS learning of pre-service teachers (Abd-El-Khalick and Akerson, 2004). Akerson *et al.* (2000) noted that while an explicit reflective approach to NOS instruction was found to be effective in improving some elementary teachers' views of NOS, the same reflective approach might be more effective if embedded within a 'conceptual change' framework.

Factors Influencing the Translation of Nature of Science into Practice

Research has consistently indicated that the relationship between teachers' conceptions of NOS and their classroom practices is very complex (Abd-El-Khalick and Lederman, 2000). The research exploring the relationship between teachers' conceptions of NOS and classroom practices has shown several variables that mediated and constrained the translation of teachers' conceptions of NOS into practice (Abd-El-Khalick and Lederman, 2000).

The constraining factors for translating the conceptions of NOS into practice include pressure to cover content, classroom management and organizational principles, concerns about student abilities and motivation, institutional constraints and teaching experience. Most of these constraints have been inferred by researchers rather than articulated by teachers as possible explanations for the lack of instructional emphasis on NOS (Bell *et al*., 2000). McComas *et al.* (1998) proposed that not only the role of the teacher, but also the role of textbooks and activities influenced students' understandings of NOS. All levels of science teaching and textbooks emphasize facture recall of science content. Science teachers rarely have opportunities to learn how science functions in their own studies and fail to emphasize that aspect of science to their students. Moreover, Trumbull, Scarano and Bonney (2006) and Waters-Adams (2006) found that the teachers' views and beliefs about NOS and their educations affected their teaching practices.

Bell *et al.* (2000) noted that the factors that mediate the translation of science teachers' views of NOS in their teaching were: (a) perceiving NOS as less significant than other outcomes, such as science content and processes, (b) concern for students' needs and attitudes, and (c) preoccupation with classroom management and routine chores. Additionally, factors such as discomfort with understanding NOS, lack of resources and experiences for teaching and/or assessing understandings of NOS, are also constraints specific to teaching the conceptions of NOS.

Teaching Nature of Science in Elementary School

NOS addresses what science is and how it works, exploring questions such as, 'How is science similar to and different from other human endeavors?', 'How durable is science knowledge?' and 'How do scientists do science?' Because NOS may entail some sophisticated issues, most efforts aimed to improve students' understandings of NOS have focused on the secondary level and higher, when students are older and more likely to comprehend these complex issues (Olson, 2008). The question of how science is taught in elementary school has a potentially profound impact on students' abilities to develop notions of NOS, for example, when students in elementary school are required to follow a step-by-step method for all classroom science activities, students understandably think this rigid approach is required when doing science (Olson, 2008).

Consequently, some researchers have suggested that NOS might best be taught to students early in their academic careers. Lederman and O'Malley (1990), for example, suggested that it may be more productive to address the problem earlier and at its roots rather than to remedy older students' inadequate images about science. Elementary school is a time during which students begin to be exposed to formal science instruction and acquire an understanding of the world around them (Bruer, 1993). Therefore, elementary school students may develop their own views on NOS and scientific knowledge. Given the complexity of NOS, what is taught about it in school science must be a simplification, and the science curriculum is needed to guide teachers in determining what about NOS is appropriate at particular grade levels, and how to teach and assess those targeted NOS ideas in developmentally appropriate strategies (Clough and Olson, 2008).

Research to Improve Teacher's Understanding and Teaching of Nature of Science

Research indicates that teachers play a central role in reform efforts to promote student understanding of NOS (Lederman, 1992; Abd-El-Khalick and Lederman, 2000). However, to engage in effective teaching of NOS, teachers must have not only adequate understandings of NOS but also knowledge of effective pedagogical practices relative to NOS and the intentions and abilities to merge these two elements in their classrooms (Schwartz and Lederman, 2002).

Regarding the attempts undertaken to improve science teachers' conceptions of NOS, Abd-El-Khalick and Lederman (1998) noted that these attempts used one of two general approaches. The first approach was implicit which suggests that an understanding of NOS is a learning outcome that can be facilitated through science process skills instruction, science content coursework and doing science. Researchers who adopted this implicit approach used science process skills instruction and/or scientific inquiry activities or manipulated certain aspects of the learning environment in their attempts to enhance teachers' conceptions of NOS. However, research indicates that this is insufficient to change teachers' epistemological beliefs (Lederman, Wade, and Bell, 1998).

The second approach was explicit which used elements from history and philosophy of science and/or instruction geared toward the various aspects of NOS to improve science teachers' conceptions. Abd-El-Khalick and Lederman (1998) concluded that the explicit approach was generally more 'effective' in promoting 'adequate' conceptions of NOS among prospective and practicing science teachers. Most attempts to improve science teachers' understandings of NOS, were undertaken in the context of pre-service elementary or secondary science methods courses (e.g. Abd-El-Khalick and Lederman, 2000) and workshops or intervention programs for in-service teachers (Akerson *et. al.*, 2000).

Assisting science teachers in developing their views of NOS is achieved best in the context of science content courses (Khishfe and Lederman, 2007). An explicit, reflective approach to NOS instruction that is embedded in the context of learning science content not only facilitates developing science teachers' views of NOS, but also can help teachers translate their understandings of NOS into classroom practices (Akerson *et al.*, 2000; Abd-El-Khalick, 2001).

For example, Akerson and Volrich (2005) studied a pre-service elementary teacher's efforts to explicitly emphasize teaching NOS elements in her classroom. The teacher held appropriate views of NOS and had the intention and motivation to teach NOS. The researchers found that the teacher was able to explicitly emphasize NOS using three teacher-designed methods, and that the influence on students' views of the target aspects of NOS was positive.

Lederman (1999) has noted, "Teachers' conceptions of science do not necessarily influence classroom practices." Also, many science educators have claimed that improving teachers' conceptions or views of NOS is necessary but insufficient for promoting effective instruction of NOS in the classroom (Abd-El-Khalick and Lederman, 2000). However, in-depth explorations of teachers' development of NOS knowledge, instructional intentions and approaches to NOS instruction have not been the focus of much research (Bell *et al.*, 2001). Studies are needed to inform those constructing professional development programs about the needs and limitations of teachers as they develop a knowledge base for teaching NOS.

Research has demonstrated the complexity associated with the translation of NOS knowledge into instructional behaviors (Abd-El-Khalick *et al.*, 1998; Lederman, 1999; Bell *et al.*, 2000; Lederman *et al.*, 2001; Akerson and Volrich, 2006). Research indicates that the translation of one's views into practice is influenced by a variety of contextual and personal factors including classroom management, constraints of the curriculum or instruction, time, concerns for student motivation and ability and teaching experience (Bell *et al.*, 2000). Other factors relate to teachers' NOS content knowledge and subject-specific pedagogical knowledge, such as teachers' discomforts with their understandings of NOS and abilities to assess students' conceptions of NOS, as well as their lack of knowledge of the resources to teach about NOS (Abd-El-Khalick *et al.*, 1998; Lederman *et al.*, 2001). In addition, it is suggested that a teachers' intentions and beliefs toward NOS influence classroom practices when attempting to teach about NOS (Lederman, 1999; Lederman *et al.*, 2001).

In order to teach NOS effectively from policy to practice, Bartholomew *et al.* (2004) have suggested that teachers should first have opportunities to adopt a more positive approach to teaching NOS. Hipkins *et al.* (2005) note the lack of specificity of NOS content and pedagogical practice guidelines in the science curriculum. They maintain that this poses problems for the teachers who must interpret it. It is difficult to make sense of this strand in the curriculum; thus this becomes the topic that they ignore when preparing for instruction. Therefore, teachers need help to develop authentic activities related to NOS (Bartholomew *et al.*, 2004).

Secondly, teachers need to improve their own knowledge of NOS before they can effectively address it in the classroom. Many science educators have mentioned that teachers need to have NOS pedagogical content knowledge (NOS PCK) (Abd-El-Khalick and Lederman, 2000; Akerson and Abd-El- Khalick, 2003; Hipkins *et al.*, 2005). That is, teachers should have knowledge which combines subject matter knowledge and pedagogical knowledge. In the case of NOS instruction, teachers should have adequate understandings or conceptions of various aspects of NOS as well as the knowledge of how to teach those aspects of NOS effectively. They should know how to use various instructional approaches, resources and media to appropriately teach the topics of science content in a way that helps students understand the target NOS aspects.

In order to help teachers develop knowledge, beliefs and intentions as well as classroom practices, effective teacher development programs rely heavily on the constructivist paradigm (Tobin, Tippins and Gallard, 1994). Wang (2001) designed a year-long in-service program and a series of intervention courses that helped teachers clarify and understand NOS, as well as classroom practices through the implementation of the constructivist teaching model.

In the Thai context, there is a lack of research not only on teachers' understandings of NOS but also regarding teachers' instruction of NOS. Previous studies have emphasized the use of paper-pencil standardized assessment instruments in order to determine teachers' understandings or conceptions of NOS. Research that explored Thai teachers' understandings and teaching of NOS found that the teachers' understandings of NOS were generally inadequate for science teaching. Teachers did not emphasize concepts of NOS as their goals for instruction or as students' learning outcomes (Meesri, 2007).

Research conducted by Promkatkeaw (2007) showed that Thai elementary teachers' views of NOS ranged from traditional to contemporary. Teachers do not recognize or appreciate the need to understand NOS as a cognitive learning outcome that requires explicit teaching and assessment. Rather, they use an implicit approach for teaching NOS with a heavier emphasis on studying scientific concepts and a smaller emphasis on doing scientific activities. She also discovered that these findings relate to the 'newness' of this sub-strand. In other words, teachers might not be sufficiently prepared to deal with this sub-strand in their classrooms (Promkatkeaw, 2007).

Professional Development

Importance of In-service Teacher Professional Development

Educators and researchers generally agree that teachers play a central role in making educational reforms successful. An important factor that enhances this success depends on proper implementation of the new curriculum in their classes. Teachers need opportunities to develop their teaching quality and proficiency over time to ensure that innovative curricula are effectively introduced and transferred into instructional practice (Bell and Gilbert, 1996). Castle and Aichele (1994) argue that professional knowledge cannot be transferred; it is constructed by each individual teacher who brings his or her life experiences as a learner. Teacher professional development can occur actively through interaction with new ideas, understandings and real-life experiences (Loucks-Horsley *et al.*, 2003). However, research in teacher professional development has found that it is difficult to change teachers' teaching practices; teachers tend to teach as they were taught (Akerson and Abd-El-Khalick, 2003) and often feel uncomfortable and unprepared to teach science (Goodnough, 2002).

Traditionally, in international contexts, because of teachers' limited understandings of reformed curriculum, researchers and educators have sought to manipulate teacher professional development by offering short workshops and training programs (Garet, Porter, Desimone, Birman and Yoon, 2001; Lin, 2002). Although teachers are exposed to theories of learning and teaching in some teacher education programs, they are often not able to apply this knowledge to classroom practice (Cooney, 1999; Jaworski and Wood, 1999). Teachers interviewed in several studies have indicated that training programs overemphasized theory, and reported that programs would be more effective if they combined theory with opportunities for practice and structured reflection (Castro, 1991).

Recently, some research on in-service professional development has focused on providing teachers with the opportunity to reflect on their own practices as a means for increasing knowledge in teaching (Wood *et al.*, 2001; Lin, 2002). Research on in-service professional development includes a mix of large- and small-scale studies, comprised of intensive case studies of classroom teaching (Lin, 2002; Dori and Herscovitz, 2005), evaluations of specific approaches to improve teaching and learning (Akerson and Abd-El-Khalick, 2003) and surveys of teachers about their pre-service preparation and in-service professional development experiences (Lin, 2002; Watzke, 2007). Although workshops, institutes, courses and seminars are dominant approaches to in-service teacher development, they do not address the needs of teachers who are looking for new strategies and instructional methods. Separate workshops can help to introduce and model techniques and strategies, but real change happens in an actual classroom with mentorship and support (Huffman, 2006).

In the context of Thai in-service teacher development, the training courses, workshops, and professional development programs are major strategies to teacher development (e.g. Meesri, 2007; Promkatkeaw *et al*., 2007; Yutakom and Chaiso, 2007). These kinds of teacher development strategies are typically conducted by the MOE, ONEC, OBEC, IPST and the educational institutions (Pillay, 2002). However, there are some limitations to these teacher development strategies. Pitiyanuwat (2000) argued that these training courses and/or few day workshops are unsystematic; the educational organizations which have worked on teacher development do not share their frameworks and responsibilities. These strategies also do not support all in-service teachers, do not pertinently serve teaches' needs, but rather, emphasize theory over practice. As a result, teacher development programs conducted by these organizations are fragmented and lack direction or focus. Furthermore, these organizations do not have enough capacity to provide support for all in-service teachers. Distance learning is an alternative model for teacher development which is operated and aims to support in-service teachers who have no opportunity to participate in any professional development training, courses, workshops and/or seminars. Although this strategy allows in-service teachers to study by themselves through a set of integrated media (e.g., reading materials, radio and video tapes, and e-learning), it has its own limitations. This strategy lacks collaborative activities among teachers and tends to not follow up on teachers' learning after getting a certificate (Brahmawong, 1993).

Another new strategy, which focuses more on teachers' actual practices in their schools and addresses teachers' needs, is school-based training. This strategy intends to reduce the gaps between educational experts and teachers as well as that between theory and practice. This teacher training is operated in order for teachers to actively engage in improving their own practices and initiating educational changes rather than to receive and implement educational innovations developed by others (Yutakom and Chaiso, 2007).

Characteristics of Successful Teacher Development Models

A major responsibility of teachers is to facilitate student learning; therefore, the ultimate purpose of providing teacher development is to improve their abilities to facilitate student learning (Hewson, 2007). To design teacher development programs, Bell and Gilbert (1996) proposed that it is important to emphasize three interactive and interdependent components of the teacher development model. The first component, personal development, includes promoting teacher awareness of a need for professional development and enhancing their desire to acquire new ideas or strategies. The second component is social development which includes giving the teachers opportunities to discuss ideas with other teachers and to collectively renegotiate what it means to teach science and be a science teacher. The third component involves providing support for teachers to embed new ideas and strategies in their classroom practices. These three components are viewed as essential to support teachers' changes within their own classrooms and professional communities. Akerson and Hanuscin (2007) argued that the personal development components can be useful in selecting participants while social development and professional development aspects of the model can be used in designing teacher development programs.

Kimble, Yager and Yager (2006) proposed fourteen contrasting characteristics of professional development included in the National Science Education Standard (NSES) summarized as 'less emphasis on' conditions (those which commonly characterize such efforts) and 'more emphasis on' conditions (those needed to realize the visions central to the NSES). These contrasts are presented in Table 2.3 as following:

Table 2.3 Fourteen Contrasting Characteristics of Professional Development

Less emphasis on	**More emphasis on**
- Transmission of teaching knowledge and skills by lectures - Learning science by lecture and reading - Separation of science and teaching knowledge - Separation of theory and practice - Integration of theory and practice in school settings - Fragmented, one-shot session - Long-term coherent plans - Reliance on external expertise - Staff developers as educators - Teacher as technician - Teacher as intellectual, reflective practitioner - Teacher as producer of knowledge about teaching - Teacher as an individual based in a classroom - Teacher as target of change	- Inquiry into teaching and learning - Learning science through investigation and inquiry - Integration of science and teaching knowledge - Individual learning: collegial and collaborative learning - Courses and workshops - A variety of professional-development activities - Mix of internal and external expertise - Staff developers as facilitators, consultants and planners - Teacher as consumer of knowledge about teaching - Teacher as follower - Teacher as leader - Teacher as a member of a collegial professional community - Teacher as source and facilitator of change

Source: Kimble *et al.* (2006)

Several recent studies have begun to examine the importance of specific characteristics of professional development. For example, Loucks-Horsley *et al.* (2003) suggested that successful teacher development models include providing enough time to allow for acquirement of new views, along with practice, feedback, follow-up and maintenance of the new skills or ideas; allowing the teacher to reflect on the new ideas or implementation of the new skills and modeling; and allowing the teacher to see the new skills or strategies in practice. One of the best ways to help teachers learn is through immersion in actual classroom settings. The professional development experiences should focus on specific needs of teachers involved within their classroom contexts (Yager, 2005). However, the professional development shift from a focus on individuals to a focus on members of the community has implications for science teaching in general (Dori and Herscovitz, 2005). Desimone *et al.* (2002) suggested, ‘‘Collective participation of groups of teachers from the same school, department or grade level,” should be the focus of professional development, “as opposed to the participation of individual teachers from many schools.”

Moreover, Loucks-Horsley *et al.* (2003) suggested the strategies for professional learning are consistent with the principles of effective professional development. The authors describe 18 different teacher learning strategies by providing a set of key elements and implication requirements for each strategy in six categories: aligning and implementing curriculum, collaborative structures, examining teaching and learning, immersion experiences, practicing teaching and vehicles and mechanisms (see Table 2.4). Professional developers can select and make up a professional development program using multiple strategies offered simultaneously to different groups of teachers to meet their different needs or accommodate varied learning styles.

Table 2.4 Eighteen Strategies for Professional Learning

Aligning and implementing curriculum

· Curriculum alignment and instructional materials selection

· Curriculum implementation

· Curriculum replacement units

Collaborative structure

· Partnerships with scientists and mathematicians in business, industry and universities

· Professional networks

· Study groups

Examining teaching and learning

· Action research

· Case discussions

· Examining student work and thinking, and scoring assessment

· Lesson study

Table 2.4 (Continued)

Immersion experiences
· Immersion into inquiry in science and problem solving in mathematics
· Immersion into the world of scientists and mathematicians
Practicing teaching
· Coaching
· Demonstration lessons
· Mentoring
Vehicles and mechanisms
· Developing professional developers
· Technology for professional development
· Workshops, institutes, courses and seminars

Source: Loucks-Horsley *et al.* (2003: 113).

In the area of in-service teachers' professional development, action research is conceived as a central strategy teachers can use to improve their professional practice. An action research approach involves teachers using research methods of the social sciences to reflect on their own practices and then using their insights and understandings to systematically improve their teaching practices. When teachers conduct action research they engage in practice-based professional inquiry that provides opportunities to grapple with authentic issues encountered in their classrooms and schools (Loucks-Horsley *et al.*, 2003).

As previously mentioned, the aims of the study are to enhance the three case study teachers' understandings and teaching practices reflecting NOS through the professional development program in which all teachers conduct collaborative action research. Therefore, literature about action research is provided in the following section as a guiding principle of this professional development program.

Action Research as a Strategy for Professional Development

Action research is concerned with the nature of the learning process and the link between practice and reflection (Winter, 1996). Action research activities regarding the educational context are mainly focused on improving teaching and involving students in learning (Carr and Kemmis, 1986). The strength of action research as a teacher professional development strategy is that teachers are in charge of the process; for example, they can either define the research questions or contribute to their definitions, and are committed to promoting changes in practices indicated by the findings (Loucks-Horsley *et al.*, 2003). Moreover, collaborative work which is an important component of action research provides an opportunity for teachers to share ideas, benefit from one another’s teaching experience, engage in a common study to enrich their subject matter knowledge, learn more about technology and design ways to incorporate local, state and national educational developments into their teaching (Loucks-Horsley *et al.*, 2003). Because of its many benefits, action research can be introduced to support in-service teachers as a powerful professional development activity. Action research in education varies in several ways, which include the purposes and motivations of teachers who engage in the research, the conceptions of the action research process, the form and content of action research studies and the way in which the findings of the research are represented by researchers to others (Zeichner, 2001).

General Descriptions and Core Ideas of Action Research

Action research has been a part of education for a long time. Kurt Lewin is generally credited as the first person who introduced the term 'action research' in the 1940s for understanding and changing human action (Noffke, 1995). Action research has evolved in the educational community into an ongoing process of systematic study in which teachers examine their own teaching and students’ learning through descriptive reporting, purposeful conversation, collegial sharing and critical reflection for the purpose of improving classroom practice (Miller and Pine, 1990). Action research in education can also be used for different purposes, such as school-based curriculum development, school improvement, professional development, educational research, system planning, school organization, staff development, evaluation and the democratization of the workplace (Carr and Kemmis, 1986; Elliot, 1996).

There are various conceptions and definitions of action research in education. Many educators define action research as a systematic process which includes many elements such as inquiry-based practice, self-reflection, collaboration and emancipation (Feldman and Capobiance, 2000; Capobiance, 2007). Therefore, action research is known by many other names, including participatory research (Kemmis and McTaggart, 1988), collaborative inquiry (Miller and Pine, 1990; Kraft and Wheeler, 1996; van Zee, Lay and Roberts, 2003), teacher research (van Zee, Lay and Roberts, 2003) and emancipatory research (Feldman and Capobiance, 2000; Capobiance, 2007), but all are variations on one theme.

Carr and Kemmis (1986) presented a critical-reflective perspective for conducting action research. They state that action research is, "Simply a form of self-reflective enquiry undertaken by participants in social situations in order to improve the rationality and justice of their own practices, their understandings of these practices, and the situations in which their practices are carried out."

As a simple definition but the most visualization in practice, Elliott (1991) defined action research as, "The study of a social situation with a view to improving the quality of action within it." In his view, action research 'theories' are not validated independently and then applied to practice. They are validated through practice. Elliott's definition focuses on improving the quality of teaching and learning as well as on the conditions under which teachers and students work in schools.

Further adding to the above definitions, Mills (2003) defined action research more related to the educational context as, "Action research is any systematic enquiry conducted by teacher researchers, principals, school counselors or any stakeholders in the teaching\learning environment to gather information about how their schools operate, how they teach and how well their students learn."

Characteristics of Action Research

Regarding the conceptions and definitions of action research as mentioned above, there are several characteristics of action research that make it unique and distinguish it from any other strategies which have been discussed in literature (e.g., Carr and Kemmis, 1986; Winter, 1996; McNiff and Whitehead, 2002; Berg, 2009).

1) *Practitioner research*: Action research is conducted by practitioners in order to solve their own practical problems and improve their own practices. The research topics being investigated focus on practitioners' practical problems and concerns rather than global issues (McNiff and Whitehead, 2002). Practitioners can learn from what they have done through reflection. In this sense, action research is directed by practitioners' decisions about what counts as desirable or unproblematic practices and what counts as useful knowledge for them.

2) *Reflexive critique*: Action research involves the process of becoming aware of our own perceptual biases. In doing action research, practitioners are required to reflect in and on their action in order to seek strategies to understand and solve problems as well as learn from what they have done. They are continually being transformed through writing reflective journals, processing data and participating in continuous discussions regarding changing cycles of research questions and action; thereby, they become more aware of themselves and the processes they are using (Winter, 1996). In achieving reflexivity, action researchers acknowledge that their understandings of their educational contexts cannot be developed apart from their own knowledge of themselves and their location in the educational contexts (Berg, 2009).

3) *Context and/or practical-based*: Action research generally involves practical problems experienced by practitioners in their contexts. Action research focuses on real-life issues, problems and on actions to address problems that make it intrinsically unique. The action research process reflects the principle that human actions and experiences are context dependent and can be understood only within

their contexts. Rather than strip away context, action research recognizes that context deepens our understanding of human actions and experiences, and enriches the process of inquiry (Berg, 2009).

4) *Recursion and ongoing tentative*: Recursion is fundamental in the process of ongoing tentativeness inherent in action research studies. Recursion is captured by the concept of the action research spiral that is modified from the action research cycle depicted by Carr and Kemmis (1986). This cycle of action and reflection is broken into phases of planning, acting, observing and reflecting (see Figure 2.1). The cycle can begin at any stage, and it does not stop after one cycle is completed but begins another cycle and becomes more of a spiral. Most significant, through the recursive process, theory and practice are continually transformed (Winter, 1996). This transformative cycle between theory and practice is captured by teacher researchers. Avery (1990:44) has reflected on her journal writing as follows:

> …Now theory informs my practice in the classroom and classroom practice informs my theory making. I continue to research, rethink and revise. I develop patterns of learning for myself that influence my teaching. I know there will be no part answers, no universal strategies or techniques. I know that many factors influence the implementation and outcome of specific teaching strategies. I have learned to be a learner.

5) *Dialectic critique*: In action research studies, the dialectics approach asserts that individuals are the product of their social world which is structured as a series of contradictions, and is in a continuous process of change. Moreover, it is a way of understanding the relationships between these elements that make up various phenomena in our context (Winter, 1996). In this sense, while doing action research, there is a diversity of practitioners' perspectives on a particular situation. Different practitioners can see a particular situation in different ways, depending on their values, prior experiences and the social and cultural frameworks in which they live. Thus, practitioners' values and practices have evolved through a social construction process over time (Carr and Kemmis, 1986).

6) *Collaboration*: Participants in action research projects are co-researchers (Berg, 2009). Collaboration, in this sense, is intended to mean that everyone's views are taken as contributions as resources for understanding the situation, and no one's views will be taken as the final understanding of what all the other points of view really mean. The principle of collaborative research assumes that each person's ideas are equally significant as potential resources for creating interpretive categories of analysis, negotiated among participants (Berg, 2009). In doing action research, practitioners need to involve all participants to share their perspectives on the problem, clarify and investigate the problem, create and implement an action plan responding to the problem, observe and evaluate the action implemented and reflect on and learn from the action. All these activities require all participants to be part of and work together in action research (McNiff and Whitehead, 2002).

The Processes of Action Research

Loucks-Horsley *et al.*, (2003) identify the five key elements for conducting action research:

(1) Teachers contribute to or formulate their own questions, and collect data to answer these questions. This strategy gives teachers the power to make decisions and to develop professionally through action and reflection.

(2) Teachers use an action research cycle which involves a cycle of planning, acting, observing and reflecting.

(3) Teachers are linked with unknown sources of knowledge and stimulation from outside their schools. Individuals and resources that offer expertise on research methodology help teachers to ensure the quality of their methods.

(4) Teachers work collaboratively. This strategy is open for teachers to discuss problems and limitations, the ideas of others and to learn new skills and behaviors needed for the research process, and;

(5) Learning from research is documented and shared. Teachers increase their skills and knowledge from their own action research by writing about a project,

presenting their findings to various audiences and participating in discussions about the implications of the findings for teaching and schools.

There are several models of the action research process. Kemmis and McTaggart (1998) have developed a simple and helpful model of the cyclical nature of the typical action research process (Figure 2.1). This model is based on Kurt Lewin’s work. Each cycle has four steps including planning, acting, observing and reflecting.

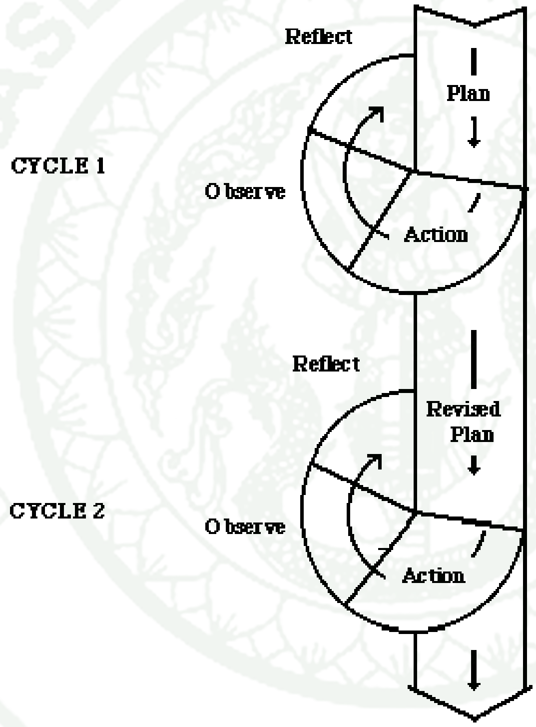

Figure 2.1 Action-Reflection Spiral

Source: Adapted from Kemmis and McTaggart (1988)

Emanating from this model, Elliot (1996: 72) explains that action research is conducted as follows:

- Initially an exploratory stance is adopted, where an understanding of a problem is developed and plans are made for some form of intervention strategy *(The Reconnaissance and General Plan).*
- Then the intervention is carried out (The *Action* in Action Research).
- During and around the time of the intervention, pertinent observations are collected in various forms (Monitoring the implementation by *Observation*).
- The new interventional strategies are carried out, and the cyclic process repeats, continuing until a sufficient understanding of (or implement able solution for) the problem is achieved *(Reflection and Revision).*

The Rational of Action Research to Professional Development

According to analysis of action research activities, Henson (1996: 56) reveals that there are many benefits of conducting action research. Action research:

- Helps solve classroom problems
- Encourages effective changes
- Revitalizes teachers
- Empowers teachers to make decisions in their classrooms
- Identifies effective teaching and learning methods
- Promotes reflective teaching
- Promotes ownership of effective practices
- Verifies what methods work
- Widens the range of teachers' professional skills
- Provides a connection between instructional methods and results
- Helps teachers apply research findings to their own classrooms
- Enables teachers to become agents of change

Over the years, many research studies have shown the benefits of teachers engaging in research of their own practices. For example, it has been asserted that doing action research helps teachers to become more flexible and open to new ideas (Feldman, Paugh and Mills, 2007), makes them more aware of their own practices

(Tabachnick and Zeichner, 1999), increases teachers' confidence and competency in their teaching practices (van Zee *et al.*, 2003), encourages systematic inquiry to answer questions about student learning, instructional strategies, and social dynamics (Cox- Petersen, 2001), and helps teachers, through collaborative work, to share ideas, gain the benefits of one another's teaching experiences, and engage in common studies to enrich their subject knowledge (Loucks-Horsley *et al.*, 1998).

Separating teaching from research creates problems in using research results in order to improve teaching (Elliott, 1991). Teachers should be reflective practitioners and act as researchers in their own classrooms (Hopkins, 1985). Reflection is the basic element of action research (Carr and Kemmis, 1986) and has been a popular professional development strategy. Schon (1987) recommends the use of reflection in varied professions to analyze, discuss, evaluate and change practices. When teachers reflect about their practice, they clarify their thinking and anticipate decisions and future actions. Reflective teaching includes teachers' sharing ideas, listening and reacting to colleagues' ideas and trying to integrate these ideas into their thinking (Zeichner and Liston, 1996; Cox-Petersen, 2001). In such a process, teachers are able to learn practical knowledge from each other. Therefore, action research has a rich potential to empower teachers and provide opportunities for them to change their teaching practices.

Collaborative Action Research

As discussed above, there are many characteristics of action research. Collaborative action research is a form of action research that frames this study. Feldman (1996) defined collaborative action research as, "The practitioners working together to take actions within their situations to improve their practice and come to a better understanding of that practice." That is, 'collaborative' means groups of teachers working together, in contrast to a relationship between university researchers and school teachers. Feldman defined the term 'research' here as systematic and critical inquiry that is made public. By 'action', he means that action research is a good way to come to a better understanding of complex system-teaching and learning by taking action within that system and paying close attention to the results of taking such actions.

Collaborative action research entails teachers joining together to examine and take action in response to different issues and concerns related to their practice (Feldman, 1994). In this approach, teacher-researchers come together to solve problems, create change and accomplish some shared goals with regard to teaching and student learning in science (Capobianco, 2006). Oja and Pine (1987:96) suggest that collaborative action research is characterized by several elements:

1. Research problems are mutually defined by teachers and researchers.
2. University researchers and teachers collaborate in seeking solutions to school-based problems.
3. Research findings are used and modified in solving school problems.
4. Teachers develop research competencies and researchers re-educate themselves in field based research methodologies.
5. Teachers are more able to solve their own problems and renew themselves professionally.
6. Teachers and researchers co-author reports of findings.

Models for collaborative teacher action research involve teacher educators working together with experienced and prospective teachers to address problematic issues in their classrooms and schools and to construct new understandings of teaching and learning (van Zee, Lay and Roberts, 2003). Some models involve a university researcher as a facilitator who encourages and supports teachers (Miller, 1990; Feldman, 1994), while others involve self-initiated and self-sustained teacher inquiry groups (Carr and Kemmis, 1986).

It is important to note that collaboration among teachers effectively causes them to join together to examine and take action in response to different issues, solve problems, create change and accomplish some shared goals regarding the improvement of their practices (Feldman, 1996; Capobianco, 2007). Moreover, the collaboration can take a number of forms, including: (1) collaborative planning of term activities, as well as individual lessons; (2) lessons taught by a teacher educator and observed by the school teacher; (3) lessons taught by the school teacher and observed by a teacher educator; (4) lessons co-taught by the collaborators; and (5) debriefings following each lesson taught as part of the collaboration (Edwards and Hensien, 1999).

Cox-Petersen (2001) studied how science teacher research was integrated into science methods courses and describes how teachers participate in collaborative action research. They found that approximately half of the teachers worked with a partner or a small group, and those group members supported each other throughout the research process. Those teachers who worked with a partner reported positive experiences; for example, some teachers noted action research can be more interesting with more people involved. Teachers indicated that the most beneficial outcome to collaboration was viewing research from different perspectives. Additionally, collaborative action research not only enhances teachers' content and pedagogical knowledge (Feldman, 1996; Capobianco, 2007), but it also gives teachers the opportunity to explore their own teaching practices and make decisions to promote effective change (Cox- Petersen, 2001; Guo and Chang, 2004).

Summary of the Chapter

The Thai science education system has been driven to reform following the 1999 National Education Act to develop a scientifically and technologically literate society. Not only have teaching and learning processes changed to emphasize the constructivist and student centered approaches, but also the national curriculum and professional development have changed to accomplish the goals of the reform. Promoting the understanding of NOS is an important component of scientific literacy and is an ultimate goal of science education. Although definitions of NOS have various characteristic and have undergone elemental changes among historians, philosophers and sociologists of science and education through years, many important conceptions of NOS are mentioned in the National Science Curriculum of Thailand and are also regarded as important components for teaching science.

Many researchers and science educators have claimed that teachers and students should construct their understandings of contemporary views instead traditional views of science. The traditional view of science is often referred to as a misconception or a naïve conception. In order to promote the teaching and learning of NOS, teachers are required to have contemporary views of science and should understand the elements of NOS. Although there are many approaches for teaching NOS, literature suggests an explicit-reflective approach that embeds NOS instruction in the context of science content is an effective approach.

In order to help teachers improve their understandings of NOS and teaching the conceptions of NOS explicitly in their practices, there are many strategies for professional learning which are consistent with the principles of effective professional development. In the area of in-service teachers' professional development, collaborative action research is thought of as a central strategy teachers can use to make their work more professional. Collaborative action research not only enhances teachers' content and pedagogical knowledge, but also gives teachers the opportunity to explore their own teaching practices and make decisions to promote effective change.

CHAPTER III

RESEARCH METHODOLOGY

Introduction

The purpose of this study is to foster three Thai elementary teachers' understanding of NOS as well as their ability to explicitly teach NOS in the classroom. The collaborative action research was selected as a promising approach. The study was divided into two consecutive phases according to the two research questions—(1) What are Thai elementary teachers' initial understandings of NOS and teaching practice related to NOS? and (2) How does collaborative action research support Thai elementary teachers as they learn how to explicitly teach NOS? Therefore, the first phase aimed to explore the teachers' initial understandings of NOS and their teaching practice related to NOS before they engaged in collaborative action research while the second phase aimed to investigate how collaborative action research supported the teachers learning to explicitly teach NOS in the classroom.

This chapter describes the research methodology used to address the two research questions, the research phases undertaken throughout the study, a description of school context, profiles of each participant teacher and details of collaborative action research respectively. Data collection and analysis methods are then described. The chapter ends with a description of techniques and strategies employed to enhance trustworthiness of research results.

Research Methodology

Interpretive Paradigm

Research paradigm can be defined as a fundamental set of beliefs that shape and guide the researcher's perspective and action in conducting a research study. It guides the researcher in defining a research question and selecting of ways to answer his or her research question (Denzin and Lincoln, 2000). In the context of social science research, there are two major philosophical traditions: positivism and interpretivism. In the positivist research, it is considered that knowledge is absolute truth, which has to be derived from what can instrumentally be observed and experienced (Guba and Lincoln, 1998). This characterizes knowledge gained from positivist research as being objective, measurable and predictable. Therefore, in order to gain such absolute knowledge, the researcher has to carefully design an experiment in order to control variables and focus on quantitative data (Cohen, Manion, and Morrison, 2000). Therefore, positivist research methods emphasize a cause-and-effect relation between the variables as it does in scientific research. Not only are generalizations eventually made, but also validity and reliability are key constructs for the positivist researcher (Powell, 1997).

In contrast to the positivist research, this study employs an interpretive research approach, which focuses on the meanings and experiences of human beings (Lincoln and Guba, 1985; Ponterotto, 2005). In an interpretive research, the researcher believes that reality is socially constructed by people, and his or her role is to understand such meanings those people have as they experience the reality—that is, the researcher aims to access the inside perspectives of the people (Schwandt, 1994; Cohen *et al*., 2000). In order to investigate such meanings experienced by the people, the interpretive researcher prefers to immerges him/herself in a natural setting to gather qualitative data related to the people's experiences, and uses inductive methods to interpret the data (Lincoln and Guba, 1985). These espouse a constructivist framework as it can be argued that those meanings are constructed by the people and that the result(s) is constructed by the researcher. The interpretive researcher focuses on understanding how the people, or a particular person, in a given social context, construct meanings of their experience (Guba and Lincoln, 1998).

In an interpretive study, the researcher is regarded as an important research instrument in collecting qualitative data related to research question(s) through observing events, interviewing people, examining records and documents available in the research setting. The researcher can use a combination of these methods as well (Berg, 2007). Data analysis in the interpretive research is an ongoing process, which normally goes hand-in-hand with data collection since the researcher gradually gets involved with what being studied in order to understand it. Therefore, data analysis in the interpretative research does not occur at the end of the study as is typically done in the positivist research. Instead, the researcher persistently works on the data such as organizing data, breaking data into manageable units, coding data, synthesizing data, and searching for patterns among data units. Such inductive processes require the researcher to make interpretations of the data.

Credibility of an interpretive study's results is derived from a number of strategies. Basically, it is recommended that the interpretive researcher has to invest sufficient time to discern both common and salient patterns of what being studied, and to ensure that another salient pattern is unlikely or less likely to emerge. He or she should build trust and rapport with the people involved in what is being studied, in order to share and negotiate different interpretations of the data. It is also important that the interpretive researcher often uses data collected from multiple sources by multiple methods to "triangulate" the emerging interpretations of the data. In addition, the researcher should regularly share the process of the study with people who are not taking part in the study in order to test any taken-for-grant assumptions. The researcher should also document the full research process to show how the results of the study have evolved. These strategies are used to ensure that the researcher' personal bias is reduced or minimized.

In this present study, during the first phase, the researcher examines what meanings related to NOS each of the participant teachers had constructed before engaging in collaborative action research. Moreover, she paid attention to possible ways in which NOS, as understood by the teachers, were integrated into their science instruction. After that, in the second phase at which the teachers engaged in collaborative action research, the researcher turned a research focus onto whether or not collaborative action research did support the teachers to have more appropriate understandings of NOS and how change(s) in understandings did affect their science instruction. In undertaking this study, the researcher was well aware that the change in the teachers' understandings and practice related to NOS, which might result from interactions among the teachers and the researcher, were neither controllable nor predicable. Therefore, the researcher considered the interpretative paradigm as more appropriate than the positivist one as it allowed her to have access to the teachers' meanings through interpreting their speech and actions (Bryman, 2001).

Interpretive Case Study

This study can be characterized as a case study in the sense that it involved a particular group of Thai elementary teachers who shared an interest in teaching NOS. As a consequence, they volunteered to engage in collaborative action research where they could work together instead of being sampled by any research methods. Despite the fact that a case study can be defined and understood in various ways, it is in general an educational research method which aims "to understand the processes of events, projects, and programs and to discover the context characteristics that will shed light on a specific issue" (Merriam, 1998: 33). Therefore, what being "case" is, which can involve one participant or participants, must be of very special interest (Stake, 1995). As engagement in collaborative action research among the elementary teachers who were interested in teaching NOS had rarely been considered or encouraged in Thailand, this study is a case study that would illustrate the complexity of supporting Thai elementary science teachers learning to teach NOS effectively.

In collaborative action research undertaken in this study, the teachers engaged in a regular discourse where they came to share ideas and insights to integrating NOS into science instruction so that they could be more effective in promoting their students' understandings of NOS. Therefore, case study is considered as a powerful research method for capturing the complexity of supporting the teachers learning to teach NOS while they engaged in collaborative action research. Case study also helps the researcher report the complexity so that readers can follow what happens in the discourse of collaborative action research. There are three cases of the three teachers reported in this study. Each case describes a teacher's initial understandings of NOS and teaching practice related to NOS before engaging collaborative action research. This is followed by her experiences in collaborative action research, resulting in improved understandings of NOS as well as ability in translating those understandings into classroom practice. Given the fact that all the teachers shared common experiences in collaborative action research, the presence of commonalities implies the influences of collaborative action research on the teachers.

As case reporting is committed to capturing complexity of what happens during the study in order to provide the readers a comprehensive understanding of it, thick (or rich) description becomes necessary. Thick description includes an in-depth description of the participant teachers (e.g., understandings, attitudes, motives, expectations, and assumptions), the intervention (i.e., collaborative action research), the circumstances or contexts in which the teachers work (e.g., cultural norms and values outside and inside the school, the nature of students) (Pine, 2009: 215). The readers can use such information, which will be presented in what follows, in judging the credibility of the results of the study.

Background and Context of the Study

This study is undertaken at an elementary school in a northern province of Thailand where all three participant teachers, who are interested in integrating NOS into science instruction, work together. It is important to note that the participant teachers of this study are not selected by a random sampling method, but rather purposefully selected to generate “information-rich” cases. According to Patton (2002), an information-rich case is one from which we can learn a great deal about issues of central importance to the purpose of a study. This method aims to provide an in-depth understanding of the case, rather than to make generalization from it to a larger population. As noted earlier, an investigation of a group of elementary teachers working together within collaborative action research on attempts of integrating NOS into science teaching is very rare in Thailand. Hence, this study can serve as an information-rich case, which provides in-depth understandings how collaborative action research supported elementary teachers learn to explicitly teach NOS.

How the researcher gets involved with the teachers.

At the beginning of the study, the researcher is a doctoral student in a science education program at Kasetsart University. She used to teach in the school located at her hometown. It is this school in which all the participant teachers teach so that the researcher knows all of them prior the study. When she was planning to do a doctoral dissertation aimed to promote teaching NOS at elementary level, she was thinking of working at her hometown in order to reduce research costs. For this reason, she did a pilot study (Suttakun *et al*., in press) which aimed to explore elementary teachers' understandings of NOS, by sending a questionnaire to all elementary schools, including hers own school, in the province. The questionnaire also asked teachers who were interested in teaching NOS to volunteer to participate in a larger teacher development study. Without knowing who it was that sent the questionnaire, four teachers from the researcher's school, among others, showed their interest. As a consequence, the researcher thought this could be a great opportunity to work with teachers she was familiar with.

In May 2009, the researcher sent a consent letter to the principal of the school in order to officially recruit the teachers to participate in her doctoral study. The principal, who also knew the researcher prior the study, considered that the researcher's study could be an opportunity for the teachers to have a professional development experience. After receiving the letter, the principal allowed the four teachers to participate in this study. However, it was very sad to note that one of the teachers died during the study from undiagnosed liver cancer. As a result, only three of the original four teachers participated in the study. These teachers had different backgrounds and taught science at different level. In what follows, the teachers are referred by the pseudonyms, Pikun, Kanya, and Sunee, in order to maintain their anonymity.

School Context

This study was conducted in a public elementary school located at a northern province of Thailand during the 2009 academic year. The school is the most famous and biggest public elementary school in the central area of the province. Most of the people around the school work for government institutes (e.g., schools, hospitals, and administration offices), business sectors, and industries. Therefore, most of students came from a wide range of families with regards to their socio-economic status. The school's vision is to "promote good and intelligent students." Also, the students are expected to appreciate the local custom and be good citizen of the nation.

The school provided instruction for Kindergartens to Grade 6 students. In the 2009 academic year, there were a total of 1,415 students attending the school (206 students in Kindergartens level and 1,209 students in elementary level). There were about five to six classes in each grade level, for a total of 40 classes. The class sizes ranged between 30 and 40 students. There were 63 government teachers on staff which included 23 specialist teacher and 40 senior teachers. In each academic year, there are two semesters; the first semester run from May to September and the second semester started in November and extended to March. Therefore, there were two vacation periods in each academic year; the first was in October and the second one was in April.

Most of teachers had responsibility for both teaching and extra work. Teachers who taught in Grade 1 and Grade 2 had to be classroom advisors and taught their advisee class a number of subjects (i.e., mathematics, Thai, art, and science). For the teachers in Grade 3 to Grade 6, some were classroom advisors while some teach only one subject for all classes in the same level. In the 2009 academic year, the school had just implemented the new school based curriculum according to Thailand's National Education Act B.E. 2542 (1999). As a consequence, science was being taught according to the National Science Curriculum Standards (IPST, 2003).

As in the urban area of the province, the school had its limited space where five classroom buildings, a sport field, a meeting hall, a library, two computer rooms, and a number of small gardens are located. There was only one laboratory room available in the school. As a result of this limitation, not all students could have access to a laboratory environment. However, many teachers opted to teach science and do hands-on activities in a normal classroom instead. Additionally, scientific materials and equipments for science instruction in the school were substantially inadequate when compared to the overall number of students.

The Participant Teachers

There are three participant teachers in this study. All the teachers come from the same school, but at different grade levels. Information background of each teacher is presented in what follows.

Ms. Pikun

Ms. Pikun was a third-grade science teacher. She had a bachelor's degree in elementary education and a master degree in education with emphasis on curriculum and instruction. She was 49 years old and had fifteen years of science teaching experiences. However, she gained such teaching science experiences in other schools as she had just come to teach in the present school two years ago. Pikun taught six classes of a third-grade science course and five classes of a subject namely, *Scientific Process Skills*, for sixth-grade students, resulting in seven teaching periods a week. The average numbers of students in third-grade classes and sixth-grade classes were approximately 31 and 40 respectively. Besides teaching, Pikun had an extra-workload as a school librarian. During last two years, she received professional development aimed to increase science learning efficiency through a distance training program, which was held by IPST, and a professional development program held by the school about how to design lessons according to the coming of the 2001 school based curriculum. Pikun expressed that she loves teaching science and is always proud of her success in teaching science, which is shown by her students' achievement. She also mentioned that she was very happy when her students were enthusiastic about her instructional activities.

Ms. Kanya

Ms. Kanya was a fourth-grade science teacher. She had a bachelor's degree in education with a major in chemistry**.** She was 51 years old and had 22 years of science teaching experiences. As she had background in science, she was selected to be the head teacher of the school's science department. Although Kanya was a classroom advisor, she had taught six classes of fourth-grade science course, resulting in eighteen teaching periods a week. The average numbers of students in fourth-grade classes were approximately 36. Similarly to Pikun, Kanya experienced a professional development program held by the school about how to design lessons according to the coming of the 2001 school based curriculum. In that program, she was responsible to developing the school's science curriculum for fourth-grade students. Moreover, she acted as the head of the teams who reviewed and edited the school's science curriculum at all grade levels. Kanya expressed that she loved teaching science. She preferred to let students learn by doing hands-on activities. However, as a busy teacher, she confessed that she did not have enough time to prepare instructions.

Ms. Sunee

Ms. Sunee was a first-grade science teacher. She had a bachelor's degree in education. Her major is elementary education and general management. She was 44 years old and had three-year experiences in science teaching. Before becoming an elementary teacher, she had worked as a government officer for an Education Service Area Office for eight years. As a Grade 1 teacher, Sunee had to teach not only science subject but also other subjects, resulting in 9 subjects and 20 teaching periods per week. (One period lasts 50 minutes.) Of those 20 teaching periods, she taught science only 2 periods per week. Besides teaching, Sunee was responsible to the school inventory management. During last two years, she had no experience in professional development in other domains. As a new teaching experience and no science degree teacher, Sunee perceived that she did not have enough content knowledge in science. Because of this, it was difficult for her to communicate scientific ideas to young students. However, because of her students' curiosity in natural phenomena as well as their enthusiasm for participating in instructional activities, she was very happy teaching science at elementary level.

Overview of the Study

This study was conducted in two phases undertaken during the two semesters of the 2009 academic year; each phase was undertaken over a semester. The first phase was planned to explore the participant teachers' initial understanding of NOS and their teaching practice related to it. The data gained in this phase served to guide the researcher to continue the study. The data gained in the first phase suggested, the teachers were not familiar with NOS or collaborative action research, although they were interested in both. Therefore, two workshops were held during the one-month vacation between the first and the second semester in order for the researcher to introduce the teachers to NOS and collaborative action research. After the workshops, the second phase was begun—that was, the researcher initiated collaborative action research and engaged in this with the teachers. An overview of each phase, and of the workshops, is presented in what follows.

Phase I: Exploring the teachers' initial understanding of NOS and their teaching practice related to NOS

The first phase was undertaken during the first semester of the 2009 academic year (July to September 2009). It was designed to explore the participant teachers' initial understandings of NOS and their teaching practices related to NOS. Data gained in this phase primarily served to address the first research question: *What were Thai elementary teachers' initial understandings of NOS and teaching practice related to NOS*? The data was used to guide the second phase of the study during which the teachers engaged in collaborative action research facilitated by the researcher. The researcher also spent time during this phase to develop better relationships with the teachers in order for her to be able to work with them. In doing so, the researcher immersed herself within the context in which the teachers worked without attempting to manipulate the context. The researcher collected the data using a questionnaire, individual semi-structured interviews, classroom observations, and a collection of instructional materials used.

Workshops between Phase I and Phase II

As the results gained from the data analysis in the first phase suggested that both NOS and collaborative action research were new for the teachers, the researcher decided to hold two successive workshops in order to introduce the teachers to important ideas of NOS and collaborative action research. Both workshops were conducted during the school vacation (October – November, 2009) in a teacher-meeting room in the school. All the participant teachers attended the workshops with the researcher and an invited science educator (a research advisor of the study).

The workshops were designed based on both personal and social constructivist theories. According to these theories, the participant teachers were viewed as learners who engaged in hand-on/ mind-on learning activities, which were highly interactive, aimed to promote their learning about some particular ideas on NOS and collaborative action research. At the beginning of each activity, the teachers were directed to reflect on their prior knowledge about a focused topic using KWL strategy—that is, the teachers had to reflect on what they Knew, what they Want to know and what they have Learned respectively. Furthermore, the teachers as a small group, had opportunities to work collaboratively, reflect on the activities they just engaged and exchange their knowledge and experience with the others. The science educator and researcher offered supports according to the needs of the teachers and gave some constructive feedbacks to them. A summary of each workshop is presented in what follows.

The First Workshop: NOS

The main purpose of the first workshop was to introduce the participant teachers to contemporary views of NOS that are relevant to elementary students, and how those views can possibly be integrated into science instruction. This workshop took place in the meeting room of the school from October 20th to 22nd of 2009. The workshop consisted of three main sessions. Session I: 'What Science Is' was composed of activities that aimed to encourage the teachers to examine and be aware of their image of science so they could build up a shared image of science. Session II: 'The Concepts of NOS' was composed of six activities that were related to three aspects of NOS — namely, the acquisition of scientific knowledge, the nature of scientific knowledge and scientific works. The last session, Session III: 'Moving towards Teaching NOS' was composed of activities that had a pedagogical focus on how the three aspects of NOS could be taught in an elementary classroom. The scope and content of the first workshop is presented in details in Appendix A.

The Second Workshop: Collaborative Action Research

Based on the data gained in the first phase, there was only one of the three teachers (Kanya) who had experience in doing action research individually while the others (Pikun and Sunee) did not do so. Therefore, as collaborative action research was quite new for two of the three teachers, the workshop on collaborative action research was held in order to introduce them to general ideas of what collaborative action research is about and how they can engage in it meaningfully. Also, it was expected that, once the teachers understand such general ideas, they could imagine the potential benefits they could gain from engaging in collaborative action research. Moreover, the workshop was intended to serve as a starting point where the teachers and the researcher could allocate roles and responsibilities for engaging in collaborative action research. This workshop consists of two main sessions. Each session was conducted separately because of the limitation of time. The first session was conducted from November 14th to the 15th of 2009, while another session was conducted from November 21st to 22nd of 2009. Session I: 'Introduction to Collaborative

Action Research' composed of three hand-on and mind-on activities related to the collaborative action research. Session II: 'Planning for Conducting Collaborative Action Research' was designed for supporting the participant teachers in planning their collaborative action research. The scope and content of the second workshop is presented in detail in Appendix B.

Phase II: Conducting Collaborative Action Research

This second phase was designed to gain data addressing the second research question: *"How did collaborative action research support Thai elementary teachers' learning to teach about NOS?"* During this phase, the influence of collaborative action research to the participant teachers' improved understandings of NOS and their attempts to teach NOS were focused. This phase was undertaken during the second semester of the 2009 academic year (November 2009 to March 2010). It involved collaborative activities among the teachers and the researcher who wished to promote elementary students' understandings of NOS. There were group meetings among them two times a month throughout the second semester. By doing this, it was expected that the teachers could learn about NOS and be able to integrate what was just learned into science instruction. Also, it was in this phase that the researcher examined how collaborative action research supported the teachers in learning about NOS. Attention was also paid to how the teachers integrated what they had learned about NOS into their science instruction.

Collaborative action research was undertaken in this study based on an assumption that knowledge is situated in the teachers' classroom experiences and can be best acquired through critical reflection (van Manen, 1977; Schon, 1983). As a consequence, the teachers were expected to be sensitive and reflective on any classroom events in order for them to learn from those events. For example, the teachers were emphasized to take what their students contributed about NOS to classroom discussions into account so that they could learn about how the students viewed some particular NOS aspects from those contributions. It was also expected that the teachers could and would adjust their science instruction in accordance to what they learned through critical reflection. It was this reflective process by which the teachers could learn to teach NOS more effectively.

The teachers could enhance their own learning about NOS when they shared their reflection with the others. Thus, collaboration among the teachers and the researcher became a key feature of collaborative action research undertaken in the study. As suggested by Baird *et al.*'s (1987, see Figure 3.1) style of collaborative action research, the teachers were expected to share their 'practical theory and expertise' (e.g., which science content students were interested in and where in such content NOS should be integrated into) while the researcher and the invited science educator, as non-teaching participants, contributed 'academic theory and expertise' (e.g., how NOS should be taught effectively) to the teachers. Through such a collaborative manner, which can be achieved by conversation (Feldman, 1999), it was expected that the teachers could enhance their learning about NOS and make better decisions regarding the teaching of NOS in the classroom.

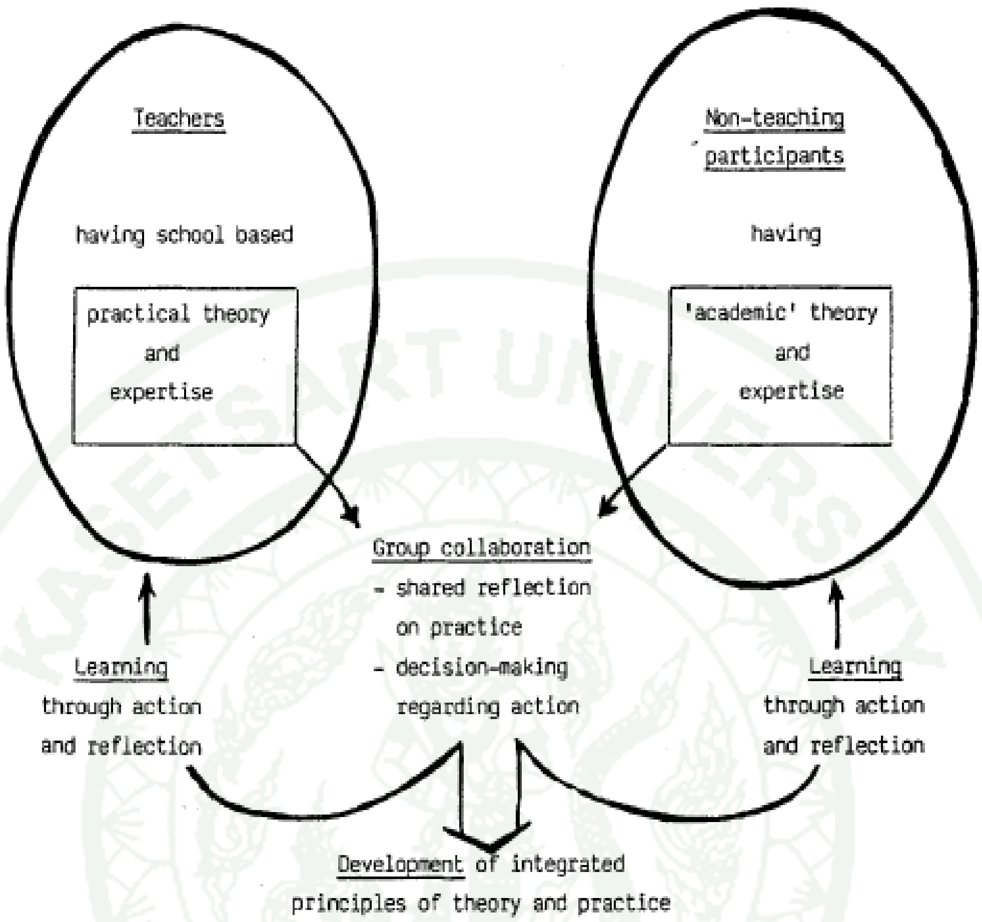

Figure 3.1 Baird *et al.*'s Style of Collaborative Action Research
Source: Baird *et al*. (1987: 135)

As suggested by Mokuku (2001) and McNiff and Whitehead (2002), there were no attempts to ask the teachers to follow any action research cycle (e.g., planning, acting, observing, and reflecting). Despite the fact that such an action research cycle was introduced during the workshop, the teachers were called attention that it was just a representation of how a collaborative action research should or might go on, but it was not the one a collaborative action research must be. As a consequence, there was flexibility of collaborative action research undertaken in this study so that the teachers could pursue their particular interest about NOS. Thus, the collaborative action research of this study could be best considered as a learning journey (Mokuku, 2001) for the teachers who wished to teach NOS effectively.

The Participants' Roles in Collaborative Action Research

As previously mentioned, there were five participants who became involved in collaborative action research; the three elementary science teachers, the researcher and the invited science educator. Despite the fact that all the participants engaged in collaborative action research simultaneously, they each had different roles, depending on their prior knowledge and experiences. These can be described in what follows.

The Teachers' Roles

According to the shared goal to promote their students' understandings of NOS, the teachers participated in collaborative action research designed to support their learning about NOS. In any discourses of collaborative action research, the teachers were expected and encouraged to examine and expose their understandings of NOS. In collaborative action research, the teachers had to share their understandings of NOS when they were prompted to do so. The main purpose was that, once the teachers shared their understanding of the focused NOS aspect to the others, they all could discuss about it in order to reach a shared one. Moreover, the teachers were expected and encouraged to think of how to possibly teach any NOS aspect in a manner accessible by their elementary students. In doing so, they were asked to develop a lesson plan where NOS was integrated, as well as help the other participating teachers do so. Once the lesson plan was implemented, they had to reflect on the applied instruction by writing a journal entry and/or being interviewed by the researcher, and then share that reflection with the other. When asked to do so, the teachers were highlighted that they could learn to improve their instruction for future implementation.

The Researcher's Roles

The researcher played two significant roles while engaging in collaborative action research—that is, the researcher aimed to collect data used to address the research questions and the facilitator of collaborative action research. According to her first role, the researcher immersed in collaborative action research and examined how collaborative action research supported the teachers learning to teach NOS. She played this role in a manner suggested by the literature about interpretative research in education (see, what was described earlier in this chapter). For the second role, the researcher facilitated the teachers in a number of ways to support their leaning about NOS. For example, she encouraged the teachers to examine and expose their understandings of NOS to the others, visited the teachers' classroom in order to facilitate their critical reflection, contributed theoretical perspectives or research-derived recommendations to the teachers while planning their lessons and encouraged teacher collaboration. Also, she acted as an organizer of the collaborative action research, who made appointment of when and where all the participants should meet and for what purposes.

The Invited Science Educator's Roles

Although a science educator was invited to participate in the collaborative action research, she could not do so throughout the entire study, but only in the workshops, due to her busy schedule and great distance between her university and the school. However, the science educator played a significant role as a consultant of collaborative action research who contributed critical suggestions to the teachers and the researcher. Through telecommunications (e.g., emails and telephone calls), the science educator provided constructive feedback on the teachers' lesson plans and recorded instruction.

CAR Group Meetings

A number of reflective discourses were investigated to support the teachers to learn about NOS and NOS instruction. In such reflective discourse, conversation played significant role that allowed the teachers to share their understandings and knowledge about NOS as well as experiences about teaching NOS in the classroom (Feldman, 1999). In doing so, despite the fact that the teachers and the researcher initially agreed that a discourse should be operated twice a month, a fewer number of discourses were actually operated because of other school activities such as sport competitions, an academic fair, and field trips. As a consequence, there were five meetings from November 2009 to February 2010. Table 3.1 overviews details of each meeting occurred during collaborative action research.

Table 3.1 An Overview of All Group Meetings During Collaborative Action Research

<table>
<tr><th>Group Meetings</th><th>Date</th><th>Duration (min)</th><th>Activities</th></tr>
<tr><td>1</td><td>November 28th</td><td>112.22</td><td>- Discussing students’ inappropriate understandings of NOS
- Seeking possible yet effective ways to teach NOS</td></tr>
<tr><td>2</td><td>December 18th</td><td>71.45</td><td rowspan="2">- Discussing and deciding which NOS aspect(s) are attainable and relevant to students in particular grade levels
- Planning lessons that reflect the attainable and relevant NOS aspect(s)</td></tr>
<tr><td>3</td><td>January 29th</td><td>58.06</td></tr>
<tr><td>4</td><td>February 12th</td><td>82.12</td><td rowspan="2">- Reflecting on the implemented instruction
- Sharing experiences and insights that emerged during the instruction</td></tr>
<tr><td>5</td><td>February 26th</td><td>78.22</td></tr>
</table>

It is important to note that the teachers were regularly interviewed by the researcher after implementing the instruction designed to communicate the intended NOS aspects to the students. In doing so, the teachers were encouraged to reflect on the recently implemented instruction individually. Collaborative action research afforded opportunities for the teachers to share their reflection on any instruction, no matter who implemented them. Therefore, the reflections that occurred during the meetings were collective rather than individual as done during the post-instruction interviews.

Data Collection

This section presents an overview of data collection methods used in the study. As this study is interpretative by its nature and purpose, it is important to note that the researcher regarded herself as the primary research instrument while she was in the research setting. Data collection involved acquiring data from a number of sources. The researcher used a questionnaire, individual semi-structured interviews, classroom/group-meeting observations, and a collection of related documents. In addition, she kept a journal during the study and asked the participant teachers to do the same; these journals were used as supplementary data. Details of each data collection methods are discussed in what follows.

Questionnaire

A questionnaire was purposively used to explore the teachers' understandings of NOS in both phases of the study at the beginning and the end of the study. Data gained from the questionnaire allowed the researcher to examine whether or not, and what aspects of, the teachers' understandings of NOS had changed during the study. The questionnaire consisted of three parts according to its main objectives. The first part was composed of checklist questions that provided information about the teachers' background (e.g., gender, age, degree of education, science teaching experiences, professional development experiences, etc.). In this questionnaire, the teachers were also asked whether or not they had prior experience conducting classroom action research. The second part composes of the questionnaire was composed of questions that aimed to explore the teachers' understanding of NOS and the last part aimed to explore how they integrated those understandings of NOS into science instruction. The questions items were adapted from the Views of Nature of Science- form C (VNOS-C) developed by Lederman *et al*. (2002) with adjustment to make it more appropriate to a context of Thai elementary teachers. A process by which the researcher acquired the questions that explore the teachers' understandings of NOS can be summarized as the following steps:

1. The researcher studied all NOS aspects relevant to Thailand's National Science Curriculum Standards (IPST, 2003).

2. The researcher reviewed the literature regarding to instruments used to explore or assess students' or teachers' understandings of NOS (e.g., Abd-El-Khalick *et al*., 1998; Akerson *et al*., 2000; Wang, 2001; Lederman *et al*., 2002; Khishfe and Lederman, 2007);

3. The researcher selected a number of questions from the literature, which are relevant to Thailand's Science Curriculum Standards (IPST, 2003) at elementary levels.

4. The selected questions were translated into Thai, and subsequently sent to advisory committees and science educational experts to check their language appropriateness and content validity.

5. The questions were adjusted according to the advisory committees' and the science education experts' comments before being tried out by six elementary teachers who were not the participant teachers.

6. The questions were revised once again before being implemented by the participant teachers.

Moreover, in the last part of the questionnaire, the teachers were asked to determine whether or not they taught NOS in whatever manners in their science classrooms. If yes, they were asked further to describe how NOS was taught. The questionnaire is shown in Appendix C.

Interview

In the interpretive research, interview often is an important data collection method. It is used to understand a social phenomenon from perspectives of research participants or informants. Thus, in addition to the questionnaire, interview was purposively used in this study to explore the teachers' understandings of NOS in more details as it allowed interactions between the teachers and the researcher. As a follow-up, the interview was individual and semi-structured, which aimed to elaborate any of the teachers' responses to the questions in the questionnaire. In doing so, this individual semi-structured interview was conducted one week after the teachers completed the questionnaire so that the teachers had an opportunity to read and clarify their answers in the questionnaire, and also to provide additional information where appropriate. This allowed the researcher to examine whether or not she had made interpretations on the questionnaire data in a congruent way with what the teachers intended to communicate.

Post-instruction interviews were also used to explore how the teachers perceived their experiences of both engaging in collaborative action research and implementing science instructions. The protocol for this interview was rather open and informal when compared to the one used to explore the teachers' understandings of NOS as they also focused on an affective aspect of the teachers. Using a few open-ended questions (e.g., what did you learn in this activity? and how is it useful to you for teaching NOS?), the teachers were encouraged to express freely about their engagement in collaborative action research (or implementation of science instruction), what they have learned about NOS through it, and how it might be useful for teaching NOS to students. Data gained from this type of interview indeed allowed the researcher to examine the influence of the teachers' engagement in collaborative action research on their learning regarding NOS. Like the individual semi-structured one described above, all of the interviews were audio-taped with the teachers' permission in order for the researcher to transcribe for later analysis and/or re-examination, if necessary. A schedule of all the interviews done in the first phase and the second phase of the study is presented in Table 3.2 and 3.3 respectively.

In addition to the interviews, it is important to note that the researcher often had informal conversations with the teachers as she had been in the research setting. During having an informal conversation with each of the teachers, the researcher tried to record main ideas of the conversation with some quotes, if possible, into her field noted instead of recording the whole conversation using an audio recorder. As a consequence, there were some useful data gained from those informal conversations.

Table 3.2 A Schedules of All Interviews Conducted in the First Phase of Research

Teacher	Type of Interview and Number of Interview Conducted	Date	Place	Time (min)
Pikun	Initial interview 1 interview	July 3rd, 2009	School	38.45
	Post-instruction interviews 6 interviews	July 15th, 2009	School	28.22
		July 27th, 2009	School	19.31
		August 5th, 2009	School	18.28
		August 6th, 2009	School	29.29
		August 19th, 2009	School	15.50
		August 24th, 2009	School	12.24
Kanya	Initial interview 1 interview	July 1st, 2009	School	59.06
	Post-instruction interviews 6 interviews	July 16th, 2009	School	26.23
		July 17th, 2009	School	18.05
		August 3rd, 2009	School	13.18
		August 6th, 2009	School	19.28
		August 24th, 2009	School	16.08
		August 25th, 2009	School	11.10
Sunee	Initial interview 1 interview	June 29th, 2009	School	46.32
	Post-instruction interviews 7 interviews	July 14th, 2009	School	44.27
		August 6th, 2009	School	21.44
		August 20th, 2009	School	13.50
		August 25th, 2009	School	5.21
		August 26th, 2009	School	6.40
		September 1st, 2009	School	8.53
		September 3rd, 2009	School	4.46

Table 3.3 A Schedules of All Interviews Conducted in the Second Phase of Research

Teacher	Type of Interview and Number of Interview Conducted	Date	Place	Time (min)
Pikun	Post-instruction interviews 5 interviews	February 10th, 2010	School	25.67
		February 15th, 2010	School	10.31
		February 19th, 2010	School	14.06
		February 22nd, 2010	School	9.04
		February 26th, 2010	School	10.14
	Final interview 1 interview	March 4th, 2010	School	49.09
Kanya	Post-instruction interviews 7 interviews	January 28th, 2010	School	8.59
		February 3rd, 2010	School	12.05
		February 8th, 2010	School	11.48
		February 10th, 2010	School	22.18
		February 11th, 2010	School	10.13
		February 17th, 2010	School	10.33
		February 19th, 2010	School	23.12
	Final interview 1 interview	March 3rd, 2010	School	59.24
Sunee	Post-instruction interviews 7 interviews	February 2nd, 2010	School	16.28
		February 3rd, 2010	School	10.08
		February 9th, 2010	School	15.20
		February 12th, 2010	School	30.02
		February 16th, 2010	School	21.49
		February 22nd, 2010	School	21.57
	Final interview 1 interview	March 6th, 2010	Home	79.01

Observation

In the interpretative research, the researcher needs to immerse himself or herself in the research setting to understand what being studied. Thus, observation becomes a powerful data collection method. In this study, classroom observation was used to gather data regarding the teachers' teaching practice related to NOS. Used together with data gained from the interviews, extended classroom observations allowed the researcher to examine whether and how the teachers translated their understandings of NOS into classroom practice. During observations, the researcher interacted with each of the teachers and used field notes to record what happened in the classroom such as classroom contexts, classroom events, and quotations of the teachers and/or students. Field note also allowed the researcher to record her reflection, as it emerged, on what is being observed. Table 3.4 and 3.5 shows all classroom observations undertaken in the first phase and the second phase respectively.

Table 3.4 Classroom Observations Undertaken in the First Phase of Research

Teachers	Classroom Observations		
	No.	**Date**	**Key Content**
Pikun	6	July 15th, 2009	The relationship between living things
		July 27th, 2009	Food chain
		August 5th, 2009	The water resource
		August 6th, 2009	The water resource in our community
		August 19th, 2009	Properties of water
		August 24th, 2009	The quality of water
Kanya	6	July 16th, 2009	Plants in our community
		July 17th, 2009	My favorite animals
		August 3rd, 2009	The growth of animals
		August 6th, 2009	History of Science Day in Thailand
		August 24th, 2009	What factors affect animal growth
		August 25th, 2009	The animals preservation

Table 3.4 (Continued**)**

Teachers	Classroom Observations		
	No.	Date	Key Content
Sunee	7	July 14th, 2009	The structure of plant (Leaves)
		August 6th, 2009	The structure of plant (Fruits)
		August 20th, 2009	The structure of Plant (Flower)
		August 25th, 2009	My favorite pets
		August 26th, 2009	Survey animals
		September 1st, 2009	The movement of animals
		September 3rd, 2009	The benefits of animals

Table 3.5 Classroom Observations Undertaken in the Second Phase of Research

Teachers	Classroom Observations		
	No.	Date	Key Content
Pikun	5	February 10th, 2010	Sunrise and sunset
		February 15th, 2010	The movement of the sun and directions
		February 19th, 2010	The day and the night
		February 22nd, 2010	The Moon and its movement
		February 26th, 2010	The Stars and their movement
Kanya	7	January 28th, 2010	The solar system
		February 3rd, 2010	
		February 8th, 2010	Developing a model of the solar system
		February 10th, 2010	The groups of planets and the earth
		February 11th, 2010	The moon
		February 17th, 2010	Asteroids, comets and meteorite
		February 19th, 2010	Astronomers and their works
Sunee	7	February 2nd, 2010	The sky during the day
		February 3rd, 2010	The sun
		February 9th, 2010	The day and the night
		February 12th, 2010	Sunrise and sunset
		February 16th, 2010	The moon
		February 22nd, 2010	The star
		September 3rd, 2009	Works of astronomers

It is important to note that a video recorder was used during classroom observations with the teachers' permission in order to enable the researcher to review any classroom events and to capture other information, which has not initially been recognized, during classroom observations. This allowed the researcher to reinterpret the data gained from classroom observations as often as possible. On some occasions, the researcher asked the teachers to see records of the classroom observations so that they could have shared interpretations on those.

Discourses of collaborative action research

Observations were also used as a data collection method while the teachers and the researcher were engaging in discourse of collaborative action research. What the teachers and the researcher had been discussing during they were engaging in discourses of collaborative action research served as important data particularly used in addressing the second research question. As both a facilitator of collaborative action research and as a researcher who is collecting data, the researcher kept records on what was happening in the discourses in addition to the use of a video recorder. Both written and electronically recorded data allowed the researcher to monitor and examine what about NOS the teachers paid attentions to and how it could influence on the teachers' understandings of NOS and, subsequently, science instruction. As previously presented, Table 3.1 shows all the discourses of collaborative action research undertaken in the second phase of the study.

A Collection of Related Documents and Artifacts

In the interpretative research, documents often are useful sources of data. They could be used to track and remind the researcher of what happened in the research setting. In this study, a collection of related documents and artifacts produced in both phases were used as additional data. Those documents and artifacts included copies of group-meeting notes both recorded by the teachers and the researcher, schedules, lesson plans, teaching materials, teacher journals, and student work. These allowed the researcher to review and revisit what happened during the study, and sometime served as a starting point to gain additional data as necessary. They were also useful for triangulation with the data collected by other methods as well.

Data Analysis

Data analysis in the interpretative research is usually conducted simultaneously with data collection (Lincoln and Guba, 1985). Bogdan and Biklen (2007: 159) refer to data analysis as “the process of systematically searching and arranging the data from a variety of source material such as interview transcripts and field notes that enable the researcher to come up with findings.” That is, data analysis is the process of making meaning of the data. It is the way in which the researcher attempts to construct meanings of the data and make those meanings explicit to others. Therefore, the process of data analysis involves the researcher’s interpretation on the data.

While there are a variety of ways and techniques of analyzing qualitative data, the constant comparative method was selected and purposively used in this study. According to Strauss and Corbin (1990), there are three steps in the data analysis process: open coding, axial coding and selective coding. The first step, open coding, involve generating categories of information through close examination of the data. During this step, the data are broken down into discrete parts, closely examined, compared for similarities and differences, and questions are asked about the phenomena as reflected in the data. The second step, axial coding, is the part of selecting one of the categories and positioning it within a theoretical model. During this step, the researcher builds a model of the phenomena that includes the conditions under which it occurs, the context in which it occurs, the action and interactional strategies that describe the phenomena, and the consequences of these actions. The third step, selective coding, involves explicating a story from the interconnection of these categories. The researcher validates the hypothesized relationships with the data available and fills in categories that need further refinement and development.

However, it is important to note that, even though the data analysis process is described in terms of the three steps discussed above, the researcher is actually moving back and forth with the data, analyzing and then collecting more data, and then analyzing some more. The steps rarely occur in a liner fashion but recur as often as is necessary to reach the appropriate conclusions (Lincoln and Guba, 1985; Mertens, 1998; Bryman, 2001).

Establishing Trustworthiness of the Study

Trustworthiness is referred to as criteria to determine whether or not the findings of this study are worth taking into account. To establish the trustworthiness of this study, the researcher had immersed in the context of the study for one academic year in order to obtain substantial data. Being in the context of the study for a substantial period of time allows the researcher to examine how the teachers have developed their understandings of NOS and how they have improved their teaching practices in details. It also allows the researcher to develop relationship with the teachers, so that they can trust the researcher and feel free to express their perspectives. This means that the researcher with the extended rapport was open to substantial data for examining how the teachers engaged in collaborative action research and how they have learned about NOS.

In addressing the research questions, the researcher used a number of data collection methods to gather substantial data, which include teacher interviews, classroom observations, group discussions, and a collection of documents (i.e., instructional materials, lesson plans, teacher journals, student work, and the researcher’s field notes). Using a variety of data allowed the researcher to do triangulation or to examine consistency or inconsistency among different data. Moreover, audio- and video-recording of what happened during data collection also allowed the researcher to re-examine the data whenever some relevant events are missing from her awareness. Using such a technical tool, the researcher was able to enhance her interpretations and be more effective in monitoring and adjusting the research process. It is this tool, too, that opened up the researcher to paying more attentions to some particular points that need to be inquired and checked with the teachers.

Throughout the study, the researcher has monitored the emergence of the research process and the development of any working hypotheses on an ongoing basis. She has regularly recorded changes that occurred during the research process and all decisions made to adjust the research process according to the changes. Also, the researcher has consulted the research committees about the adjustment of the research process, so it was possible for her to critically examine appropriateness of her decisions as well as reasonability of her working hypotheses. Moreover, the researcher has recorded how the collected data had been manipulated until the results of the study were achieved and satisfied. The record of data manipulation is always available for later re-examinations. Also with support from the research committees, the researcher's working hypotheses were carefully considered and analyzed in order to be continuously revised to be more consistent with and grounded on the data. All of these processes were conducted throughout the research, not conducted at the end of the research.

Summary of the Chapter

This research study examines the collaborative process of Thai elementary teachers conducting action research to integrate NOS in their teaching practices and to investigate the influence of collaborative action research on elementary teachers' understanding of NOS and teaching practice. The theoretical perspective of this research is based on an interpretive methodological paradigm and a qualitative or interpretive research strategy. To explore the teachers' change in their understanding of NOS and how their instructional practices reflect NOS, a qualitative case study approach was used as a research method.

This study was conducted in two phases: the first phase explores the participant teachers' prior understanding of NOS and instructional practices related to it. The data from Phase I, together with the related data from a variety of documents, are further used in Phase II to support of the process of designing and conducting collaborative action research. The changing of the teachers' understanding of NOS and their attempts to teach reflecting NOS through the collaborative action research are also evaluated.

There were a variety of instruments used in this study: questionnaire, individual semi-structured interview, classroom observations, group discussions in the meetings, and a collection of documents. The content analysis and constant comparative method were used as the analysis procedure of this research. Many strategies such as, multiple methods and sources of data, triangulations, prolonged engagement, and providing thick descriptions were used to ensure the trustworthiness of the research study.

CHAPTER IV

RESULTS OF WITHIN-CASE ANALYSIS

Introduction

This chapter describes what the three participant teachers (named Pikun, Kanya, and Sunee) had experienced and learned about NOS as well as teaching NOS while being involved in this study. The chapter is presented in a case report format. Each case begins with the teacher's personal background and current classroom settings, which are followed by descriptions of her initial understanding of and teaching practices related to NOS accordingly. After that, major developments in the teacher's understanding of NOS after engaging in NOS activities during the workshop are highlighted. Due to what was learned about NOS, the teacher's subsequent attempts to teach NOS in the actual classroom are presented. Each case ends with a brief summary.

Unfortunately, Ladda, one of the teachers who had been a participant in this research died from cancer during the course of this study, and thus her case study was not completed. Thus, a discussion of Ladda's case is not included in the chapter. However it is important to acknowledge that Ladda's involvement in this study made significant contributions to what the other three teachers experienced and learned about NOS. One of Ladda's significant contributions was that she, with support by Kanya, encouraged the other teachers to use astronomy as a content context for conducting collaborative action research since she had attended a workshop about teaching astronomy and had a variety of computer-based instructional media that the teachers could try out. Despite not being familiar with astronomical content, the other two teachers (i.e., Pikun and Sunee) complied with Ladda's encouragement.

Mrs. Pikun's Case

Personal Background

Pikun was 49 years old and taught third-grade science in the participating school. She grew up in a small and poor agricultural family that appreciated the importance of education. As an elementary student, Pikun loved learning science and mathematics and she did quite well in those subjects. Although being a teacher was not Pikun's first intention, an expectation set by her parents influenced her to study in a teacher college for her associate's degree with a major in general science. After taking two years to complete that degree, she was qualified to become a government elementary school teacher at a small public school. After working as an elementary teacher for four years, Pikun had not taught any science subject so she decided to pursue a bachelor's degree in elementary education, instead of science education, during her weekends. Later, she ignored her bachelor's degree in elementary teaching and decided to become a government officer involved in education. In making that decision, Pikun reasoned that she was tempted by a promise of an increased salary. After eight years of working as a government officer, she realized that she rather liked teaching more than working on documents in an office. Pikun thus turned back to the teaching profession again. She had been teaching science at her school for five years when she joined this research project.

At the time of the study, Pikun taught science in six, third-grade classes and an elective course called 'scientific process skills' in five sixth-grade classes, resulting in 17 teaching periods a week. Similarly to other science teachers in the school, Pikun experienced a professional development program held by the school about how to design lessons according to the 2001 school based curriculum. She, and the other science teachers, became involved with the development of the school science curriculum for third-grade students. Besides teaching, Pikun worked as a school librarian, recording books that were borrowed and returned by students as well as maintaining any worn-out books. During the last two years, she received professional development aimed to increase science learning efficiency through a distance training program held by the IPST. She did not receive any professional development experience about NOS.

As a renewed science teacher, Pikun was confident, stating that she loved teaching science and preferred to let students learn by engaging in hands-on activities. On her perspective of teaching and learning science, she mentioned that she aimed to support her students ‘to learn about things around them,’ ‘to be able to use scientific knowledge in any good ways for themselves and for their society’ and ‘to love learning science.’ To her, the students will learn best when they do science projects by themselves. She reasoned that doing a science project affords students opportunities to learn science content, practice scientific process skills, and develop scientific attitude simultaneously. Furthermore, she went on to say, confidently, that she was able to help 80% of her students to love learning science.

Classroom Setting

As previously mentioned, Pikun taught science in six third-grade classes and only one of those classes under her responsibility was focused upon in this study. In that class, there were 32 students (15 boys and 17 girls) of diverse socioeconomic status. The normal arrangement of students’ desks was set according to a traditional format—that is, they were in pairs and in rows—as illustrated in Figure 4.1. There were some learning facilities (e.g., a television and a book case) provided. The classroom was decorated to look like a zoo with many cartoon pictures of animals displayed on the walls. The students’ work and some learning information (e.g., Thai adages and English vocabulary) were positioned on small boards. Surprisingly, there was very little information related to science on display in the classroom.

During her participation in the collaborative action research, Pikun decided to bring the students into another (more interactive) classroom (shown in Figure 4.2.) She was encouraged to do this by Ladda in order to use video and simulation program as instructional media for encouraging the students understanding of intended astronomy content. Moreover, she reasoned that such a classroom setting could allow the students more opportunities to do the activity and discuss in groups.

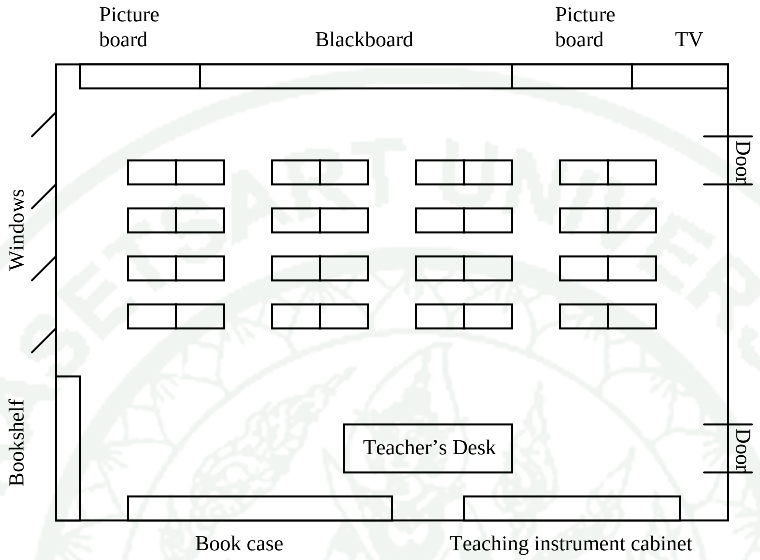

Figure 4.1 Pikun's Normal Classroom Arrangement

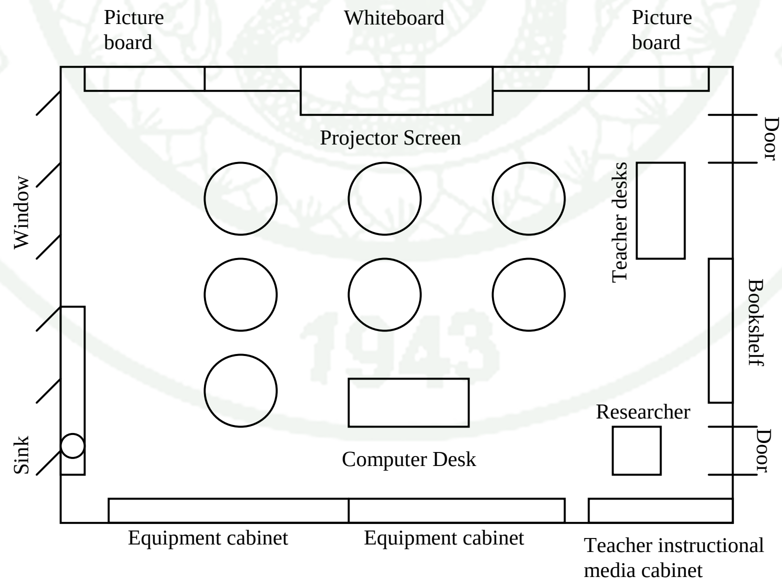

Figure 4.2 Pikun's More Technologically-Supported Classroom Arrangement

Initial Understandings of NOS

At the beginning of the study, Pikun was asked to complete a questionnaire, which was followed up by an individual semi-structured interview about her understanding of NOS. The data analysis showed that she had desired understanding of all three focused aspects of NOS (*Scientific knowledge acquisition, Nature of scientific knowledge, and Interrelation among science, technology, and society*), although she was not familiar with the term 'nature of science' itself. Despite the fact that Pikun did not have an educational background in science, her desired understanding of NOS should not be surprising when considering the fact that she herself loved learning science and had some experiences teaching science at an elementary level. Moreover, it was likely that Pikun's desired understanding of NOS resulted from her personal habit of being an active learner who 'like(s) searching for interesting readings from the Internet' when she wanted to know about something (e.g., NOS). Pikun's understanding of each aspect of NOS is described in what follows.

Scientific Knowledge Acquisition: "It's more imaginative than logically following the scientific method."

Pikun tended to have a naïve understanding of how scientists acquire scientific knowledge, with the scientific method being 'the most common way' to do science. She explicated that the scientific method 'must begin with thinking (and) generating a question, studying (related) information, hypothesizing, and testing the hypothesis' [Initial interview: July 3rd, 2009]. Pikun was however uncertain about whether or not the scientific method must be stepwise. In addition to the scientific method, Pikun elaborated that "science knowledge acquisition" could happen in more than one way:

> There are other ways (for the scientists) to acquire scientific knowledge for sure. I think 80 percent is the scientific method (and the remaining 20 percent is) observing and making notes. [Initial interview: July 3rd, 2009]

Pikun could neither provide any examples of the remaining 20 percent in addition to the 80 percent scientific method answer she gave for acquiring scientific knowledge, nor could she say with certainty where such a ratio came from. However, she believed that scientists' imaginations play significant roles throughout the process by which scientists work to acquire scientific knowledge.

Researcher: Do you think whether or not scientists use their imagination while doing their work?

Pikun: Yes, they do. Indeed, it's (imagination) very important. If the scientists don't have any imagination, there must be no new knowledge. […] they (scientists) use their imagination throughout the process even when they are sleeping, I think. It also occurs at any step (of the scientific method) even at the 'conclusion' and 'discussion' steps. [Initial Interview: July 3rd, 2009]

In addition to her undertsanding that imagination is important throughout the process of acquiring scientific knowledge, Pikun understood that scientists' prior knowledge could influence the scientific knowledge they produce. She tended to understand the inferential NOS, responding to the question of what could possibly make scientists disagree upon causes of the dinosaur extinction by saying, "No one was present during that time (when dinosaurs were extinct) so they conclude differently from available data" [Initial Interview: July 3rd, 2009].

Nature of Scientific Knowledge: "Scientific knowledge is empirically-based and tentative, and derived from human inferences."

In responding to questions related to the nature of scientific knowledge, Pikun expressed her understanding in a manner consistent with science education reform efforts, despite the fact that her spoken words sometimes suggested a realist philosophy. For example, she explained empirically-based NOS as:

> Scientific knowledge is based on facts and reasonableness. It could be able to be proven and experimented on. One can examine its reasonableness. […] Experimental results are empirical and support what scientists have been saying. Scientific knowledge is proven by using experiments that produce empirical results. [Initial Interview: July 3rd, 2009]

According to the response above, one might be tempted to think that Pikun might possess a realist philosophy when she used the terms 'fact' and 'prove.' However, when further probing the response Pikun clarified the term 'fact' as "things that can be observed" [Initial Interview: July 3rd, 2009]. In a similar vein, she expressed that her use of the term 'prove' to mean an action that "scientists seek evidence to support what they suppose to have" [Initial Interview: July 3rd, 2009]. Thus, it is likely that Pikun understood the empirically-based NOS but was struggling to use 'more appropriate' words. Also, she understood the tentative NOS and was able to provide an example:

> Scientific knowledge can be changed. It's not absolutely certain. If there is something confuting (existing scientific knowledge), it will change. For example, it was believed in the past that the Earth was flat but, now, we all are convinced with photos taken from space that the Earth is spherical. [Initial Interview: July 3rd, 2009]

Interrelation among Science, Technology, and Society: "Science is socially and culturally embedded."

Pikun demonstrated some understanding of interrelations among science, technology, and society. That is, she could explain the relationship between science and technology in terms that development of the latter needs knowledge produced by the former. Moreover, she agreed with the statement that science is socially and culturally value-embedded, saying that social and cultural values and needs influence how science progresses.

> Science involves social culture. It's not separate from human society. […] Human thinking and needs always influence science. For example, at present, AIDS is spreading out. So, scientists have to turn their attention to this illness. They have to serve a social need. This is also the case of bird flu. […] Scientific work must be done according to the social context. Scientists have to know what the social needs are and then work on them. [Initial Interview: July 3rd, 2009]

However, Pikun did not mention or tended to ignore that science can in turn influence how technology is developed and advanced as well as how it influences human society. Thus, the data suggests that at the start of this study Pikun had a limited understanding of the relationships among science, technology, and society.

Initial Teaching Practice Related to NOS

Despite the fact that Pikun expressed some desired understandings of NOS, as just illustrated, she was not familiar with the term NOS itself; NOS tended to be a technical term to her. Thus, she interpreted what it means by 'teaching NOS' in a broad sense of teaching science content, scientific process skills, and scientific attitudes without references to any NOS aspects. According to such a broad interpretation of the term NOS, however, Pikun claimed that she taught NOS. For example, in the lesson about living things and their environment, she argued based on her interpretation of teaching NOS that:

> At least, I teach facts as they are apparent in nature (e.g., content about reciprocal relationships with living things and environment). It could also be (scientific) processes such as observing and classifying. […] At the end of instruction, I also emphasize (scientific) attitude (that students must not destroy environments where living things live). [Interview after First Classroom Observation: July 15th, 2009]

Regardless of the indirect approach to teaching NOS through asking the students to observe and classify given things, none of the data gained from six classroom observations indicated that Pikun did *explicitly* teach NOS to her third-grade students. That is, she placed more emphasis on teaching content using a didactic approach. She did sometimes use demonstrations to show the students some particular natural phenomena, which might then be followed by a whole-class discussion. By doing that, Pikun reasoned that such an instructional strategy was appropriate because it served as a solution to the problem that there was inadequate laboratory equipment in the school, and that it was effective in terms of classroom management and gaining student participation.

By the end of the first semester, it was clear that Pikun did not know what the term 'NOS' meant, even though she tacitly possessed an understanding of some NOS aspects. Despite the fact that she sought information about NOS from the Internet, she confessed that she did 'not really understand' such a term. Moreover, she went on to say that, "It's quite hard for me to interpret the term 'nature of science." Consequently, Pikun tended to interpret the term NOS literally, word by word—that is, the former part of the phrase is about nature and the latter part is about science—with no meanings related to contemporary views of NOS. She was struggling with a very broad interpretation of NOS as science content, scientific process skills, and scientific attitudes throughout the first semester.

Learning the Inferential NOS and Scientists' Limitations during the NOS Workshop

During the workshop, Pikun with the other teachers had opportunities to participate in a set of activities designed to communicate important aspects of NOS. With her tacit understanding of NOS, when prompted by the researcher, Pikun contributed what she understood about NOS to the other teachers during the group discussion. It was often her contributions that helped the researcher guide the group discussion towards the intended understanding of NOS aspects more easily. For example, while all the teachers were discussing whether or not a traditional Thai belief of what caused lightening and thunder could be accepted as science, Pikun shared her understanding of empirically-based and tentative NOS in her own terms.

Pikun: There was a change in people's beliefs. When there is some (conflicting) event, any belief can change. In the past, Thai people might have believed it (the traditional Thai belief), but now it changed already.

Researcher: Do you mean that any traditional beliefs are science?

Pikun: I mean knowledge is often derived from people's beliefs. When they studied (a natural phenomenon) and got facts or had other reasons (conflicting that belief), they could change their belief. It's like a change in belief about the Earth's shape.

[Group discussion in workshop: October 20th, 2009]

As noted earlier, Pikun used the term 'facts' in referring to a meaning close to 'empirical evidences,' which can cause a traditional belief change towards more reasonable and reliable knowledge—that is, the tentative NOS. Moreover, Pikun sometimes challenged the other teachers' (e.g., Kanya's) understanding of this NOS aspect in a gracious manner.

Researcher: Do you agree with the statement, "The Earth occurred six billion years ago and there is nothing to change this knowledge?"

Kanya: I think 'Yes' because that statement has resulted from many studies.

Pikun: I agree with, "The Earth occurred six billion years ago," but I would argue with, "There is nothing to change it." I may be thinking too deeply but it must be changeable. I mean scientific knowledge is changeable.

[Group discussion in workshop: October 20th, 2009]

During this episode, Pikun was asked to clarify what she had just said. In doing so, she elaborated further that, "Scientific knowledge could either change or not change, depending on whether there is conflicting evidence. So, we cannot say with certainty there is nothing to change that knowledge." Then, Kanya seemed to internalize that, by saying, "I see. It's the statement that they (scientists) have proposed, but it's likely to be changed." However, it was important to note that the other teachers interpreted Pikun's contributions in different ways, depending on their different prior knowledge and experiences. For example, even though Pikun mentioned many times that scientific knowledge can be changed when new data is acquired, Ladda interpreted this to mean that scientific knowledge changes because of the changing of nature instead.

Insofar as NOS was concerned, Pikun seemed to be the first person, among all the participant teachers, who became aware of the inferential NOS while engaging in the 'Mystery Box' activity even though she did not express it explicitly by using any technical terminology. During that activity, Pikun said:

Pikun:	I use some of my senses (to observe the 'Mystery Box')— seeing, listening, smelling, (and) touching—but not all five. I didn't taste it. [Laughing]
Researcher:	What kind of data did you get after using those senses?
Pikun:	The data might not be totally right. Using our eyes, we can only know its (the Mystery Box's) outside shape. Most of the data is gained from using our ears. This is just the data perceived by our observations. […] We listen (when shaking the Mystery Box) and use the data (gained from listening) together with prior experiences. […] There could be prior experiences, observations, and interpretations.
	['Mystery Box' activity: October 20th, 2009]

At this moment, Kanya then elaborated on Pikun's statement by adding, "According to what we observe, we *infer* that it (what is inside the box) could be this thing (a coin)." Once the term 'infer' was introduced in the discussion, the researcher turned all the teachers' attention toward how human inference plays a role in the process of acquiring scientific knowledge. Such a turn led to a fruitful discussion among all the teachers, through which the inferential NOS was made explicit (for details, see Kanya's case). Once, Pikun became aware of the inferential NOS, the researcher was able to point out that scientists have to make inferences based on their observations because of limitations in their senses to observe things that are too small or too big. Pikun was able to accept what the researcher pointed out easily and she was able to provide an example of objects which scientists cannot directly observe (e.g., atoms). Not until the 'Hole Picture' activity did Pikun understand that, to observe and gain data from what's being studied, scientists can enhance their senses by using instruments.

Pikun:	If the holes were bigger, the data would be clearer and we could make better inferences. It would be better if the number of holes increased also.
Researcher:	What, in scientific terms, can the number of holes be compared with?
Pikun:	The way that scientists gain data.
	['Hole Picture' activity: October 20th, 2009]

By the end of the workshop, Pikun's tacit understandings of the empirically-based and inferential aspects of NOS had become more explicit. Moreover, she was convinced after hearing from the research about studies on teaching NOS (e.g., Akerson et al., 2000; Khishfe and Abd-El-Khalick, 2002) that an effective strategy to teach NOS would be to make NOS aspects explicit to students so that they could be able to understand them. It was apparent that she began to construct an image of 'teaching NOS', and also became aware of the importance of teaching NOS to her third-grade students, expressing that:

> As I engage in the activities (during the workshop), I think I better understand (NOS). I confess that I had never paid attention to it (NOS) until you came to ask me. Of course, I have noticed it in the (national science) curriculum but it's not enough to understand it in details. […] I just focus on teaching content. [Third Group Meeting: January 29th, 2010]

Translating the Empirically-Based and Inferential NOS into Classroom Practice

The workshop seemed to achieve its aim in the sense that after participating, Pikun appeared to gain a richer understanding of NOS. Her increased awareness of the importance of teaching NOS to her third-grade students was evident: as she said, "I think it's (NOS) necessary for the students to learn. If they know it, they could learn science better." She went on to express her intention of teaching NOS in group discussion:

> I must teach them to understand how scientists work until they (scientists) obtain knowledge. What seems to be basic for them to learn science is about (the difference between) observation and inference. […] I want them to know (that scientific knowledge) is empirically-based. [Second Group Meeting: December 18th, 2009]

As a consequence, Pikun decided to teach these aspects of NOS even though she was recognized that she was 'not quite familiar with astronomy (i.e., the content to which the NOS aspects were integrated).' As earlier noted at the outset of this chapter, Pikun's decision was influenced by the other teachers' (i.e., Ladda's and Kanya's) encouragement.

Data gained from five classroom observations during the second semester on an instructional unit about the sunrise and sunset indicated that Pikun continued to emphasize the presentation of science content in the same manner as she did in the first semester. However, during her teaching she explicitly mentioned aspects of NOS where appropriate. However, Pikun's inclusion of NOS aspects appeared to be an emergent feature of her teaching that depended on her real-time decision–making, rather than something she planned. This is shown in the following excerpt:

> While teaching, I may think of an NOS aspect so I may immediately add it (into the instruction). But, after teaching it (the NOS aspect) for a while and I feel it doesn't work, I may take it out (of the instruction). [Fourth Group Meeting: February 12th, 2010]

It appeared that Pikun would mention particular NOS aspects that came to mind while teaching, even though this was not written into her lesson plans. For example, during a lesson where she planned to introduce her third-grade students to the difference between observation and inference, she introduced the idea that a scientific model is not a copy of reality.

Pikun:	Today, we're going to learn about sunrise and sunset. Some of you asked me why the sun rises in the East and why it sets in the West. To understand how sunrises and sunsets occur, scientists have *observed* the sun and its position in the sky at different times. Let's take a look at this (a model of the Earth). What does the Earth look like?
Students:	Round.
Pikun:	Is it (the Earth) exactly like this (the model)?
Students:	No.
Pikun:	Do you know why scientists don't make it exactly same as the real Earth? Is that easy to do?
Students:	No.
Pikun:	Yes. It must be complicated. So, they must develop a model to represent what they want to observe or study. The model they develop can help us study and learn (about the Earth) more easily since we cannot go into the space to see what the Earth's shape actually looks

like. Also, scientists use it to further study and understand phenomena (related to the Earth).
[Second Classroom Observation: February 15th, 2010]

This example illustrates that Pikun introduced her students to the idea that a scientific model is not a copy of reality even without explicitly planning to teach this NOS concept. Pikun came back to the NOS aspect she had planned to teach (i.e., the difference between observation and inference) in the last ten minutes of the period after she presented scientific content about how the Earth turns itself around, which was a response to the student question of why the sun rises in the East and sets in the West. To teach this, she showed the students some pictures of sunrises (and sunsets) from different places in Thailand before asking them to observe and infer from those pictures. By the last picture, Pikun's third-grade students appeared to be able to distinguish the difference between observation and inference as illustrated by the excerpt below.

Pikun:	According to this picture, what do you observe?
Students:	Water (e.g., the sea); the sun.
Pikun:	This is data we gain from observation. In which region of Thailand, do you think this picture was photographed?
Students:	The south.
Pikun:	How do you know that? You observe the sea and the sun and then you infer that the place in the picture could be the south. Is this either observation or inference?
Students:	Inference.
	[Second Classroom Observation: February 15th, 2010]

However, it was not possible to judge whether all of Pikun's third-grade students were able to distinguish the difference between observation and inference since she did not use any assessment other than listening to some student responses during the whole-class discussion. Consequently, Pikun repeated teaching that same NOS aspect in the next period to check whether her third-students were able to apply an understanding of the difference between observation and inference to another situation. Given a picture of the moon at night, the students were asked to answer whether the picture was photographed during daytime or nighttime. It appeared that her students were able to make inference that the picture was photographed during nighttime based on their observation of the dark background in the picture. Pikun believed she has been successful in teaching her students the difference between observation and inference.

> According to what they (students) answered (during instruction), I could say with 100 percent certainty that most of them understand. They can answer what they observed and be able to infer which time it was (from the photograph). Also, they can say where such an inference came from. It's from observation. [Interview after Second Classroom Observation: February 15th, 2010]

As the second semester continued Pikun went on to explicitly teach other NOS aspects in addition to the inferential NOS. Using an understanding of the inferential NOS as a starting point and using the 'Mystery Box' activity as a context of learning, she introduced her third-grade students to the imaginative, empirically-based and tentative aspects of science. Also, she linked those NOS aspects with scientists' work. At the end of the activity, she explained to her students that:

> When doing this (Mystery Box) activity, you cannot open the box so you don't know exactly what's inside it. However, you can observe it by shaking and listening to its sound. By doing this, you can infer what's inside the box. Do you think if what you have done (during the activity) is similar to how scientists work? Scientists observe the moon and its position in the sky and ask themselves whether or not the moon orbits the Earth. […] Oftentimes, scientists cannot directly observe what they are studying. We cannot observe a living dinosaur, for example. Thus, scientists use all available data such as fossils and then imagine what a dinosaur looks like. […] Since scientists infer based on data they have, it isn't necessary for them to obtain the same result

(e.g., inference). It's like what we have done in this activity. We have the same data but we have different inferences. Thus, scientific knowledge may change when new evidence is obtained. [Fifth Classroom Observation: February 26th, 2010]

By nearly the end of the second semester, Pikun became aware that she 'like(s) teaching the nature of science' even though 'it's new' to her. She also argued that science teachers have to emphasize any NOS aspect many times wherever and whenever appropriate until students understand it. However, Pikun recognized that sometimes her instruction went 'not so smoothly' and she suspected, based on her personal experience of teaching NOS, that what hindered her in teaching NOS effectively was her weak content knowledge.

As I told you previously, I'm not familiar with this content (i.e., astronomy) so I'm not confident teaching it. I don't know what kinds of key ideas of that content my third-grade students are able to understand. The problem is not about NOS but the content itself. I don't know how to begin adding NOS into the content being taught. [Interview after Fifth Classroom Observation: February 26th, 2010]

In summary, Pikun's case illustrates that elementary teacher may have some tacit understanding of NOS, which need to be supported and supplemented in order for them to be able to teach NOS in the actual classroom. It appears that providing particular activities that affirm or activate the teacher's tacit understanding of NOS may be necessary to advance the teaching of NOS (Akerson and Abd-El-Khalick, 2003). In Pikun's case, the opportunities to engage in the activities during the workshop affirmed her tacit understanding of NOS, which she made more explicit in group discussions. Additionally, listening to what the other participants, including the researcher, understood about NOS appeared to help her to solidify and perhaps re-conceptualize her own understanding of NOS. Engaging in the activities also may have helped her construct an image of what 'teaching NOS' could look like in her own classroom. Ultimately, Pikun was able to explicitly teach certain aspects of NOS (e.g., inferential NOS) to her third-grade students. However, Pikun's limited understanding of the Astronomy concepts in which NOS was to integrated appeared to be a factor that influenced her ability to translate her understanding of NOS into classroom practices (Schwartz and Lederman, 2002).

Mrs. Kanya's Case

Personal Background

Kanya was 51 years old and taught fourth-grade students at the participating school. She had grown up in a large agriculturist family that admired government officers who had a high level of education. So, Kanya had been encouraged to get as much education as possible in order to become a government officer. As a result, she committed herself to becoming a government teacher—the profession she was most familiar with. As Kanya was interested in science since she was young, she decided to study in a faculty of education with a major in chemistry in a teacher college. Once she got a bachelor's degree in chemistry teaching, Kanya was qualified for teaching in a rural elementary public school. Surprisingly, she taught many subjects, but not science, for the six years she spent in that school. Kanya began teaching elementary science when she moved to her present school 22 years ago.

At the time of this study, it was the tenth year that Kanya had taught fourth-grade science. She was responsible for six classes overall, resulting in 18 teaching periods a week (three periods a week for each class). Moreover, as she was one of a handful of elementary teachers who had an educational background in science, Kanya was selected by the principal and other teachers to be the head teacher of the school's science department. According to that additional role, she was responsible for reviewing and, if necessary, revising the school's science curriculum at all grade levels, which were developed by other teachers in addition to her. After having professional development experience and continuously getting involved in curriculum development, she became a science specialist teacher[1] when she developed and implemented an instructional unit on astronomy two years ago.

Kanya expressed that she loves teaching science and prefers to let students learn through hands-on activities. She believes that hands-on activities are needed that allow the students to experience scientific processes authentically, in order for them to acquire scientific knowledge. According to her, students learn best when they 'discover' knowledge by themselves. Furthermore, she believes that students should have opportunities to work collaboratively. As a busy teacher, she confessed that she sometimes did not have enough time to prepare instruction.

Classroom Settings

As previously mentioned, Kanya taught science in six, fourth-grade classes. Of those classes, one was focused upon in this study. In that class, there were 37 students (18 boys and 19 girls). The normal arrangement of students' desks was in pairs and rows as illustrated in Figure 4.3. However, when the students had to do group work, Kanya usually asked them to sit on the floor around the classroom. Similarly to Pikun's classroom, the students' work, pictures and information (e.g., Thai adages and English vocabulary) were posted in Kanya's classroom. Little space was devoted to information related to science.

In addition to the normal classroom arrangement, Kanya sometimes brought her students into another classroom, which had more technological facilities, when she wanted to use a computer and projector available in the class in order to show the students a video or a simulation of the intended content. In that classroom, student desks were arranged in groups as illustrated in Figure 4.4. Such a classroom

[1] Teachers in Thailand can be classified into four levels (i.e., teacher, senior teacher, specialist teacher, and senior specialist teacher), which relate to their maximum level of salary (ONEC, 2000). To upgrade his or her level, a teacher has to do and submit some academic work (e.g., conducting classroom research and developing instructional innovation) to be assessed by educational scholars. Mrs. Kanya is one of specialist teachers in the province who achieve at the third level.

arrangement, Kanya reasoned, could allow the students to work and discuss in groups more easily.

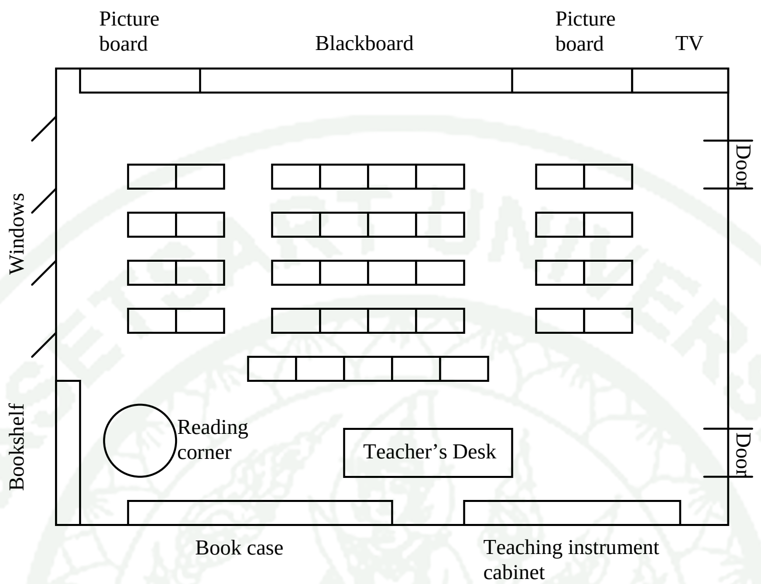

Figure 4.3 Kanya's Normal Classroom Arrangement

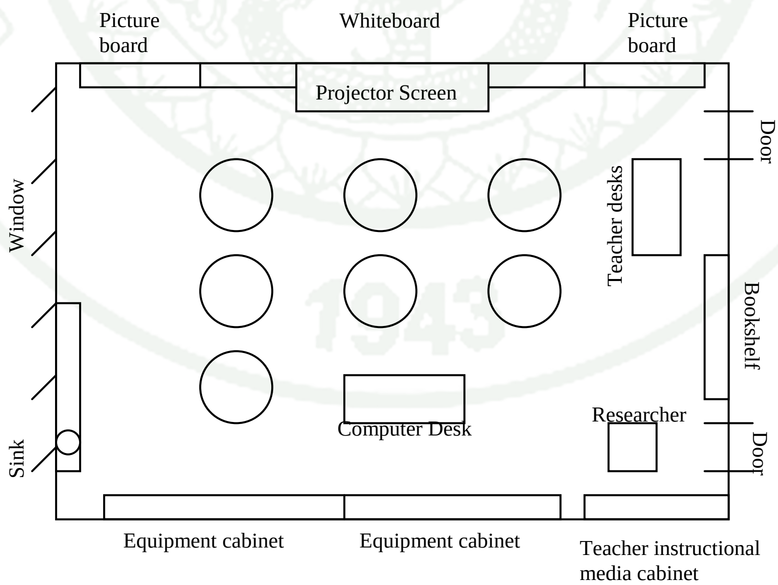

Figure 4.4 Kanya's More Technologically-Supported Classroom Arrangement

Initial Understandings of NOS

At the beginning of the study, Kanya was asked to complete a questionnaire, which was followed up by an individual semi-structured interview, about her understanding of NOS. The data analysis showed that, in all three focused aspects of NOS, Kanya had understandings of some NOS aspects and lacked understandings of other NOS aspects. In general, she understood that science aims to explain natural phenomena and that science produces knowledge used to develop/improve daily human life. According to her, NOS is about scientific processes used to acquire scientific knowledge. Therefore, teaching NOS means, to her, helping students acquire scientific process skills. Similarly to teachers in other studies (e.g., Abd-El-Khalick *et al*., 1998), Kanya appeared to confuse NOS with scientific processes.

Scientific Knowledge Acquisition: "It's as simple as following the scientific method."

Kanya's understanding of scientific knowledge acquisition was naïve, even though she mentioned that 'there could be various ways' that scientists acquire scientific knowledge. However, she was unable to provide any examples of these "other ways" that went beyond 'the most common way' by which 'scientists begin with observing [and] collecting (data), experimenting, searching for related information and concluding (the data gained) into knowledge.' [Initial Interview: June 29th, 2009] Moreover, according to Kanya, skipping one of the steps could reduce the reliability of scientific knowledge.

> It is a process (of acquiring scientific knowledge). Suppose they (scientists) observe [and collect data] but do not experiment and search for more information, they cannot analyze the data collected. There should be a stepwise procedure so that they can obtain a reliable conclusion. [Initial Interview: June 29th, 2009]

However, Kanya provided an exception to the statement above in that ‘expert scientists’ may not have to strictly follow such a stepwise procedure. They can skip some unimportant steps such as searching for related information since those ‘expert scientists have worked on what is being studied for a long time.’ From this, it was apparent that Kanya’s understanding was close to the myth that “a general and universal scientific method exists” (McComas, 2000: 57). Additionally, once Kanya was prompted to answer the question of whether or not scientists’ imaginations and creativity play a role in their work and subsequent knowledge they produce, she expressed that:

> Creativity and imagination are part of the process of acquiring scientific knowledge. It (scientific work) begins from imagination. […] Scientists use imagination while designing and doing an experiment. They may ask what would happen next if the result goes this way, for example. […] During the step of making a conclusion, there is no imagination involved. It (the conclusion) must only come from real data. [Initial Interview: June 29th, 2009]

This comment suggests that Kanya did not have a deep understanding of the role that imagination and creativity play within scientific working. She appeared to believe that only at the beginning of a scientific endeavor or study did imagination and creativity play a role in scientific working; but not at moment of making a scientific claim. That is, she was not aware that scientists can draw on their imagination when developing an explanation of what is being studied, nor that scientists regularly make inferences about data gained from observations.

Nature of Scientific Knowledge: “Scientific knowledge is empirically-based, subjective, and tentative.”

In responding to questions related to the nature of scientific knowledge, Kanya expressed her understandings in ways that are consistent to science education reform efforts (e.g., Abd-El-Khalick and Lederman, 2000; Lederman *et al.*, 2002). She understood that scientific knowledge is empirically-based, as she argued that:

> When they (scientists) are doing an experiment, they have to look at data carefully. Even though someone else studied it, they have to re-study further whether or not it goes that specific way. If not, there must be a reason provided. […] Scientific knowledge must begin from observation. [Initial Interview: June 29th, 2009]

As the excerpt above suggests, Kanya understood that scientific knowledge is derived from scientists' observations. She also believes that scientific knowledge is built in part from the opinions of scientists:

> Scientific knowledge partly results from opinions. […] Scientists may have opinions on what they are studying and those opinions may be put into scientific knowledge. [Initial Interview: June 29th, 2009]

That is, Kanya demonstrated an understanding that scientists' observations are likely to be theory-laden and subjective as they have some particular opinions upon what is being studied. She was also aware that scientists can challenge existing knowledge when new findings emerge as they continue to observe what is being studied. In other words, she understood the tentative NOS.

> Scientific knowledge occurs all the time. (Scientists) can always find new evidence. So, it's not surprising if someone comes to challenge the existing knowledge—the Earth's shape, for example. Recently, we were given a reason why Pluto is not a planet anymore. […] Scientists are always open-minded if there is evidence suggesting new knowledge. [Initial Interview: June 29th, 2009]

Interrelation among Science, Technology, and Society: "One-way relationship among science, technology and society."

Nearly at the end of the interview, Kanya responded to the question of how science, technology and society are related together. Her response suggested that she held a directional view of these interrelations:

> Scientific knowledge leads to technology. There must be scientific knowledge before the occurrence of technology. As many scientific studies are undertaken, many kinds of technology will subsequently occur. This (technology) results in changes in environments. [Initial Interview: June 29th, 2009]

When asked for other relationships among science, technology and society, Kanya could 'not recall anything else.' This suggests that her understanding of interrelations among science, technology and society was limited.

Initial Teaching Practice Related to NOS

In addition to the initial interview, the researcher observed Kanya's fourth-grade class in order to know whether and how she taught any NOS aspects. As previously mentioned, Kanya appeared to confuse NOS instruction with instruction that helped the students gain scientific process skills. This confusion is evident in the following explanation:

> The teaching nature of science is about the 13 scientific process skills … such as exploring, searching, experimenting, and so on. […] The teacher can let students do an experiment, or let them investigate and explore (some natural phenomenon). […] Many of the scientific process skills could be integrated in such activities. It is about the 'nature of science' instruction. [Initial Interview: June 29th, 2009]

The excerpt above clearly suggests that Kanya held the assumption that students will come to understand NOS by engaging in scientific inquiries and/or investigations rather than by paying explicit attention to NOS (Abd-El-Khalick and Lederman, 2000). Consequently, she claimed quite confidently that she had been teaching NOS since she emphasized to students the importance of practicing those scientific process skills. Research has shown that such an assumption is not valid (Abd-El-Khalick *et al*., 1998).

Data gained from six classroom observations of lessons on plants and animals indicated that Kanya usually taught science through the didactic approach. Unlike what she mentioned in the initial interview, she rarely provided opportunities for her students to engage in hands-on activities. In response to this, she confessed that frequently she could not implement lesson plans exactly as how she had intended. She argued further that contextual factors (e.g., time and equipment) limited her ability to implement those lesson plans in the actual classroom. Therefore, what she normally did was ask the students to observe things (or pictures of things) and group those things using either a given criterion or student-developed criteria. She argued that these activities reflected some NOS aspects.

> I do (teach NOS). At least, I have the students observe and classify leaves. They have to observe and think of it (how to classify different kinds of plants). The nature of science is about process skills (e.g., observing and classifying). As you can see, some (students) can classify those leaves into two or six groups. [Interview after First Classroom Observation: July 16th, 2009]

Insofar as NOS was concerned Kunya's observed instruction indicates she used an implicit approach to NOS instruction (Abd-El-Khalick and Lederman, 2000) as she allowed her students to 'do science' (e.g., observing and classifying things). However, she did not explicitly mention to her students that in order to classify anything, they need to draw upon their imagination and creativity. Nor did she emphasize to her students that it is okay to come up with different results, even if they have the same set of data, because conclusions are in-part products of imagination and creativity.

Learning the Inferential and Imaginative NOS during the Workshop

Despite the fact that Kanya engaged in activities designed to communicate various NOS aspects, it was most apparent that Kanya learned and appreciated inferential and imaginative NOS due to Pikun's contributions and the researcher's facilitations. At the beginning of the workshop, Kanya still believed that human imagination does not play a significant role in scientists making meaning from the data they collect, though she did believe imagination was important when they were designing an experiment. This belief was apparent again when Kanya discussed an ancient Thai explanation for the cause of lightening and thunder:

> I think people in the past could not explain what was happening (lightening and thunder). So they thought and imagined in order to understand and explain it. […] It was not science. It was just derived from imagination (or) belief. [Group discussion in workshop: October 20th, 2009]

Although what Kanya stated is reasonable in the sense that the Thai explanation is not scientific, her comment seems to suggest that she did not believe that imagination plays an important role in the development of scientific explanations.

Kanya's understanding of the inferential and imaginative aspects of NOS appeared to occur during the 'Mystery Box' activity. In that activity, she and the other teachers were asked to respond to the question, "What's inside the box?" after having interactions with it. Although Kanya made many inferences based on her observations, she was not aware that she was making inferences. At best, Kanya mentioned that, "We use many ways to know the answer such as shaking it. And then, we *guess* what could be inside the box." Kanya's use of the word 'guess' suggests that she had some implicit understanding of making an inference from the data. Once Pikun pointed out that, "It (the way to know what was inside the box) begins with observing and guessing […]. We put some *personal opinions* on it (guessing),” Kanya then was able to further clarify her idea:

> According to what we observe, we *infer* that it (what is inside the box) could be this thing (a coin). [Group discussion in workshop: October 20th, 2009]

Once the term ‘infer’ was introduced into the discussion, the researcher turned the teachers’ attention to how human inference plays a role in the process of acquiring scientific knowledge. Such a turn led to a fruitful discussion among all the teachers.

Researcher:	Scientists try to explain a natural phenomenon, which they want to know how it happens. But, it is very often that they cannot directly observe what they are studying. It’s like all of you cannot directly see what’s inside the box. What should they do so?
Pikun:	They use prior experiences.
Researcher:	Yes, they do. So, it means that they acquire scientific knowledge using… [Interrupted]
Pikun:	[Interrupting] Both their prior experiences and observation.
Kanya:	They put some personal opinions into it.
Researcher:	Do you think that is always true?
Kanya:	Some of them are but sometimes others may be not.
Researcher:	And, what will the scientists do to make other people believe in scientific knowledge they develop?
Kanya:	There must be data supporting it.
	[Group discussion in workshop: October 20th, 2009]

At this moment, Kanya seemed to understand that human inference plays an important role when scientists want to know about things that they can not fully observe. Her last point in the above excerpt, illustrates that Kanya made a link between the empirically-based and inferential NOS. The empirically-based NOS is what she understood prior to the study while the inferential NOS is what she learned during the workshop.

After participating in the 'Great Fossil Find' activity, Kanya was convinced that scientific knowledge is partly a product of human inference and imagination. This happened after she was presented with a set of fossil-fragment pictures and then asked to make a detailed diagram of them. In doing so, Kanya and the other teachers had to make inferences of what particular animal the fossil-fragment pictures represented. During this process, all the teachers, including Kanya, made many inferences, saying, "It could be a reptile (Kanya)," "It could be a carnivore cause its fangs are quite long (Ladda)" and "This may be a wing (Kanya)." At the end of the activity, the researcher initiated a discussion in order to point out to the teachers the imaginative aspect of NOS. It was apparent in the discussion that Kanya understood this NOS aspect quite well.

Researcher:	When scientists are doing their work, do they use imagination?
Kanya:	They do.
Researcher:	Is their imagination just some drivel?
Kanya:	No, it's not. It must be reasonable based on available data.
	['Great Fossil Find' activity: October 20th, 2009]

A similar moment occurred during the 'Hole Picture' activity where the researcher went on to emphasize the imaginative aspect of NOS. Using this activity, Kanya and the other teachers were presented with the idea that scientists have to use their imaginations because when they cannot directly observe what is being studied. Following Pikun's contribution, the researcher used 'atoms' and 'dinosaur extinction' as examples. At this moment, Kanya held the belief that imagination must have an explanatory function with regards to the targeted natural phenomenon. This should not be surprising since her understanding before the study began was that science aims to explain natural phenomena. At the end of the workshop, Kanya summarized what she had learned:

> Scientific knowledge *may be* derived from human inference and imagination. If we consider to what extent inference and imagination will be accepted, it depends on reasons and data they (scientists) have and give. This is because no one has actually seen atom. [‘Hole Picture’ activity: October 20th, 2009]

The excerpt above illustrates change and growth in Kanya’s understanding of the inferential and imaginative aspects of NOS as she succeeded linking her prior understanding of the empirically-based NOS with what she had learned. However, her use of the term ‘may’ in the excerpt above suggests that she was still feeling tentative and perhaps needed more time and effort to internalize the newly-learned NOS aspects.

Translating the Inferential and Imaginative NOS into Classroom Practice

Despite the fact that the workshop achieved its aims in that Kanya had better understandings of NOS and more appreciated the importance of teaching NOS to her fourth-grade students than she did prior to the study, it was important to support Kanya to translate what she recently learned about NOS into classroom practice. As Kanya conflated teaching NOS with teaching that helps the students to have scientific process skills, it was necessary to introduce her to research results (e.g., Akerson *et al*., 2000; Khishfe and Abd-El-Khalick, 2002) suggesting that explicitly addressing NOS aspects to her students is more effective in promoting the students’ understandings of NOS than simply engaging them in hands-on or inquiry-based activities without explicit reference to NOS.

In the second semester, Kanya was responsible to teach her fourth-grade students about the solar system. As a science specialist teacher who developed and implemented an instructional unit about astronomy, Kanya was very familiar with astronomical content, including the solar system. With the intention of teaching NOS, she tried to mention any NOS aspects as often as possible using a didactic approach and used questioning technique. Similarly to what she did in the first semester, she rarely used her students' responses in developing their understandings of the focused NOS aspects. Thus, her instruction was implemented as if she was lecturing about the intended NOS aspects to her fourth-grade students. For example:

Kanya:	How do scientists study about astronomy? They *observe* stars in the sky. [Showing a picture of a galaxy] What do you know in this picture?
Students:	Comet; galaxy.
Kanya:	While we are looking at this picture, we are also *imagining*, aren't we? As scientists are looking upon the sky at night, they see so many stars. Some of them try to *explain* how the universe occurs. How do scientists know that our universe looks like this picture? How do they get this knowledge?
Student:	They *observe* … using a telescope.
Kanya:	Besides *observing* and using a telescope, do they *imagine*?
	[First Classroom Observation: January 28th, 2010]

This excerpt illustrates how Kanya tried to explicitly address the imaginative aspect of NOS. However, the students seemed to not understand what she tried to communicate even though they tried to guess what she expected them to say. After this period, Kanya reflected on how in her initial attempts she did not achieve her intention.

> I tried (to mention the imaginative NOS) but I did not succeed. I feel that I cannot explain (how scientists use imagination in understanding the universe). I think that I have to find a clear example. [Reflection on First Classroom Observation: January 28th, 2010]

Kanya recognized that despite having sound content knowledge, she was not certain about where and how to appropriately introduce the intended NOS aspect into the instruction; and, when she tried she felt it was 'not natural.' Not knowing where and how to address the intended NOS aspect could be interpreted in terms that Kanya lacked the necessary pedagogical content knowledge for teaching NOS (Schwartz and Lederman, 2002; Akerson and Abd-El-Khalick, 2003). However, despite recognizing there were problems in her approach to introducing NOS, in her second attempt she still focused on the imaginative aspect NOS using the same didactic approach and questioning technique, as she asked and explained why scientists have to use imagination.

Kanya:	[Showing a picture of the Milky Way Galaxy] Where is our solar system? Here! [Pointing to the position of the solar system in the picture] Where do scientists get information so that they know here is the solar system?
Student:	Using a telescope.
Kanya:	Yes. They use instruments in studying (astronomical phenomena). Do they use only the instruments? What else do they do?
Student:	Making notes.
Kanya:	And then, they use all of what they note to explain where our solar system is in the galaxy. Can they go into the galaxy to study it? It's beyond their ability. […] What do they do if they cannot go there (the galaxy)? What do they use?
Student:	Imagination.
Kanya:	Yes. Scientists can use their imagination if they are studying something too far away from them. However, their imagination must be based on evidence. This is how the scientists work.
	[Third Classroom Observation: February 8th, 2010]

After this instruction, Kanya perceived 'a little improvement.' She argued that she lectured 'more naturally' than ever and was able to 'play with' the students' responses. As can be seen in the excerpt, not only did Kanya explicitly mention the imaginative NOS but also the empirically-based NOS. Also she linked both to scientific working. Being encouraged by 'a little improvement,' Kanya continued her attempt to use lecture to introduce the students to the notion that a model of the solar system is not a copy of reality, but rather is created in order for the scientists to understand and explain the solar system:

> Is this picture (of our solar system) real or just a model? […] Can they go (into the galaxy) to study stars? It's difficult, isn't it? This is because it's far away from us. They have to create a model to explain it instead. Thus, a model itself is not real. It's created to make a clear explanation. [Fourth Classroom Observation: February 10th, 2010]

At the end of the second semester, Kanya perceived that she better understood the imaginative aspect of NOS, saying, "Scientists use their imaginations together with empirical evidence and logical reasoning in order to construct a scientific model that has an explanatory function. Their imagination must be based on evidence or what happens in nature." Moreover, she was more confident and more comfortable teaching the imaginative NOS aspects even though she still used the didactic approach and questioning technique. She said that:

> I feel that the instruction is smoother and I better understand (NOS). If I try three or four more times, it (the instruction) would be much smoother [Laughing]. I can mention (the imaginative NOS) more appropriately. It isn't like my earlier attempts. I tried to add it (the imaginative NOS) even though the situation (i.e., content) did not allow. So, it made me nervous. Now, it (the instruction) is more natural. [Reflection after Seventh Classroom Observation: February 19th, 2010]

During the last interview at the end of the study, Kanya expressed that her understanding of what was meant by 'teaching NOS' was broadened from teaching the students to have scientific process skills towards teaching them to understand how scientists acquire scientific knowledge.

> [Before the study] I had never studied the nature of science so I understood that it was just about scientific process skills. Actually, it's much more than that. It's about the ways scientists use to acquire scientific knowledge. Scientists not only use scientific process skills but also observations, imaginations, and so on. [Post Interview: March 3rd, 2010]

Moreover, Kanya recognized that, to teach NOS effectively, the teacher has to select any NOS aspect(s) relevant to the content being taught as well as to think of which moment to address these aspects appropriately. Her statement supports research suggesting that science teachers should have opportunities to develop pedagogical content knowledge for teaching NOS (Schwartz and Lederman, 2002; Akerson and Abd-El-Khalick, 2003).

> To teach NOS effectively, we (teachers) have to think of which content to teach our students today. What is its key idea and which NOS aspects are relevant to it? Then, we will know how to integrate (the intended) NOS aspects into instruction. This could make the students understand better (thee intended NOS aspects). [Post Interview: March 3rd, 2010]

To sum up, Kanya's case illustrates a challenge that some elementary teacher may have encountered when asked or encouraged to teach NOS—that is, she possessed inadequate understanding of NOS despite having an educational background in science. In addition, Kanya's case also highlights a problematic assumption, which is pervasive among science teachers (including Pikun), namely that students will understand NOS through engaging in inquiry-based activities. Thus, she needed support that helped her to acquire a more appropriate understanding of NOS, and to construct an image of what 'teaching NOS' looks like. She received this support when she engaged in the activities designed to communicate NOS explicitly, and discussed the aspects of NOS with the other participant teachers and the researcher. It was evident that Kanya was able to link her prior understanding of certain NOS aspects to what she learned about NOS through her participation in this study. This finding supports Akerson *et al.*'s (2000) claim that a conceptual change approach can be used to promote teacher learning of NOS. However, while she learned about NOS during the workshop, this learning was not sufficient to prepare Kanya to teach NOS in an actual classroom. She still needed more opportunities to try translating her new understandings of NOS aspects into classroom practice. Indeed, she needed to develop pedagogical content knowledge for teaching NOS (Schwartz and Lederman, 2002; Hanuscin, Lee, and Akerson, 2010).

Mrs. Sunee's Case

Personal Background

Sunee was 44 years old and taught first-grade students at the participating school. She had grown up in a large family with most of the members being teachers. Being surrounded by teachers, Sunee was molded and expected to become a teacher. She recalled that she, as a young student, was good at literacy and art. Although to Sunee, science was 'interesting,' it was 'too difficult.' Thus, after completing lower secondary education, she decided to study in a vocational college with a major in accounting rather than to pursue her higher secondary education. She had never taken any science courses (e.g., biology, chemistry, and physics), leaving her educational background in science at a ninth grade level. After completing a vocational education, which is equivalent to a higher secondary education, Sunee decided to pursue an associate's degree in another college with a major in management.

After spending two years to complete her associate's degree, Sunee had worked on documents for an educational service office, which was 350 kilometers away from her hometown, for fifteen years. It was during this period that she spent her weekends pursuing two bachelor's degrees. One was about advanced management, which was a continuation of her associate’s degree, while the other was elementary education, which was related to her career. Once having obtained a bachelor’s degree in elementary education, Sunee decided to move back to her hometown and worked on documents for her present school. Two years ago, Sunee began teaching science to elementary students because there was a lack of teachers in her present school. Being away from science for a number of years, she was frustrated with teaching science because of her inadequate content knowledge. Only the students’ innocence made her happy working as an elementary teacher.

At the time of the study, Sunee was a first-grade teacher, who taught nine subjects, resulting in 20 teaching periods a week. Of those 20 teaching periods, she taught science 2 periods a week. Besides teaching, Sunee who had skills in document management was responsible for keeping all records related to cost and use of any equipment and materials in the school. To prepare for the introduction of the school-based curriculum introduced in 2001, Sunee participated in a professional development program held by the school that dealt with how to design lessons according to the new school-based curriculum. She and other first-grade teachers were involved with development of the school science curriculum for first-grade students. During the last two years, she had no experiences in professional development in any other domains including NOS.

As a first-grade teacher, Sunee emphasized helping her students to be able to read and write Thai (i.e., literacy) rather than understand natural phenomena (i.e., science). In general, she was interested in doing classroom action research, developing instructional media and knowing more about instructional strategies in order for her to ‘teach better.’ Also, she wanted to learn ‘anything’ about science instruction as she was not familiar with this subject. When asked about the aim(s) of teaching and learning science, Sunee expressed that she aimed to help students ‘know things around them,’ ‘practice scientific process skills,’ ‘be able to solve problems’ and ‘understand nature.’ She went on to say that, to teach science effectively, the teacher should use a variety of instructional media and strategies as well as start from real (i.e., authentic and concrete) things and move to more abstract ideas.

Classroom Setting

As previously mentioned, Sunee taught a total of 9 subjects for a first-grade class, which was also under her advisory responsibility. In that class, there were 24 students (11 boys and 13 girls). Similarly to any traditional classroom, the students' desks were arranged in pairs and in rows as illustrated by Figure 4.5. This classroom arrangement was organized by Sunee herself. However, some learning materials (e.g., color pencils, plasticine, rulers, rubbers, and paper cards) were available for the students to use when needed. Like Pikun's and Kanya's classrooms, students' work, pictures, and information (e.g., Thai adages and English vocabulary) were posted on Sunee's classroom walls with little space devoted for information related to science. As Sunee focused on teaching literacy, she provided a reading area behind the classroom where the students could practice reading and writing skills during their leisure time. Some equipment (e.g., a television and a radio) were available for use.

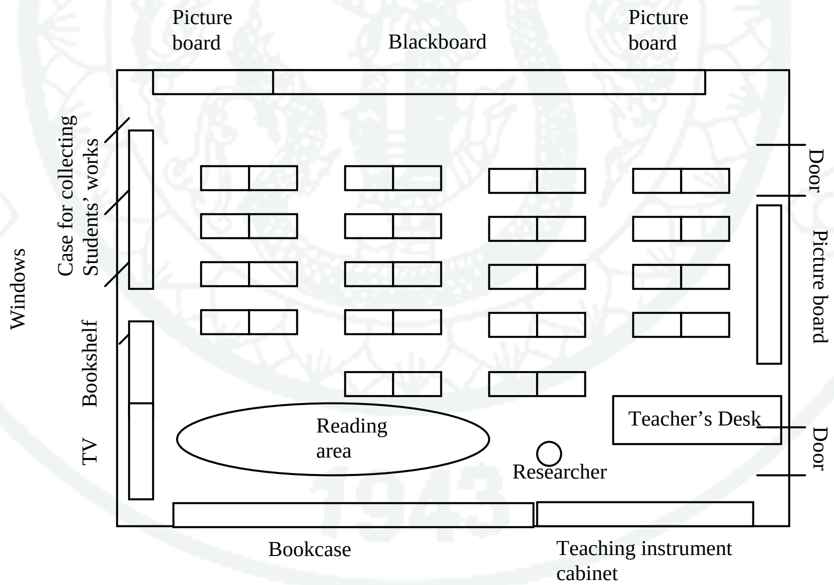

Figure 4.5 Sunee's Classroom Arrangement

Initial Understandings of NOS

Like the other participant teachers, Sunee was asked to complete a questionnaire in conjunction with an individual semi-structured interview about her understanding of NOS at the beginning of the study. The data analysis showed that she possessed a naïve understanding of all three focused aspects of NOS; namely, Scientific knowledge acquisition, Nature of scientific knowledge and Interrelation among science, technology and society. This should not be surprising when considering her educational background and her statement that, “NOS is very new to me.” Thus, when asked to give a definition of NOS, she simply stated, “It’s studying about nature—what can occur spontaneously—such as the sunrise and tides” [Initial Interview: June 29th, 2009]. By saying that, it seemed that she just translated the term ‘nature’ as a part of the term ‘NOS.’

Scientific Knowledge Acquisition: “It’s a logical stepwise procedure of the scientific knowledge.”

Sunee expressed a naïve understanding of how scientists acquire scientific knowledge. Initially, she argued that scientists do their work according to their own interest in order to gain ‘more knowledge.’ That is, they have to do experiments in order to know ‘what really happens.’ She agreed with the statement that ‘scientists have to follow the stepwise procedure of the scientific method’ in order for them to acquire scientific knowledge. She said:

> I agree. To acquire any kind of knowledge—not just scientific knowledge, there must be an order of steps. If one skips any step, it is not likely for them to obtain knowledge that is correct and complete. [Initial Interview: June 29th, 2009]

Sunee added that the scientists may have to study work done by others who are interested in the same or similar things (or phenomena) as they aim to ‘merge the knowledge together.’ Moreover, in her view, when doing scientific work, there was no involvement of scientists’ imaginations or perspectives:

> Imagination’s like dreaming. Scientists won’t use imagination in proving or doing experiments. It (science) is about real things […] Different scientists

> might reach different conclusions even if they have the same set of data. Perhaps, this is because they might have different hypotheses …or (they) might have some kind of errors in their experiment. But, it doesn't come from their perspectives. [Initial Interview: June 29th, 2009]

Hence, what Sunee said at this moment implies that she tended to understand scientific processes as knowledge accumulation. It also implies that she tended to possess a realist epistemology, viewing science as having an aim to 'produce knowledge of an extrasensory world (p.163)' and to 'uncover the hidden nature of reality (p.164)' (Matthews, 1994).

Nature of Scientific Knowledge: "It's absolute truth."

Sunee's realist epistemology became more apparent when she expressed her understanding about nature of scientific knowledge. Despite the fact that she appeared to understand that scientific knowledge is empirically-based as evidenced by her arguments that science knowledge is supported by 'things that we can see everyday' or that 'things occur and manifest in the way that supports scientific knowledge,' she believed that scientific knowledge is 'correct' because it was 'proven true.' That is, she perceived scientific knowledge as something uncovered by scientists. Moreover, despite registering her agreement with the statement that 'scientific knowledge is changeable,' Sunee argued that such a change occurs due to 'a change in the nature' instead of the way in which scientists understand the nature of something is changed. Thus, the tentative nature of scientific knowledge, as understood by Sunee, occurred in the sense of gaining 'more knowledge.' In addition, she viewed scientific knowledge as being authoritative so that people 'must study and believe in it.' She argued that scientific issues (e.g., the explanation for what made dinosaurs extinct) cannot be counted as scientific knowledge because scientists continue to debate these issues and lack specific and certain answers. That is, Sunee did not understand the subjective nature of scientific knowledge.

Interrelation among Science, Technology and Society: "Science is universal and above human society and culture."

Sunee possessed a naïve understanding of interrelations among science, technology and society. She did not understand that science is socially value-embedded, that is, she perceived science as being universal or context- and value-free. She said, "Science is not related to people. In fact, it is universal. They (people) try to be involved with science otherwise" [Initial Interview: June 29th, 2009]. Sunee's statement should not be surprising when considering that she had a realist epistemology as previously discussed. However, when prompted to clarify such a statement in more details, Sunee then expressed broadly:

> Everything in the world is interrelated […] Technology depends on scientific knowledge. Inventing something (technology) must rely on scientific knowledge. Living also depends on science—sleeping and eating depends on science. [Initial Interview: June 29th, 2009]

Unfortunately, there was no example provided for the above statements since Sunee was reluctant to elaborate on this point.

Initial Teaching Practice Related to NOS

After the initial interview, the researcher visited and observed Sunee's first-grade class in order to know whether and how she taught any NOS aspects. Data gained from seven classroom observations confirmed that she neither understood nor knew what it meant to teach NOS. Thus, she was not sure whether or not she had ever taught NOS in her first-grade class. Sunee's reflection after the first classroom observation supported this interpretation.

> Today, I just want students to understand how to observe leaves. I cannot recall what I have told you (about NOS). […] I don't know what NOS is. I don't know how I can teach it. After I consulted with Kanya, I just know a

> little bit more that NOS is about scientific process skills […] but I cannot particularly remember what kind of skills those are. I haven't heard the term NOS until you came to interview me. The term nature could mean characteristics of science or something like that. I'm sure that it doesn't mean nature or the environment. [Reflection after First Classroom Observation: August 6th, 2009]

From the excerpt above, it is clear that Sunee, after being interviewed by the researcher, went to consult Kanya about NOS. Following that consultation she referred to NOS as scientific process skills in much the same way as Kanya. It apears then that Kanya's naive assumption that students would understand NOS through engaging in inquiry-based or hands-on activities (Abd-El-Khalick and Lederman, 2000) was being introduced to and accepted by Sunee. This was an unintended outcome of conducting collaborative action research with teachers in a single school.

During the first semester, Sunee taught her first-grade students lessons about plants and animals. For her lessons she often brought 'real things' (e.g., leaves and fruit) into the classroom so that her students could experience those authentically. On some occasions, she brought the students outside the classroom in order for them to explore animals living in the school (e.g., butterflies and ants). She spent time encouraging the students to observe and draw such things as well as identify components of what was drawn onto prepared worksheets. Since she was not sure what it meant by teaching NOS, despite Kanya's consultation, Sunee was still not certain whether or not she taught her students NOS.

> I don't know. Now, I am teaching about plants. Is that NOS if I bring the students outside (the classroom) to observe real things (local plants)? […] Perhaps, I haven't taught it (NOS). [Initial Interview: June 29th, 2009]

In addition Sunee did not seem to appreciate the importance of teaching NOS to her first-grade students. The most important thing to Sunee was to help her first-grade students to become literate in Thai. She went on to reason that teaching literacy was placed at a higher level on her instructional priorities than teaching science.

> I give more precedence to literacy than science. Although I'm responsible to teach science as well as other subjects, I have to help my students be literate in Thai first. So, I may spend less time teaching science. [Reflection after First Classroom Observation: July 14th, 2009]

Due to that instructional priority, Sunee's solution was that, sometimes, she integrated science into literacy. For example, she would ask the students to observe and draw specific things (e.g., plants and animals) before asking them to write the name of those things onto worksheets. Once the students finished writing, it was time for them to read what they wrote aloud simultaneously. This strategy allowed Sunee to examine whether or not the students were able to write and pronounce Thai words correctly. If not, she was able to correct them. Sunee seemed unaware that there were resources she might have used to combine the teaching of NOS with the teaching of literacy skills (see e.g., Hanuscin *et al*., 2010).

By the end of the first semester, it was clear that Sunee did not know what NOS was and whether or not she taught it. Sometimes, she stated that NOS was about scientific process skills while, at other moments, she mentioned that teaching NOS was teaching according to the students' interests. It is likely that Sunee had acquired such an understanding of NOS through her consultation with Kanya. Having consultation with the other science teachers can be inferred to mean that Sunee wanted to know more about NOS.

Being Challenged by Contemporary Views of NOS during the Workshop

In the workshop, Sunee with the other participant teachers engaged in a set of activities designed to communicate important aspects of NOS. Despite the fact that the activities were intentionally open for the teachers to express what they were thinking related to the underlying NOS aspects, it was apparent that Sunee focused on what *the* right answer could be for each activity. For example, in the 'Mystery Box' activity as well as the 'Hole Picture' activity, she was eager to know what was inside the 'Mystery Box' and what the hidden picture looked like, respectively. Focusing on the right answer was congruent with her realist epistemology, but it seemed to inhibit Sunee's learning about the intended NOS aspects of each activity.

For instance, at the start of the workshop, Sunee and the other participant teachers were asked to write down what they wanted to know about NOS. The researcher intended to use the teachers' answers as a 'spring board' that initiated a group discussion. While Sunee's colleagues were writing some of what they wanted to know about NOS, Sunee's response was less about NOS and more about science as a subject.

> Science is things around us that can occur any time. This is the definition of science, isn't it? I'm not sure. [Turning to consult Pikun] I can write what I understand but I don't know what I want to say [Laughing]. [Group discussion in workshop: October 20th, 2009]

A few moments later, Sunee turned to ask what Kanya wanted to know in order to write it down on her own document. This event during the workshop indicated, once again, that Sunee viewed science in a realist sense as she expected the researcher to tell *the* right answers. Also, it implied that she tended to be a passive learner rather than a self-directed one.

One instance that illustrated how Sunee's focus on the right answer inhibited an opportunity for her to learn about NOS, occurred during the 'Mystery Box' activity. At the beginning of the activity, Sunee made a number of inferences of what could be inside the Mystery Box even though she seemed unaware that she was making those inferences.

> I'm shaking (the box) and thinking what's in the box. At first, I thought it is a pebble or a coin or things like that. Is what's inside the box metal [*Based on*

the researcher's interpretation, Sunee tended to mean 'solid']? It is. When thinking how many metals (solids) there are, the answer is more than one. By shaking (the box) and observing (its sound) once again, it seems like marbles. They can roll. Then, I'm asking myself if it is marbles? The answer is right! ['Mystery Box' activity: October 21st, 2009]

In the statement above Sunee seems certain of her answer (i.e., the marbles), but no one, except the researcher, knew in an exact way what was inside the box. Once the researcher introduced the teachers to the idea that the way in which they were working to determine what was inside the box is similar to the ways scientists work to answer their scientific questions, the other teachers (i.e., Pikun and Kanya) seemed to realize the role human inference plays in both processes. However, in line with her realist epistemology, Sunee continued to believe the 'real' answer could be determined.

Researcher:	So, when comparing the way that we are working on the Mystery Box with scientific working, how do scientists work to obtain scientific knowledge?
Sunee:	There must be a way to prove it (the answer) true. [Group discussion in workshop: October 20th, 2009]

At the end of several activities, Sunee was the first person among all the teachers who urged the researcher to tell *the* answer (i.e., what was inside the Mystery Box, which kind of dinosaur the fossil fragments represented and what the picture behind the holes was). Sunee was very satisfied when she found that her answer was right, saying, "Yeah! To be honest, it's (the answer) exactly right. I'm right in many activities. Should I go to pursue a doctoral degree? [Laughing]" [During the 'Hole Picture' activity: October 20th, 2009]. Interestingly, while Sunee's comments were made in jest, she did appear to have a talent for keen observation and drawing good inferences.

On some occasions, it was evident that Sunee was not satisfied when the researcher delayed in providing information related to the intended NOS aspect of the activity. During the "Sketch a Scientist" activity in which the researcher aimed to introduce the teachers to the idea that scientists are everyday people, for example, the researcher asked the teachers to draw an image of what a scientist looks like and to write down about what they knew and what they wanted to know about scientists in the K and W columns using the KWL strategy. It appeared that Sunee wanted to know whether or not what she wrote in the K column was correct, and she did not want to continue to fill in the W column until she received the researcher's feedback on her K column. Without that, Sunee tended to lose interest and become disengaged from the activity.

However, engaging in the activities with the other participant teachers provided Sunee opportunities to learn some particular NOS aspects. As Sunee listened to her colleagues' ideas, although she rarely contributed any potential ideas to the group discussion, she was influenced to accept an emerging yet shared understanding among her colleagues. Evidence for this occurred during the 'Great Fossil Find' activity as follows:

Researcher:	How about the 'Fossil' activity and the 'Hole Picture' one?
Sunee:	We hypothesize it could be this (or) it could be that.
Kanya:	We imagine! [Contributing this answer using what she have learned from the 'Mystery Box' activity]
Sunee:	Yes! We used imagination. [..] But, I'm not actually clear with it (how imagination plays a role in scientific working) yet. ['Great Fossil Find' Activities: October 20th, 2009]

In the above excerpt, Sunee responds to the researcher's question using her prior understanding of how scientists acquire scientific knowledge. That is, the scientists use *the* scientific method which includes hypothesizing as one of its steps. She seemed unaware of how imagination plays a role in the process of hypothesizing. Once Kanya pointed it out, Sunee tended to agree even though she was not clear how imagination plays a role in scientific working. Similar evidence also occurred when Pikun and Kanya reached agreement with the idea that there are many methods used to acquire scientific knowledge. Despite showing an acceptance to that idea, Sunee still had challenging questions from her realist way of thinking.

Sunee:	What other ways can scientists use to acquire knowledge that is clear and correct?
Researcher:	So, it means, you are thinking that there should be a number of ways (that scientists use to acquire scientific knowledge)? And, you want to know those.
Sunee:	Yes. In addition to hypothesizing, designing and doing experiments, what other ways? I'd like to know what I don't know yet.
	[Group discussion in workshop: October 20th, 2009]

It appears that Sunee's initial understanding of NOS was challenged by contemporary views of NOS presented during the workshop. However, she still needed more time and effort to internalize those contemporary views of NOS. As evident in this study, the acceptance of contemporary views of NOS does not occur easily, especially in the case of teachers who hold a realist epistemology.

Attempts to Teach the Inferential NOS in the Classroom

The workshop did not seem to help Sunee understand contemporary views of NOS or appreciate the importance of teaching NOS to her first-grade students. Video recorded during the workshop also confirmed that she had less verbal participation than the other participant teachers (i.e., Pikun and Kanya) and that her contributions rarely helped move the group discussion towards the targeted NOS aspects. Sunee's realist epistemology seems to hinder her appreciation of constructivist accounts of science and her ability to teach NOS in the actual classroom.

During the second semester, data gained from seven classroom observations of lessons about the sun, the moon and stars indicated that Sunee gave more emphasis to teaching science than she did in the first semester. The presence of the researcher in her classroom probably played a role in this change of practice. Following Kanya, Sunee tried to help her first-grade students understand the difference between observation and inference. She asked the students to go outside the classroom to observe the sky and the sun using a light filter. However, rather than discussing with the students about their observations and inferences as well as the difference between these, she wanted the students to 'really observe' without making any inferences. She announced during the early moments of the lesson that:

> Today, I want you to observe the sky. First of all, we have to make an agreement that we will not see the sun with our naked eyes because it can make your eyes damaged. So, you have to use a piece of film to filter sunlight. […] We will not bring any other things except the film. Then, you will go back into the classroom and draw what you just observed. […] Remember that you must draw only what you observed. Don't add anything else to what you observe. [First Classroom Observation: February 2nd, 2010]

It was apparent that Sunee focused on whether or not the students followed the pre-determined procedure—that is, recording only what was being observed and not adding anything else. However, she seemed unaware that observation and inference occur almost simultaneously, particularly in the case of young students. Without facilitation that helps them to recognize the difference between observation and inference, it seemed hard for Sunee's first-grade students to do so themselves. Thus, although Sunee kept telling them 'to record what you actually see' and 'not to add your own opinion (imagination),' she found that:

> They (students) don't understand. For example, they observe the sky is blue but they draw it white with some clouds of blue. Some of them didn't see any birds (or an airplane) but they still draw it. It's not the way I want. They don't

know what observation is. [Reflection after First Classroom Observation: February 2nd, 2010]

At this moment, it seemed that Sunee focused more on following a pre-determined procedure in order for the students to obtain *the* right answer. She expected that all the students would draw the same picture of the sky and the sun as they were observing the same sky and the same sun. However, given the fact that human observations are theory-laden, it was likely that different students (as well as Sunee herself) could observe the sky and the sun differently. Thus, it was common that different students could draw different picture of the sky and the sun based on their theory-laden observation. By expecting all the students to produce the same drawing of the sky and the sun, it was obvious that Sunee did not recognize the subjective NOS. In response to this, the researcher suggested to Sunee an alternative way that could help the students understand the difference between observation and inference as follows:

> After you ask each of the students to describe what they actually observed and then their drawing, you may use some of their drawings to point out … which (in the drawing) is actually observed and which is not? This way could help them better understand (the difference between observation and inference). [Researcher's suggestions after first classroom observation: February 2nd, 2010]

The researcher's suggestion aimed to help Sunee's first-grade students know, using a number of examples, that what they included in their drawing could be either an observation or an inference or a product of both. After that, Sunee will be able to point out that what observation means, what inference means and what the difference between both is. Sunee seemed to accept the researcher's suggestion as she promised to try it in the next period. Despite such acceptance, she was very concerned that the students 'won't be unable to learn other subjects' as much as those in other first-grade classes do.

As the second period came, Sunee seemed to forget the researcher's suggestion as she asked the students to observe the sky and the sun once again. Before doing that, she emphasized to the students:

Sunee:	Observation is seeing. Which organ will we use to observe things?
Students:	Eye.
Sunee:	In order to observe things, we will not add our own opinion. For example, if you see a white cloud, you have to fill it white. We will not add our opinion that the cloud is blue. That's not observation. […] Observation is when we record what we actually see. […] We will not draw an airplane if we don't see any airplanes. Today, I will see what will happen when all of you observe the same sun.
	[Second Classroom Observation: February 3rd, 2010]

Sunee expected that all of her first-grade students would draw the same picture of the sky and the sun. She went on to announce that, "Whoever adds other things (in exception of the sky and the sun) will have to observe again and will not get any marks." Until this moment, it was obvious that Sunee was much too concerned with whether or not her students made the exact drawing as they followed her authoritative procedure. Sunee's procedure and directions suggest that she was not aware that all observation is subjective (as illustrated by many of her first-grade students). After this class period ended, Sunee claimed that she had a fever and thus had not done a good job in planning and teaching this lesson.

In the few next periods, it was evident that Sunee did not teach or mention any NOS aspects. Rather, she just presented the students with scientific ideas using a didactic approach. During the fourth period, which aimed to help the students to appreciate the benefits of the sun, Sunee asked the students to observe some slices of bread. In this instance, she had some success teaching the students to be able to 'really observe' a given thing.

Sunee:	Tell me the characteristics of what's in my hand.
Students:	It's soft. It's square shape. It smells good. It's white. Its edge is brown. There're little holes (in it).
Sunee:	How do you know it smells good?
Student:	I smell it.
Sunee:	What do you use to smell it?
Student:	Nose.
Sunee:	How do you know it's soft?
Student:	I touched it.
Sunee:	How do you know it is square?
Student:	I see it.
Sunee:	Who just says there're little holes on it? How do you know that?
Student:	I see it.
Sunee:	(Using results of the students' observation,) What can we call the thing that's in my hand?
Students:	Bread!! [Answering simultaneously]
	[Fourth Classroom Observation: February 12th, 2010]

The students seemed to understand that a given thing can be observed using different senses, leading to different observation results. Despite the fact that there are a number of NOS aspects embedded in this event (i.e., the theory-laden and empirical NOS), Sunee did not make those explicit to the students. Neither did she make the difference between observation and inference explicit. She reasoned that 'it seems too hard for the students' to understand the difference between observation and inference. What she said supports Schwartz and Lederman's (2002: 231) argument, "If one does not feel NOS is important, relevant or *attainable* by students, one is not likely to teach NOS" [Italics added].

As Sunee did not have an educational background in science, she was neither familiar with the content being taught nor the NOS aspects introduced by the researcher. Moreover, she was very concerned with classroom management.

> I don't know why the students are not interested (in the instruction). I've tried to integrate NOS, but it (the instruction) doesn't seem relevant [and] clear (to the students). Astronomy is far away from the students' real life experiences; they don't see it everyday. So, they're not interested in it. It's not like what I expected. (Being concerned with content being taught and classroom management) made me forget to mention NOS. [Reflection after Fifth Classroom Observation: February 16th, 2010]

All of the challenges that limited Sunee ability to teach science as well as NOS effectively are well documented in science education literature (e.g., Lederman, 1992; Abd-El-Khalick *et al*., 1998; Schwartz and Lederman, 2002). Sunee perceived those challenges as she expressed at the end of the second semester that:

> Actually, if this (participating in the researcher's study) is not your doctoral study, I would give up doing it. Directly saying, it's very hard for me because I don't have any background in science. Unlike Kanya, she can do it well. […] I'd have rarely taught NOS if I didn't participate in your study. In the first grade, we emphasize teaching Thai and mathematics more than teaching science. You can see that teachers in other first-grade classes rarely teach science except mine. [Final Interview: March 6th, 2010]

To sum up, Sunee's case illustrates how some elementary teacher particularly those who do not have an educational background in science, may encounter significant challenges when they try to teach NOS in their classroom. As contemporary views of NOS are rooted under constructivist epistemology, elementary teachers who have a realist epistemology (e.g., Sunee) can have difficulty interpreting how to teach particular NOS aspects. Such a difficulty may be more apparent when the teachers do not have strong content knowledge and lack an instructional archive.

Also, Sunee's case illustrates that teachers have to understand relevant NOS aspects as well as appreciate the importance of teaching NOS before they will be able to teach those aspects in the actual classroom (Lederman, 1992, 1999). Lastly, this case suggests that a longer period of time and more efforts, or even different kind of professional development activities, may be needed to help teachers with a realist epistemology learn how to teach NOS effectively.

Summary of the Chapter

This chapter describes the participant teachers' experiences and learning about NOS as well as teaching NOS in the format of case reports. As just presented, the three participant teachers had different initial understandings of NOS due to their different prior experiences. It was evident from the findings that the teachers who had either experiences teaching science for a long period of time and/or a educational background in science (i.e., Pikun and Kanya), were able to explicitly address some NOS aspects after receiving some specific support. However, the teacher who had neither prior experience in teaching science nor an education background (i.e. Sunee), struggled to understand contemporary views of science. Consequently, she had little success in explicitly addressing the intended NOS aspects. The next chapter examines these cases together and presents a cross-case analysis to address the research questions.

CHAPTER V

RESULTS OF CROSS-CASE ANALYSIS

Introduction

This chapter presents results of a cross-case analysis among the participant teachers as well as suggestions gained from the study. It is basically designed to address to the two research questions: (1) What are Thai elementary teachers' initial understandings of NOS and teaching practices related to NOS, and (2) How does collaborative action research support Thai elementary teachers learn to explicitly teach NOS? The cross-case analysis includes six assertions; the first and the second assertions address the first research question while the third and the fourth ones address the second research question. The fifth and sixth assertions serve as a conclusive result of the study and a discussion for future studies. At the end of the chapter, suggestions are provided for further supporting elementary science teachers to explicitly teach NOS.

Assertions from Cross-Case Analysis

This section describes six assertions which were generated by the cross-case analysis among three participant teachers (i.e., Pikun, Kanya and Sunee). Note that more contextualized details of what each teacher was learning to explicitly teach NOS are provided to the reader in the previous chapter.

Assertion 1: Initially, none of the teachers possessed complete understandings of NOS and how to teach NOS.

Insofar as NOS takes its place at the center of science education reforms (e.g., AAAS, 1993; IPST, 2003), science teachers are expected to have an understanding of NOS as well as ability to translate that understanding into classroom practices so that their students can, in turn, develop desired understandings of NOS. However, as the previous chapter has illustrated, two of the three participant teachers came into the study with understandings of NOS that were not consistent with those espoused by science education reforms. Table 5.1 provides a summary of each participating teachers' understandings of NOS at the beginning of the study. It is important to note that, in using ‘+’ and ‘–’ in Table 5.1 to represent whether particular aspects of NOS were understood, the researcher does not intend to communicate in any sense that the teachers’ understandings of NOS are ‘binary’ (Khishfe and Lederman, 2007: 948), but rather to provide an overview and general sense of these teachers’ understandings of NOS.

Table 5.1 Each Teacher’s Understanding of NOS Before and After the Study

NOS aspects	Pikun		Kanya		Sunee	
	Before	After	Before	After	Before	After
Empirical	+	+	+	+	+	+
Tentative	+	+	+	+	–	+
Subjective	+	+	+	+	–	–
Inferential	+	+	–	+	–	–
Imaginative/Creative	+	+	–	+	–	–
Stepwise scientific method	–	+	–	+	–	–
Socio-cultural	+	+	–	+	–	–

Of the three participant teachers, Pikun appeared to have the most robust and extensive understanding of NOS prior to participating in this collaborative action research while the other two participant teachers (i.e., Kanya and Sunee) had more naïve understanding of NOS. Although a number of studies report that teachers’ understandings of NOS tend to be independent of educational background and/or years of science teaching experience (Abd-El-Khalick and Lederman, 2000), it appears in this study that Sunee, who had neither an educational background in science nor science teaching experience, possessed the most naive understandings of various NOS aspects. This result is contradictory to other studies that were reviewed. However, when considering the backgrounds of Pikun and Kanya, it appears that Kanya had a more relevant educational background in science and longer science teaching experience, but possessed a less informed understanding of NOS than Pikun. Therefore, a direct relationship between the teachers' understandings of NOS and educational backgrounds (or even science teaching experience) does not necessarily seem to exist. Further studies need to focus on 'learning experiences' that the teachers had in science courses as well as professional development rather than simply paying attention to their educational degrees or years of teaching experience. Also, the teachers' personal interests in science could be a relevant factor that needs to be considered in relation to their understandings of NOS.

All of the participant teachers had naive ideas about what it meant by 'teaching NOS.' Generally speaking, the teachers understood that teaching NOS is about teaching students to have scientific process skills. In other words, they believed that the students would learn some NOS aspects by simply engaging in hands-on or inquiry-based activities (e.g., observing and classifying given things). This implicit approach to teaching NOS has been proven as ineffective in promoting students' desired understandings of NOS (Abd-El-Khalick and Lederman, 2000; Khishfe and Abd-El-Khalick, 2002). In order to understand these teachers' interpretations and ideas of 'teaching NOS,' it is useful to take a critical look into Thailand's *National Science Curriculum Standards* (IPST, 2003), which the participant teachers referred to as the source of their interpretations.

In the *National Science Curriculum Standards* (IPST, 2003), there are eight strands, which include (1) Living Things and Living Processes, (2) Life and Environment, (3) Matter and Properties, (4) Forces and Motion, (5) Energy, (6) Processes that Shape the Earth, (7) Astronomy and Space and (8) The Nature of Science and Technology. NOS is described as a key component of the last strand where students should 'use *scientific* *process* and a *scientific mind* in doing scientific inquiries and solving problems,' 'know that most natural phenomena have particular patterns, which can be studied and explained using *empirical data* and instruments available during a given period of time' and 'understand that *science, technology, society and the environment are interrelated*' [Italics added]. It is important to note that, although the content of the last strand does cover the empirically-based aspect of NOS as well as the sociocultural aspect of NOS, it does not make such NOS aspects explicit. Rather, it could tempt science teachers to interpret that NOS is about 'scientific process and scientific mind' instead.

Also, it needs to be emphasized that in the curriculum document, there are specific learning 'indicators' presented according to each grade level. Most, if not all, learning indicators provided at all grade levels tend to describe NOS as ’scientific process’ and do not explicitly mention other underlying NOS aspects to science teachers. For example, the learning indicators describe that six-grade students should be able to:

> (1) pose questions about an issue … (2) plan for [doing] an investigation … (3) select equipment and ways to do the investigation … (4) record and analyze … data … (5) pose a new question for further investigations …

As a consequence, it should not be surprising that the teachers in this study, and perhaps other Thai science teachers, conflate NOS with scientific process. That is, they mistakenly interpret NOS, because of ‘implicit curriculum messages’ (Hipkins *et al*., 2005), as scientific process rather than a cognitive learning outcome, as recommended by Abd-El-Khalick and Lederman (2000). In other words, the participant teachers were struggling with ‘translating the language of the reforms’ (Hanuscin *et al*., 2010: 10-11) into practical guidelines that can be used for explicit NOS instruction.

Assertion 2: Due to limited understandings of NOS *and/or* naive interpretations of what it means to 'teach NOS,' the teachers did not explicitly teach NOS to their students.

As none of the participant teachers possessed robust and complete understandings of NOS *and* what it meant by 'teaching NOS,' they did not, and perhaps could not, explicitly teach NOS to their students. The teachers who understood some NOS aspects (i.e., Pikun and Kanya), claimed that they taught NOS by offering hands-on or inquiry-based activities (e.g., observing and classifying given things) in which their students could engage. In doing so, they tended to assume that the students would learn about NOS as a by-product of engaging in those activities. This approach, which has been referred to as the implicit approach to teaching NOS (Abd-El-Khalick and Lederman, 2000), is not effective in promoting students' desired understandings of NOS (e.g., Khishfe and Abd-El-Khalick, 2002).

Abd-El-Khalick and Lederman (2000) provide a possible explanation for why science teachers might employ an implicit approach to teaching NOS. These authors believe that teachers who see NOS as an affective learning outcome rather than a cognitive outcome will teach NOS using an implicit approach. These teachers simply suppose that learning about NOS would result as a by-product of engaging in hands-on or inquiry-based activities. For them, there is no need to make any NOS aspects explicit. However, research has suggested, and continues to suggest, that science teachers have to make any intended NOS aspect explicit to their students as well as ask them to reflect on what they think of that NOS aspect so that the students can and will learn about NOS (Akerson and Volrich, 2006; Khishfe and Lederman, 2007; Hanuscin *et al*., 2010). This strategy for teaching NOS is referred to as an explicit approach (Abd-El-Khalick and Lederman, 2000).

In the case of Sunee who had the most limited understanding of NOS, it was obvious that she could not teach what she herself did not understand (Lederman, 1992). In addition to the lack of adequate understandings of NOS and 'teaching NOS,' other factors such as content knowledge, viewing NOS as less significant than other instructional outcomes, preoccupation with classroom management, routine chores, the lack of practical resources and supports for teaching NOS and other institutional constraints, became interacting factors that hindered explicit teaching of NOS by all of the participant teachers (Abd-El-Khalick *et al.*, 1998; Abd-El-Khalick and Lederman, 2000; Schwartz and Lederman, 2002). Consequently, the teachers needed supports to enable them to explicitly teach NOS in their science classroom.

Assertion 3: The teachers needed various supports to enable them to explicitly teach NOS in the actual classroom.

Due to the hindrances discussed above, it became very challenging for the participant teachers to explicitly teach any intended NOS aspects (even those that they understood quite well). It appeared that the participant teachers needed specific supports in order to address these hindrances before they could or would explicitly teach NOS to their students in the classroom. However, as shown in Table 5.1, each of the participant teachers came into the study with different initial understandings of NOS and different interpretations of 'teaching NOS.' For example, Pikun came into the study with various informed yet tacit understandings of NOS and a broad interpretation of 'teaching NOS,' while Sunee came with limited understandings of NOS and without knowing what it means by 'teaching NOS.' Thus, the participant teachers each needed different specific supports to be able to explicitly teach NOS in the classroom. As a consequence, a variety of supports becomes essential in helping all the participant teachers explicitly teach any intended NOS aspects.

In Pikun’s case, her informed yet tacit understanding of NOS needed to be activated or affirmed first in order for her to be certain and, subsequently, explicate NOS to her students (Akerson and Abd-El-Khalick, 2003). Also, she needed a support to reinterpret what it meant by 'teaching NOS.' She was informed, at the conclusion of the workshop, that understandings of NOS should be regarded as a cognitive learning outcome (Abd-El-Khalick and Lederman, 2000) rather than an affective one or a set of scientific process skills. If NOS was viewed as a cognitive learning outcome, she could see that it is necessary to make any intended NOS aspects explicit during instruction in order for her students to develop desired understandings of NOS As a teacher who intended to teach NOS, Pikun became motivated and able to explicitly teach the intended NOS aspects in the classroom after obtaining such supports.

Kanya, who came into the study with initial understandings of empirical, tentative and subjective NOS, was struggling with understanding the inferential and imaginative NOS. The inferential and imaginative aspects of NOS were in conflict with her initial understanding of the stepwise scientific method. However, with contributions by Pikun and support from the researcher, she succeeded making a link between the inferential and imaginative aspects of NOS and her initial understandings of the empirically-based and subjective NOS. In other words, with specific support (i.e., challenging her understandings and introducing new ones), Kanya began to change her understanding of NOS (Akerson *et al*., 2000). However, this was not sufficient by itself to enable her to explicitly teach NOS in the classroom. Like Pikun, Kanya needed to be informed that it was crucial to make any intended NOS aspects explicit to her students. Moreover, on-site supports that helped Kanya find where and how to address the intended NOS aspects in instruction were also essential.

Sunee came into the study with less understanding of NOS than Pikun and Kanya. In fact, she maintained statements that implied a realist epistemology, which is inconsistent with contemporary views of NOS. Due to this, it became very challenging for Sunee to accept the views of NOS recommended by science education reforms. Moreover, she viewed NOS as less significant than other instructional outcomes (e.g., literacy) and did not believe that NOS was attainable by her students. These factors inhibited her learning about NOS. As evident in this study, the activities specifically designed to introduce NOS did not appear to be sufficient in supporting Sunee to develop a stronger understanding of NOS. At best, she became more appreciative of the importance of teaching NOS. In the end, she could not explicitly teach NOS in the classroom despite on-site supports by the researcher. This illustrates that other relevant supports were needed to help Sunee acquire a deep understanding of NOS and be able to explicitly teach NOS.

Given the fact that the participant teachers came into the study with different understandings of NOS and interpretations of 'teaching NOS,' it became crucial to provide a variety of supports to them. Indeed, a predetermined workshop or training course cannot effectively deal with these kinds of differences because it may not address what each of the teachers needed to understand about NOS and then translate their understandings of NOS into classroom practice. Therefore, any professional development activities designed for science teachers, who intend to teach NOS, must be flexible in order to tackle and overcome any hindrances they may encounter. Collaborative action research, as a format of teacher professional development (Feldman and Capobianco, 2000), can provide various supports for the teachers who are learning to teach NOS.

Assertion 4: Collaborative action research afforded various supports to the teachers who were learning to explicitly teach NOS.

From the beginning to the conclusion of the study, it appears that collaborative action research, which by definition included the workshop and regular discourses, provided various and relevant supports to the participant teachers who intended to learn about NOS in order to be able to explicitly teach it in the actual classroom. First, the activities during the workshop introduced the teachers to various NOS aspects espoused by science education reforms so that they, at any later moment, could pay explicit attention to those NOS aspects. Once NOS came into the foreground, the teachers were able to examine their own understandings of NOS in line with those introduced during the workshop, resulting in them either affirming, internalizing, challenging or changing their understandings more appropriately. On many occasions, the teachers came back to refer to what they learned about NOS during the workshop when they were planning to teach NOS. That is, the activities during the workshop provided explicit references to NOS for the teachers.

Second, discussion about contemporary views of NOS, which are espoused by science curriculum standards (e.g., AAAS, 1993; IPST, 2003), allowed the teachers to pay explicit attention to NOS and also reinterpret what it meant by 'teaching NOS' more appropriately. For example, the excerpt below illustrates a fruitful discussion among the teachers and the researcher while reading both Thai and American science curriculum standards.

Researcher:	You can see that the nature of science exists in both Thai and American [science curriculum standards]. … Similar to ours (Thai science curriculum), there are descriptions about what students at each grade have to learn (about NOS) in the American (science curriculum).
Kanya:	Do they (American science teachers) either teach NOS directly (i.e., explicitly) or just integrate it into science content?
Researcher:	They teach NOS explicitly. In fact, NOS should be regarded as a subject matter (i.e., a cognitive learning outcome) like chemical substances.
Kanya:	So, they teach NOS as content … but our (Thai science curriculum) want us to integrate it (NOS). It pretty much looks like scientific process instead.
Pikun:	We don't know exactly whether IPST wants us to either teach NOS explicitly or just integrate it into science content.
Researcher:	I think IPST wants us to integrate (NOS into content). … even though research suggests that explicitly teaching NOS seems more effective.
	[First Group Meeting: November 28th, 2009]

The discussion above addressed the mixture between NOS and scientific process that most of the teachers initially admired. As such conflation has been challenged by research results (e.g., Khishfe and Abd-El-Khalick, 2002), what followed this discussion was an agreement among the teachers that NOS should be explicitly taught rather than implicitly integrated into any science content. Indeed, the discussion led the teachers to reinterpret what it means by 'teaching NOS.'

Third, collaborative action research afforded the teachers opportunities to discuss which NOS aspects seemed attainable by their students. In line with Thai and American science curriculum standards (AAAS, 1993; IPST, 2003), the teachers helped each other select any NOS aspects that were accessible to their students at particular grade levels. For example, Kanya initially thought that the empirically-based and tentative NOS, which she understood well, seemed appropriate for her fourth-grade students. However, after discussing with the other teachers and the researcher, she changed her mind to instead focus on the inferential and imaginative NOS with which she was not yet certain. Kanya reasoned that those selected NOS aspects ’fit’ with content being taught (i.e., the Earth) in terms that the students should know that scientists have to use their imagination in order to infer what is inside the Earth and make a model of the Earth. Also, research results (e.g., Akerson and Volrich, 2006), which were bought into the discussion, convinced Kanya, and the other teachers, that those selected NOS aspects were attainable by her students.

Fourth, the teachers received constructive feedback when they reflected on any implemented instruction with the other teachers and the researcher. For example, during early attempts, none of the teachers addressed any intended NOS aspect(s) in their lesson plans even though they were committed to teaching it. They argued that they would improvise, mentioning it wherever appropriate in their instruction. While reflecting on the implemented instruction, what the teachers learned was that it would be better if there was the presence of any intended NOS aspects in the lesson plans, as Kanya said:

> At least, we can come back to look at the lesson plans (after each implemented instruction) to check whether we mentioned NOS. If not, we will know that we have to do so in future lessons. [Fifth Group Meeting: February 26th, 2010]

Moreover, sharing alternative ideas about how to explicitly address the intended NOS aspect also became valued by the teachers. For example, once Sunee expressed the challenge that her first-grade students could not 'really observe' the sky and the sun as she expected, the other teachers then came up with alternative ideas, such as:

> Sometimes, if drawing individually didn’t work, we might ask the whole class to collectively draw what they observe. By doing this, we can point out whether all of them observed one particular thing (e.g., an airplane). If not, it shouldn’t be added into the drawing. This would lead to 'collective observations.' We can use this to further point out that there must be empirical evidence on which all (observers) agree. [Pikun, Fourth Group Meeting: February 12th, 2010]

Regardless of who gave or took ideas, such 'idea-sharing' events provided opportunities for the teachers to learn about NOS from each other. As a consequence, each of the teachers to some degree improved her understandings of NOS by the conclusion of the study.

Assertion 5: At the conclusion of the study, the teachers’ understandings of NOS improved differently, depending on their prior knowledge about NOS.

At the conclusion of the study, the participant teachers were asked to complete the same questionnaire they filled out at the beginning of the study. As previously presented, the questionnaire in conjunction with an individual semi-structured interview was designed to explore their understandings of NOS (Lederman *et al*., 2002). By comparing the teachers’ understandings of NOS at the conclusion of the study with those at the beginning of the study, changes between both could possibly be discerned. Such changes could possibly result from the teachers’ learning about NOS while they were engaged in the study. Generally speaking, all the teachers more or less improved their understandings of NOS by the conclusion of the study. However, there is significant difference among the teachers’ improvement in understandings of NOS.

In the case of Pikun who came into the study with a set of tacit understandings of NOS, it was apparent that she maintained her understanding of NOS throughout the study. Indeed, she was able to explicate her own understanding more confidently. Furthermore, she used ‘more appropriate’ wording when discussing NOS. For example, she used the term ‘empirical evidences’ instead of ‘facts’ when she intended to communicate about the empirically-based NOS. Also, she changed from using the term ‘prove’ to the term ‘test hypothesis’ instead. Such changes in the use of more appropriate terminology have instructional implications given the fact that ordinary classroom language used by the teacher can convey, often unintentionally, some particular view of NOS (e.g., a realist view) to students (Zeidler and Lederman, 1989).

In case of Kanya, it was evident that she maintained her initial understandings of the empirically-based, subjective and tentative NOS aspects throughout the study. In addition to this, she significantly improved her understandings of the inferential and imaginative aspects of NOS. For example, she said at the conclusion of the study that:

> Scientists use imagination together with empirical evidence in order to construct a model used to explain natural phenomena. […] Imagination is helpful when scientists infer about what is being studied which they cannot have direct access or directly observe—something extremely far away from them, for example. It (imagination) also helps generate hypotheses or theories (for further studies). [Interview: March 3rd, 2010]

Moreover, Kanya went beyond her initial understanding of a one-direction relationship where science produces knowledge used in developing technology, which can subsequently have social impact. In doing so, she argued further that, “There are times that people in society disagree with scientific working. They may give some feedback that could stop it—human cloning, for example. Even though it could make a big progression in science, it can be stopped (by public disagreement).”

In the case of Sunee who came into the study with a realist epistemology, it was apparent that she maintained a desired understanding of the empirically-based NOS. Also, she learned the tentative NOS aspect as she said, “It (scientific knowledge) is changeable if there is a discovery of new evidence. The new evidence can confute existing evidence, resulting in new knowledge that is clearer or more correct” [March 6th, 2010]. However, it was also evident that a realist epistemology inhibited Sunee learning about contemporary views of NOS. In the end, she maintained most of her naive understandings of NOS and never fully accepted the stepwise of scientific method, subjective, inferential, imaginative, and sociocultural aspects NOS. Indeed, she needed more effort and time, or even other professional development activities, to internalize contemporary views of NOS.

Pikun and Kanya understood that there is no single way of the scientific method used in science as they both were aware of the role that scientists' imaginations and creativity play in scientific working. Both the teachers tended to view scientific working as a reflective practice rather than simply following a stepwise procedure. However, Sunee, with her realist epistemology, struggled with this idea. She indicated her agreement with the statement that ‘scientists have to follow the scientific method,’ saying, “I agree because it (following the scientific method) can help scientists produce reliable knowledge. It can prove what really happens. If some particular step is skipped, how is knowledge completed?” She continued to say that she would answer ‘yes’ if she was asked whether or not there are other ways to do science, even though she could not provide any examples of those ways.

In conclusion, all the teachers more or less improved their understandings of NOS and that at least some of them (i.e., Pikun and Kanya) were able to explicitly address particular NOS aspects in the actual classroom quite confidently. Only one teacher struggled in understanding contemporary views of NOS, and she was not able to explicitly mention NOS in the actual classroom. However, the two teachers who were able to explicitly teach NOS mainly employed the didactic approach and questioning technique. In other words, they still needed more support to develop what

Hanuscin *et al*. (2010) and Schwartz and Lederman (2002) called ‘pedagogical content knowledge for teaching the nature of science,’ as they still had difficulty transforming what they just learned about NOS into a form attainable by their students. Thus, the approach adopted for this study in helping teachers understand and teach NOS met with some limited success.

Assertion 6: Despite the improved understandings of NOS, the teachers needed further support in developing pedagogical content knowledge for teaching NOS.

Even though the participant teachers improved their understandings of NOS and some of them were able to explicitly mention the intended NOS aspect in the classroom, they heavily relied on the didactic approach and used questioning technique to teach NOS—that is, they tended to directly ask and tell the intended NOS aspect to the students. The heavy use of the didactic approach and questioning technique implies that the teachers did not yet transform their own understandings of NOS into an instructional form that would be comprehensible by the students. As research has been discussed (e.g., Abd-El-Khalick *et al*., 1998; Schwartz and Lederman, 2002; Hipkins *et al*., 2005; Hanuscin *et al*., 2010), the teachers needed to develop ‘pedagogical content knowledge for teaching NOS' or ‘NOS PCK.'

Shulman (1986) first introduced the notion of ‘pedagogical content knowledge,’ or PCK, as a fundamental component of the teacher’s knowledge base for teaching a specific subject matter (e.g., Newton’s first law of motion or photosynthesis). Simply put, PCK is knowledge of ‘subject matter *for teaching’* (p. 9, emphasis in original), or a product of the process by which the teacher transforms his or her subject matter knowledge together with other kinds of knowledge (e.g., pedagogical knowledge) into forms that are accessible and attainable by the students. If NOS is accepted as a cognitive learning outcome (Abd-El-Khalick and Lederman, 2000) the teacher will then need to transform his or her knowledge about or understanding of NOS just as they must do for other subject matters in order to be able to teach NOS in such a way that is accessible and attainable by the students.

Schwartz and Lederman (2002: 232) depicted a diagram, which represents three fundamental domains of knowledge that contribute to developing PCK for teaching NOS (Figure 5.1). Those domains include subject matter knowledge, NOS knowledge and pedagogical knowledge. It is argued that, 'Subject-matter knowledge alone, NOS knowledge alone or pedagogical knowledge alone will not suffice.' In other words, lacking one of those domains of knowledge will possibly lead to difficulty in developing PCK for teaching NOS.

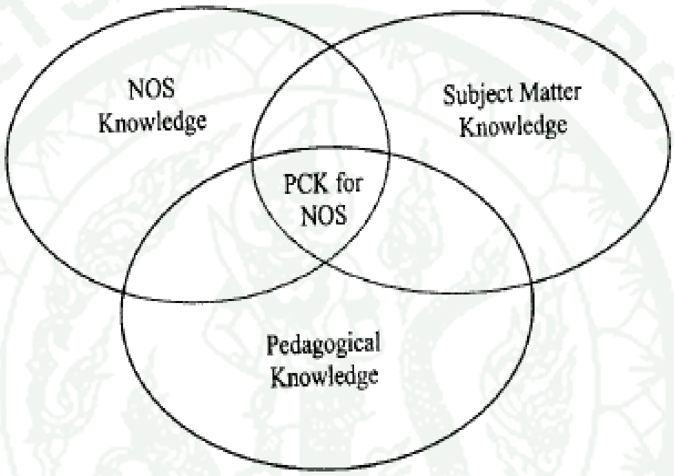

Figure 5.1 Pedagogical Content Knowledge for NOS
Source: Schwartz and Lederman (2002: 232)

By adapting Magnusson *et al.*'s (1999) model, which consists of five fundamental components of PCK for science teaching (i.e., orientations toward science teaching, knowledge and beliefs about science curriculum, knowledge and beliefs about students' understanding of specific science topics, knowledge and beliefs about assessment in science and knowledge and beliefs about instructional strategies for teaching science), Hanuscin *et al.* (2010) proposed a diagram (see Figure 5.2), which represents those five fundamental components that contribute to developing PCK for teaching NOS. Given the fact that a teacher's PCK 'originates in the wisdom of practice' (Shulman, 1986: 9), Hanuscin *et al.* (2010) argued based on their diagram that science teachers should be supported to have these five components in order for them to continuously develop PCK for teaching NOS.

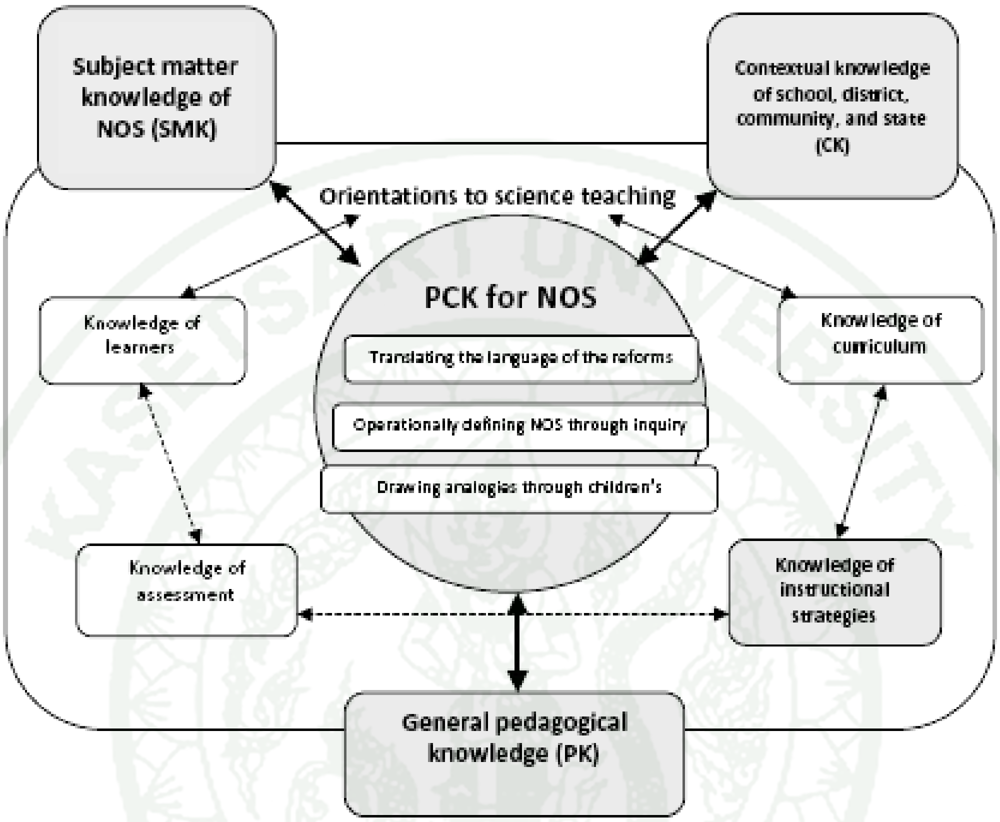

Figure 5.2 Teachers' PCK for teaching NOS
Source: Hanuscin *et al.* (2010: 16)

Moving back to the present study, it was apparent that the participant teachers were not familiar with explicitly teaching NOS. Based on data analysis, one of the hindrances was that none of them possessed complete understandings of NOS *and* appropriate interpretations of teaching NOS. Using Schwartz and Lederman's (2002: 232) diagram, it can be interpreted that the teachers, at the very least, lacked NOS knowledge. The lack of NOS knowledge inhibited them from developing PCK for teaching NOS, which can be used to explicitly teach NOS in the classroom. In the particular case of Sunee, who just began teaching science a few years ago, it was likely that she also lacked subject matter knowledge, pedagogical knowledge or both.

As a consequence, it was even more difficult for her to develop NOS PCK in order for her to explicitly teach NOS in the classroom.

In the cases of Pikun and Kanya who had educational backgrounds in science and/or greater science teaching experiences, it was apparent that once supported to have desired and explicit NOS knowledge as well as more appropriate interpretations of teaching NOS, both the teachers could and did develop PCK for teaching NOS (Schwartz and Lederman, 2002) used to explicitly teach NOS in the classroom. However, as they both still used the didactic approach and questioning technique to teach NOS, this implied that they might need further support with these three knowledge domains, which will take a longer period of time, in order for them to develop PCK for teaching NOS. In addition, according to Hanuscin *et al*.'s diagram (2010), all the participant teachers needed to be supported in 'knowledge of assessment' specific to NOS instruction as well as 'knowledge of learners,' which highlights possible difficulties that their students might encounter when learning about NOS. It seems unlikely the teachers would continue developing PCK for teaching NOS if they lack these two components.

Conclusion and Discussion

NOS has stood at its own place in Thailand's *National Science Curriculum Standards* for over a decade (IPST, 2003). However, as research suggests (e.g., Kijkuakul *et al*., 2005; Mahalee and Faikhamta, 2010), many Thai students do not have desired understandings of NOS yet. The results of this study, similar to those of others (e.g., Promkatkeaw, 2007; Yutakom and Chaiso, 2007; Buaraphan, 2009; Chamrat and Yutakom. 2009), underscore an obstacle that Thai science teachers need to overcome. As a consequence, it is necessary to support Thai science teachers to possess adequate understandings of NOS (Lederman, 1992) and be able to translate those understandings into instructional forms that are accessible and attainable to students (Hanuscin *et al*., 2010).

As Bianchini and Colburn (2000: 206) point out, teaching NOS should be recognized as ‘complex and challenging task,’ which is ‘difficult to achieve.’ Therefore, supporting Thai science teachers to be able to explicitly teach NOS is equally complex and challenging. However, this study did pave a way to accomplish this task. First, it is necessary to support the teachers to have complete understandings of NOS so that it is likely for them to teach NOS in the classroom. Activities described in the literature that are designed to communicate NOS (e.g., Lederman and Abd-El-Khalick, 2000) could help, especially when used with teachers who have educational backgrounds in science and/or science teaching experiences. However, as illustrated by one case in this study, those activities may not be sufficient. Therefore, alternative ways to support the teachers to learn about NOS also should be taken into account. For example, peripherally yet authentically participating within scientific working (Schwartz *et al*., 2004) and/or discussing about NOS with practicing scientists (Morrison *et al*., 2009) are promising as long as NOS is made explicit for the teachers.

Although having desired understandings of NOS is necessary for the teachers to explicitly teach NOS, it is not sufficient. Teachers need to appreciate the importance of teaching NOS to their students as well as believe that their students are capable of learning about NOS (Schwartz and Lederman, 2002). Moreover, teachers have to possess appropriate interpretations of what is meant by 'teaching NOS.' Therefore, as *the National Science Curriculum Standards* (IPST, 2003) is a main resource of many teachers, it would be better to make any intended NOS aspects, which at present seem to be ‘implicit curriculum messages’ (Hipkins *et al*., 2005; 246), more explicit to them. Doing this could help the teachers more easily understand what they are expected to do. Once they understand their task of teaching NOS, they would possibly appreciate its importance.

In addition to supports that help teachers have desired understandings of NOS, appropriately interpreting what it means by 'teaching NOS,' intending to teach NOS to students and appreciating its importance, relevant on-site supports are also essential. For example, teachers may need help in planning a lesson where NOS is integrated, briefing content-specific NOS ideas, or even demonstrating explicit NOS instruction (see, Akerson and Abd-El-Khalick, 2003). In doing so, collaborative action research (e.g., Baird *et al.*, 1987; Feldman, 1996) where the teachers can regularly come to share reflection on teaching practices can afford opportunities for them to learn about teaching NOS or even about NOS itself. Indeed, collaborative action research is an appropriate place where science educators can come to facilitate teachers to develop NOS PCK necessary for explicit NOS instruction. This study also indicates that support should be varied according to the needs of individual teachers.

Even though the present study illustrates some potential uses of collaborative action research as a way to support Thai elementary teachers to learn about teaching NOS, it met with only limited success. Longer support for the teachers to develop PCK for teaching NOS, which can potentially enhance their NOS instruction, was also limited in this year-long study. As experience of teaching particular content is the major source for developing PCK for teaching that content (van Driel *et al.*, 1998), it is necessary for the teachers to continue their attempt to teach NOS and reflect on their teaching practice regarding NOS. Also, it is necessary for the teachers to assess and analyze their students' understandings of NOS (Hanuscin *et al.*, 2010). Results of the assessments used can provide teachers insight into what kinds of difficulties the students encounter in understanding contemporary views of NOS and how to develop NOS instruction that can help the students overcome those difficulties. These recommendations can positively contribute to the teachers' professional learning about teaching NOS.

A discussion provided herein is theoretically grounded upon Bell and Gilbert's (1994) model of teacher development, which emphasizes three components: (1) personal development, (2) social development and (3) professional development. At the stage of *personal development*, teachers must be aware and accepting of instructional dissatisfaction and the desire to acquire new ideas or insights related to that dissatisfaction. In the present study, the participant teachers were not initially aware that they had not taught NOS until they were interviewed by the researcher. Being interviewed about NOS with which the teachers were not certain created dissatisfaction on their part. The interview also aroused the teachers' interests in teaching NOS, which is described as a strand in *the National Science Curriculum Standards* (IPST, 2003). Such awareness served as a starting point for the teachers to continue to learn about NOS and teaching NOS throughout the study.

At the stage of *social development*, teachers need opportunities to discuss with other teachers about the shared dissatisfaction itself and how to deal with it effectively. As apparent in the present study, the participant teachers brought their dissatisfaction about NOS and teaching NOS into a group discussion during the workshop. Once they were introduced to contemporary views of NOS, which are somewhat inconsistent with or even contradictory to their initial understandings of NOS, a fruitful discussion on what NOS means to them and to curriculum makers, and how they as teachers—the curriculum implementers—could teach it in the actual classroom emerged. At this point in time, the teachers could clarify their own understandings of NOS and what is meant by 'teaching NOS.' Also, they could come to appreciate group discussion as a valuable opportunity, since they learned new ideas and insights related to their dissatisfaction.

At the stage of *professional development*, teachers take risks to bring any new ideas or insights, which are learned from other teachers, into their own classrooms before coming back to share what was learned by implementing new ideas with the other teachers. As such a group discussion regularly occurs, teachers with support from colleagues can learn and continue their professional learning. In the present study, collaborative action research afforded an opportunity for the participant teachers to take risks in introducing the intended NOS aspects to their students. Also, it afforded an opportunity for the teachers to reflect on their implemented NOS instruction and, subsequently, share reflections with the other teachers. With relevant on-site support from the researcher who provided theoretical perspectives about teaching and learning science (e.g., constructivist ones), the teachers learned to explicitly teach NOS meaningfully.

It is important to note that these three components of teacher development should not be regarded as a linear process. Rather, they occurred as a cyclic process by which each was interactive and interdependent with the others. More importantly, the teachers had to sustain and continue this process for their own sake rather than being controlled by the researcher. Therefore, teacher development should be regarded as teacher learning rather than as others getting teachers to change (Bell and Gilbert, 1994). Nevertheless, it was important to provide the teachers relevant support in order for them to continue learning. Also, each of the teachers who came into the study with different backgrounds might take a different period of time to understand new ideas and insights, and then be able to implement those in the actual classroom. This supports Bell and Gilbert’s (1994: 496) argument that, “The precise direction of any change was not pre-determined by (the researcher) … (Teacher development process) could not be neatly orchestrated for within the tight timelines.”

Summary of the Chapter

This chapter presents a cross-case analysis of the three participant teachers. It describes the teachers’ initial understandings of NOS, interpretations of 'teaching NOS' and teaching practices related to NOS. Also, it highlights that the teachers at the beginning of the study, did not explicitly teach NOS in their classrooms as they were inhibited by their limited and naive understandings of NOS and/or their interpretations of 'teaching NOS.' As a consequence, each of the teachers needed various supports to be able to explicitly teach NOS. The collaborative action research adopted for this study afforded such supports, and contributed in improved understandings of NOS and, at least in two of the three case study teachers, the ability to explicitly teach NOS. Nevertheless, further supports were still needed in order for the teachers to develop pedagogical content knowledge for teaching NOS. In the next chapter, implications of this study are presented.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

This chapter provides conclusions and recommendations of the study. Conclusions are presented in relation to the main research questions. Then, recommendations for professional development and future research that aim to support elementary science teachers' learning to teach NOS are provided.

Conclusions

Background of the Study

The present study was undertaken in response to Thailand's science education reform, which requires all Thai science teachers to teach NOS at all grade levels. As described in *the National Science Curriculum Standards* (IPST, 2003), NOS is perceived as necessary for Thai students to be scientifically literate insofar as they are expected to participate in and contribute to a scientifically knowledge-based society. However, nearly a decade after the implementation of Thailand's science education reform, contemporary views of NOS are still new for many Thai science teachers including those who teach science at elementary levels (Promkatkeaw *et al*., 2007; Yutakom and Chaiso, 2007; Chamrat and Yutakom, 2008; Buaraphan, 2009). In other words, a number of Thai elementary science teachers have not complete understandings of NOS, and do not teach NOS in their elementary science classrooms (Suttakun *et al*., in press).

As NOS was introduced in *the National Science Curriculum Standards* (IPST, 2003) about a decade ago, many Thai in-service elementary teachers who teach science might have neither experienced nor been prepared to teach it during their teacher education times (Gallagher, 1991; McCommas, 2000). While much effort has been devoted to prepare Thai pre-service science teachers to understand and be able to teach NOS (e.g., Nuangchalerm, 2009; Yuenyong, 2010), Thai in-service science teachers seem to be left behind. As Feldman (1996: 513) pointed out "unless these reform efforts are willing to wait a biblical forty years for a new generation, they are dependent on the successful in-service education of experiences science teachers." It therefore is equally important to prepare Thai in-service teachers to understand and be able to teach NOS as well.

Research (e.g., Abd-El-Khalick and Lederman, 2000; Khishfe and Abd-El-Khalick, 2002; Khishfe and Lederman, 2007) has suggested that, in order for K-12 students to understand NOS, an explicit and reflective approach to teaching NOS is more effective than an implicit one. It is argued further that understanding of NOS like understanding of other subject matter, should be regarded as a cognitive learning outcome, rather than an affective outcome. Therefore, the science teacher has to make any intended NOS aspect explicit to students so that it will have their attention, instead of expecting them to learn the intended NOS aspect as a by-product through a process of engaging in inquiry-based or hands-on activities. Such a research-based argument indicates the science teacher should develop and implement a lesson where NOS is intentionally taken into account. Specific support structures are needed for many in-service elementary teachers if the expectation is for them to explicitly teach NOS (Akerson and Abd-El-Khalick, 2003).

As a pilot study suggested (Suttakun *et al*., in press), however, many Thai in-service elementary teachers are not yet familiar with NOS, which is described in Thailand's science curriculum documents (IPST, 2003). Neither they understand contemporary views of NOS, nor do they explicitly teach NOS in the classroom. This finding of the pilot study suggests necessary to support the in-service elementary teachers to teach NOS. Collaborative action research (Baird *et al*., 1987; Feldman, 1996; Erickson *et al*., 2005; Capobianco, 2007) was selected for this study as a promising approach that might provide support for the elementary teachers who wished to learn about NOS relevant to elementary education and translate what is learned into classroom practice. The study aimed to examine whether and how collaborative action research could support Thai in-service elementary teachers to understand and teach NOS.

For this study, the collaborative action research was undertaken to provide a structure for regular discourse by a group of elementary in-service teachers. The teachers came together to discuss and share their understandings of NOS as well as experiences about teaching NOS. During group meetings, the teachers reflected upon some particular NOS aspect they had planned to teach to their students, as well as the NOS instruction just implemented in their classroom. As a facilitator of the collaborative action research, the researcher contributed research-based recommendations to the teachers who had to make decisions on whether and how those contributed recommendations worked for them. The decisions were done by the teachers after they gained ideas related to NOS instruction from the other participants of the collaborative action research. As group discussions were regularly undertaken, the collaborative action research became a cyclic activity in which the teachers learned to explicitly teach NOS.

The present study was designed to address to two research questions: (1) What are Thai elementary teachers' initial understandings of NOS and teaching practice related to NOS? and (2) How does collaborative action research support Thai elementary teachers as they learn how to teach about NOS? The first research question was generated to explore elementary in-service teachers' initial understandings of NOS and their teaching practice related to it. Data gained to address to this research question were subsequently used as guiding information to continue the study—that is, the teachers came to engage in the collaborative action research, which was facilitated by the researcher. Once the collaborative action research began, the focus was turned to addressing to the second research question. Therefore, the study was divided into two consecutive phases according to the research questions.

Research Methodology

The study was interpretive by its nature and purposes as the researcher aimed to understand the phenomenon being studied (Erickson, 1986), which was guided by the two research questions. The researcher used a variety of data collection methods including teacher interviews, classroom observation, group discussion and a collection of materials to obtain qualitative data with minimized attempt to manipulate the research setting (Lincoln and Guba, 1985). In addressing to the first research question, the researcher interviewed the participant teachers in order to understand their initial understandings of NOS, and acted as a non-participant observer, who regularly visited the teachers' science classes, to understand whether and how NOS was taught. Classroom observations were done with attempts to avoid any disturbance to classroom activities. This first phase of the study was undertaken during the first semester of the 2009 academic year.

In the second semester of the 2009 academic year, the researcher initiated a collaborative action research group where the teachers came together to share and discuss their ideas about NOS and NOS instruction. At this phase of the study, the researcher became more active supporting the participant teachers to learn about NOS as well as NOS instruction. The researcher employed an emergent design to collect and analyze data associated with what and how experiences in the collaborative action research supported the participant teachers' learning to explicitly teach NOS. Data collection and analysis were undertaken in an ongoing and reciprocal manner to generate working hypotheses relevant to addressing to the second research question. Through prolonged engagement and rapport, the researcher was able to have access to credible data from the teachers. A number of techniques that included triangulation and member checks were also used to establish trustworthiness of the study.

Participant Teachers

Initially, the participant teachers included four volunteer elementary in-service teachers from a public elementary school located in the northern part of Thailand. All of the teachers indicated an interest in learning about NOS and NOS instruction after they were asked to complete a questionnaire administered in the pilot study (Suttakun *et al*., in press). All the participant teachers were females with a wide range of educational background and science teaching experiences. The research was undertaken throughout the 2009 academic year; each phase took each of the two consecutive semesters. Unfortunately one of the participant teachers died from cancer early in the second semester of the study. Consequently, there were only three teachers who participated in the study until its end.

Conclusions in relation to the first research question

In addressing to the first research question, the researcher collected data using teacher interview and extended classroom observation. Data analysis was conducted with an aim to create a profile of each participant teacher's initial understandings of NOS and how NOS was taught in their classroom. It was evident at this phase of the study that the participant teachers, with a wide range of educational background and science teaching experiences, had different understandings of NOS. However, none of them possessed deep understandings of NOS *and* productive strategies for teaching NOS. One participant teacher (i.e., Pikun) possessed tacit understandings of all NOS aspects while the other two teachers (i.e., Kanya and Sunee) had less complete understandings of the NOS aspects. Only did one of the teachers (i.e., Sunee) hold a realist epistemology, which is against to contemporary views of NOS. However, a direct relationship between the participant teachers' understandings of NOS and their educational background as well as science teaching experiences does not necessarily seem to exist.

All of the participant teachers had limited understanding about teaching NOS. Similar to the findings of Abd-El-Khalick and Lederman (1998), the participant teachers conflated NOS with scientific process, claiming that teaching NOS was about teaching students to have scientific process skills. The data from extended classroom observation indicated that the teachers adopted an implicit approach to teaching NOS, and did not explicitly mention NOS aspects during the instruction. The participant teachers seemed to assume that students would learn about NOS through simply engaging in inquiry-based or hands-on activities (e.g., observing and classifying given things). As argued by Abd-El-Khalick and Lederman (2000), such an implicit approach to teaching NOS is not effective in promoting the students' desired understandings of NOS.

The research results addressing to the first research question provided some insights into what is needed to support the teachers in understanding NOS and learning to explicitly teach NOS in the classroom. As none of the participant teachers possessed complete understandings of NOS *and* how to effectively teach NOS, they indeed needed supports to have deeper understandings of NOS and gain ideas regarding how to teach NOS effectively. A workshop, which was designed to introduce contemporary views of NOS espoused by science education reform efforts, was then held. In it, the teachers were asked to reflect on their understandings of NOS in comparison with contemporary views of NOS as well as to re-interpret or translate curricular messages about teaching NOS. These kinds of support that prepared the teachers to have better understandings of NOS and gain ideas regarding effective NOS instruction facilitated the teachers learning to explicitly teach NOS during the collaborative action research.

Conclusions in relation to the second research question

Collaborative action research was initiated and sustained throughout a semester in order to address the second research question. During this part of the study the participant teachers, with the researcher's facilitation, regularly met to discuss and share ideas about particular NOS aspects and how to possibly translate those into classroom practice. It appeared that the collaborative action research afforded varied supports that assisted the teachers in moving toward a more explicit approach to teaching NOS. A variety of support structures were needed because of the wide range of the participant teachers' initial understandings of NOS, their interpretations of teaching NOS, and other contextual factors (e.g., preoccupation with classroom management and routine chores) that facilitated and/or inhibited them to explicitly teach NOS. Those varied supports can be summarized as follows:

- The teachers needed support that activated or affirmed their initial tacit understandings of NOS. This support helped the teachers become aware of their own understandings of NOS and more confident in explicitly presenting their views of NOS in the classroom.

- The teachers needed support that challenged some of their naïve understandings of NOS. This support helped the teachers become aware of their confusion regarding NOS. This helped them to critically examine their understandings of NOS in light of those espoused by science education reform efforts. For this purpose it was useful to introduce contemporary views of NOS to the teachers.

- The teachers needed support that helped them re-interpret or translate curricular messages associated with NOS, which seem to be implicit, more appropriately. The study indicated that teachers needed to appreciate that NOS should be regarded as a cognitive learning outcome (instead of an affective one) and that NOS should be made explicit to their students.

- The teachers needed support to help them decide which NOS aspects are accessible or attainable by their elementary students. It was determined that discussion with colleagues as well as consultation with relevant literature could serve for this purpose.

- The teachers needed an opportunity to reflect upon on their own NOS instruction so that they could gain insights into how to improve their NOS instruction in future. As reflective practice takes time to develop, support was provided to help the teachers begin this process.

- In addition to an opportunity to reflect upon their own implemented NOS instruction, the teachers needed to receive constructive feedback from their colleagues about alternative ideas associated with the implemented NOS instruction. Similarly to reflective practice, an idea-sharing event will not spontaneously happen unless support of such an atmosphere is provided.

This study found that when provided with these varied supports, the participant teachers made the modest gains in their understandings of NOS and demonstrated some improvement in their translation of those understandings into classroom practice. A possible explanation for such success is that the present study did emphasize all three components of Bell and Gilbert's (1994) model of teacher development. That is, the participant teachers after being interviewed by the researcher at the start of the study felt some dissatisfaction after recognizing that they did not teach NOS to their students. This in turn may have leaded them to seek a way to deal with this dissatisfaction (i.e., personal development). Then, the collaborative action research afforded them opportunity to discuss their dissatisfaction and how to possibly deal with it effectively (i.e., social development). Subsequently, they took risks by bringing new ideas and insights about NOS into the classroom (i.e., professional development). All of these facilitated them to learn about NOS and NOS instruction purposively.

Despite achieving only limited success in promoting the participant teachers' learning to explicitly teach NOS in the classroom, the present study provides insight into what is needed to further support teachers in continuing their learning about NOS and NOS instruction. This study indicated, as also suggested by Hanuscin *et al*. (2010) and Lederman (2006), the participant teachers need to develop "pedagogical content knowledge for teaching NOS" in order for them to make decisions on which particular NOS aspect(s) should be effectively addressed where and when during the instruction. Also, it seems necessary to prepare teachers to be able to assess and analyze their students' understandings of NOS. The results of such assessment can provide insights about what kind of difficulties the students may encounter in understanding contemporary views of NOS, and inform teachers on how to develop NOS instruction that could help the students overcome those difficulties. This, in turn, may encourage and support the participant teachers in continuing their professional learning about teaching NOS.

Recommendations for Professional Development

This section provides recommendations for professional development regarding NOS. As illustrated in this study and also in other studies (Abd-El-Khalick and Lederman, 2000; Khishfe and Abd-El-Khalick, 2002), an explicit and reflective approach to teaching NOS has been shown to be more effective than an implicit approach for both science teachers and students. Thus, an explicit and reflective approach to teaching NOS should be emphasized in professional development activities. Collaborative action research can afford a fruitful context in which teachers can explicitly and reflectively discuss NOS and NOS instruction. Such a context creates learning opportunities for them to develop more accepted and complex understandings of NOS, which will subsequently be translated into classroom practice.

In order to use collaborative action research as an approach to supporting elementary science teachers' learning about NOS and NOS instruction, one should ensure that the three elements of Bell and Gilbert's (1994) model of teacher development are provided. That is, elementary science teachers must recognize (or at least be helped to recognize) that NOS is important for their students and thus, should be taught. Such recognition will motivate the teachers to seek out new ideas or insights necessary for implementing NOS instruction (i.e., personal development). Also, the teachers must have opportunities for social interactions with others so that they will learn about teaching NOS with others (i.e., social development). Last but not least, the teachers must have opportunities to teach NOS in the actual classroom as well as reflect on the implemented NOS instruction (i.e., professional development). These three elements are interactive and interdependent so collaborative action research must be undertaken in a manner that encompasses and integrates them all.

However, opportunities to learn about NOS for elementary science teachers should not be limited to engaging in collaborative action research. Alternative approaches to supporting the teachers to learn about NOS should be taken into account. For example, peripherally yet authentically participating within scientific work (Schwartz *et al*., 2004) and/or discussing NOS with practicing scientists (Morrison *et al*., 2009) are also promising approaches as through these NOS can be made explicit for the teachers. Moreover, an opportunity to explore, analyze and assess others' understandings of NOS (e.g., students') can facilitate the teachers to learn about NOS as well (Hanuscin *et al*., 2006).

Recommendations for Future Research

This section provides recommendations for future research that aims to support elementary science teachers' learning to teach NOS. As learning is often a time-consuming process, promoting a change in an elementary science teacher's understandings of NOS towards contemporary views of NOS may take time. Moreover, this period of time might vary among different elementary science teachers, depending on their initial understandings of NOS and how to teach NOS. Due to limitations in times and budget, the present study could not be continued to further examine whether what the participant teachers had learned about NOS can and will be sustained in future. It is equally interesting to investigate how elementary science teachers' understandings of NOS develop over time when they engage in ongoing professional development activities designed to promote contemporary views of NOS. Moreover, given the fact that all NOS aspects are interrelated and interdependent, it also would be interesting to identify which NOS aspects are easy or difficult to change. All of these are suggested as issues that could be examined in future research.

The present study indicated there are some factors that appear to impede science teachers understanding of contemporary views NOS espoused by science education reform efforts, future research should pay serious attention to investigating any impeding factors in order to identify and provide relevant support that can help teachers overcome those impediments. For example, Lederman (2006) points out that one's understandings of "NOS may be a subset of one's worldview or is at least impacted by one's worldview". This was also evidenced in the present study and as one of the participant teachers-demonstrated that a realist epistemology that seemed to make it difficult for her to understand and embrace contemporary views of NOS. This suggests there should be research that examines the relationship between Thai teachers' personal epistemologies and their understandings of NOS as well as the influence of such epistemologies for learning about NOS.

As the present study primarily focused on the participant teachers' understandings of NOS, their teaching practice related to NOS, and how collaborative action research supported them to learn about NOS and NOS instruction, the study was limited to focus on how the participant teachers' NOS instruction influenced their students' understandings of NOS. This does not mean that students' understandings of NOS are less important than those of the teachers. Rather, the ultimate goal to support the participant teachers' learning about NOS and NOS instruction is to have the students with informed understandings of NOS. To achieve that ultimate goal, we need teachers who possess informed understanding of NOS and are able to teach NOS effectively. Thus, there is much work needed that goes beyond the end of the present study. Future research needs to consider the ultimate goal of having the students with informed understandings of NOS.

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APPENDICES

Appendix A

The First Workshop: The Nature of Science

The First Workshop: The Nature of Science

Session 1: What Science Is

This session aims to build up a general image of science shared among the teachers. In doing so, the teachers were invited to engage in a discussion on the questions: “What is science?” and “What is not science?” To discuss on these questions, the teachers are expected to reach the key concepts that:

> Science has a primary purpose to uncover mechanism of natural phenomena and represent it in particular forms of knowledge. Science has its own way of knowing, values, and beliefs that are different from those used in other disciplines. Science can be referred to as knowledge and as a process by which such knowledge is constructed.

Moreover, at the end of this session, the teachers had opportunity to discuss why science should be taught at elementary level. The discussion is prepared to help the teachers appreciate the importance of teaching science (and of its nature) to young students. In the discussion, the teachers are expected to reach the key concept that:

> A well understanding of science (and of its nature) could assist a person to be able to critically examine scientific issues or claims, and to make informed decisions on those.

Session 2: The Nature of Science

Session 2 consists of a set of hands-on, minds-on activities, which aim to introduce the teachers to particular aspects of NOS. All of the activities are adapted from (Lederman and Abd-El-Khalick, 1998) with little adjustment (e.g., language used) to make them more suitable to the participant teachers. In each activity, the teachers working as a group are encouraged to discuss and reflect on their understanding of the targeted aspect of NOS. Details of each activity are presented accordingly.

Mystery Boxes: Scientific knowledge is changeable

In this activity, the teachers are presented sealed "mystery" boxes and asked to manipulate them in order to guess what is inside the boxes—that is, a moving ball and a fixed barrier or two. Initially, an uncertainty inherent in the process of guessing is experienced by the teachers, but gradually reduced as they explore the boxes in more details. Through this activity, the teachers are expected to learn that their guesses, which are metaphors of scientific knowledge, are subject to change and based on empirical evidence from observations. Besides, they are supposed to know that such guesses are created from human logical reasoning, creativity, and imagination.

Tricky Tracks: Observation versus inference and there is no single answer to a scientific question

In this activity, the teachers are shown three pictures of "Tricky Track" respectively. In each picture, they are asked to make observation and draw inference to what caused the track. By observing each of the tracks, the teachers are gradually gained additional data that they need to incorporate them into account. Through this activity, the teachers are shown that there is the difference between observation and inference and that, due to such difference, many answers can be inferred based on the same set of the data. At this point in time, the teachers are introduced to the idea that scientists make similar inferences as they attempt to answer to a scientific question. Even though their answers are consistent with the evidence available to them, there is no single (or absolute) answer for that evidence. Similar to the case of "Tricky Tracks," the point is made that scientists can never find the answer to what has really happened in nature.

The Great Fossil Find: Scientific knowledge is constructed by human attempts.

In this activity, the teachers were given a closed envelop, which contains a set of pictures representing different parts of fossils of some unknown creature. Following a script read by the researcher, the teachers open the envelope and then take only a few pictures once at a time from the envelope. With a limited number of pictures, the teachers have to construct and reconstruct the whole image of the creature fossil. In doing this, their fossil-image construction tends to change as they take new parts of fossil pictures from the next chances to open the envelope. Through this activity, the teachers are expected to learn that scientific knowledge, which is now metaphorically represented by their fossil image, had been constructed by human attempts. That is, scientists gather and interpret data in order to construct knowledge relevant to their questions (e.g., how does this creature look like?). Similarly to the way that the teachers construct the whole image of the creature, scientists use inference and creativity to construct scientific knowledge.

The Hole Picture: Scientists normally have limitation to do scientific work.

This activity is used to introduce the teachers to a situation regularly faced by scientists when they are doing their work. That is, scientists as humans have limited access to the phenomenon they intend to investigate. Astronomers, at least for now, can not visit and explore the sun by themselves, for example. In the activity, the teachers are given a closed envelope, which contains a piece of paper that represents a colorful picture. By seeing through a hole on the envelope, the teachers are asked to propose what kind of the picture in the envelope looks like. Once possible pictures are proposed, the teachers have opportunity to compare and contrast those pictures. At this point in time, the teachers are introduced to the idea that scientists while investigating a natural phenomenon, they have their own limitation to the data they can access about it. One such limitation can be human sense, for example. However, scientists can sometimes use instruments to enhance their ability to gain more data. Nonetheless, they can at best use on the data available to them to construct scientific knowledge.

Pictorial Activities: Scientists are influenced by their prior knowledge and experience.

Given a set of pictures, which can be perceived differently (such as either a “young” or “old” woman, either a rabbit or a duck, or either an aging president or a woman), the teachers were asked to tell what kind of the pictures they perceive. One can expect to have different results of the teachers' perception as a result of their prior knowledge and experience. As a consequence, the different perceptions were discussed and related towards an aspect of NOS. That is, when facing any given data, scientists' prior knowledge and experience always influence their interpretation on the data. Such prior knowledge and experience also affect what scientists decide to observe (and not observe). It is this individuality that accounts for the role of subjectivity in the process that scientists construct scientific knowledge. Therefore, the same set of data can be interpreted in different ways by different scientists.

Sketch a Scientist: "Social and cultural context" and "Scientist is common human"

The teachers are asked to draw an image of a scientist based on their perceptions. They are asked to compare their drawing with those of others. As they do this, the teachers evaluate stereotypes in all of the drawings and then discuss the origins of such stereotypes. Through this activity, the teachers are expected to be aware that the public's perception of scientists is biased towards particular stereotypes that may not be representative of real scientists. Through this the teachers are introduced to idea that scientists are regular human being, similar to themselves.

Session 3: Moving towards Teaching NOS

This session is designed to raise awareness about the presence of NOS in Thailand's National Science Curriculum Standards and how particular aspects of NOS, as presented in the previous session, can be taught at elementary level. The teachers are asked to identify some parts of the curriculum document that reflect any aspects of NOS. It is this session where the teachers are also asked to think about instructional activities that can use to teach the identified aspects of NOS. After that, some examples of lessons that reflect NOS (such as an inquiry-based approach and a historical approach) are presented to the teachers. Based on the examples presented, the teachers are prompted to notice that NOS can be taught either implicitly or explicitly. At the end of the session, the teachers are asked to reflect on their understanding about NOS in the form of journal writing exercise.

Appendix B

The Second Workshop: The Collaborative Action Research

The Second Workshop: Collaborative Action Research

Session I: Introduction to Collaborative Action Research

At the beginning of the session, the teachers were invited to engage in a discussion on the hand-on and mind-on activities that aim to introduce them about the characteristics of action research. After that the teachers are presented with a definition of collaborative action research as:

> …a form of systematic inquiry conducted by practitioners (i.e., teachers) in a situation in which they are actually involve. The main purpose of doing action research is to improve a situation, that those practitioners feel is problematic. In doing so, the practitioners need to understand the situation critically and take possible actions to improve it. [Workshop document: 21/11/09]

After being presented with such definitions and characteristics of action research, the teachers' attention is turned back to the current situation in Thailand's elementary education, which is relevant to them—that is, NOS has been marginalized in Thai elementary classrooms. As the value of teaching NOS has gradually been developed in the previous workshop, it is during this period of time where the teachers share a concern they have about how they should teach NOS to their students.

Once the teachers have a shared concern with teaching NOS to their students, it is time for the researchers to introduce them to the process of collaborative action research. Initially, Kemmis and McTaggart's (1988: 10) action research cycle, which consists of four phases—planning, acting, observing, and reflecting—is presented. To elaborate this, Zuber-Skerritt's (1992:11) description of action research cycle, as shown below, is followed.

> The plan includes problem analysis and a strategic plan; action research refers to the implementation of the strategic plan; observation includes an evaluation of the action by appropriate methods and techniques; and reflection means

reflecting on the results of the evaluation and on the whole action and research process, which may lead to the identification of a new problem or problems and hence a new cycle of planning, acting, observing and reflecting.

Moreover, the teachers are informed that it can be more beneficial when the practitioners work collaboratively in order to improve a situation in which they actually involve. In addition, some fundamental characteristics of collaborative action research (such as being systematic, reflective, collaborative, and critical) are introduced through a discussion (although they are not strongly emphasized).

Session II: Planning for Conducting Collaborative Action Research

The ultimate aim of the second session is continued to prepare the teachers to engage into the first phase of action research cycle—that is, planning. As the focus of this particular collaborative action research project is advance the teaching of the NOS to elementary students, the researcher then suggests the teachers to explore how their young students understand some particular aspects of NOS. They are asked to select any aspects of NOS, and student grade, according to their interest. The teachers are then introduced to instruments used to explore students' understandings of NOS. Data gained from such instruments will allow the teachers to see problems, which need to be taken into account for further instruction. The teachers are provided with opportunities to exchange their ideas and experience about the process of conducting classroom action research and how to teach the concepts of NOS. During this activity, the science educator also provides feedbacks suggestions about the teachers' instruments and plans. A simple timeline for collecting data and further instruction is made. At the end of the workshop, each teacher presents their planned action how to explicitly teach the NOS.

Appendix C

The Nature of Science Questionnaire

The Nature of Science Questionnaire

Part 1: Teachers' background (10 questions)

1. Gender ( ) Male ( ) Female

2. Age ( ) 20-29 years ( ) 30-39 years
( ) 40-49 years ( ) more than 50 years

3. Education ( ) Lower than Bachelor's degree : ……………………………
( ) Bachelor's degree: ………………………………………
( ) Master's degree : ………………………………………..
( ) Doctorate: ………………………………………………
( ) Other: ……………………………………………………

4. Status ( ) Government employee
( ) Government officer
( ) Temporary employee
( ) Other……………………………………………………….

5. Science teaching experiences………………..years

6. Please specify the subjects, grade, teaching hours/week, the number of classes, and the average of students/class in the two tables.

Semester 1: Academic year 2007

Subjects	Grade	Teaching hours/ week	The number of classes	The average of students/ class

Semester 2: Academic year 2007

Subjects	Grade	Teaching hours/ week	The number of classes	The average of students/ class

7. Please specify the other works aside from teaching in academic year 2007

( ) None of other works

( ) Academic administration	( ) Head of 8 areas content standards
( ) Financial and account administration	( ) Boy scouts/ Girl Guides/ The Thai red cross youth movement
( ) Education guidance	( ) Class master
( ) Administration	( ) Head of level
( ) Register and assessment	( ) Student activity

( ) Others …………………………………………………………………………

8. Have you ever participated in training about the development of teaching and learning science during 2006-2007?

( ) Have ( ) Do not have

If you have, please specify the topics of the training…………………………

……………………………………………………………………………………..

9. What is your feeling about teaching science?

( ) Good ( ) Not good or not bad ( ) Bad

Explain……………………………………………………………………………

……………………………………………………………………………………

10. What are your needs to improve your teaching profession?

( ) Curriculum

( ) Teaching Approaches

( ) Instructional Medias and Instruments

( ) Science Contents ………………………………………………………………

( ) Other …………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

Part II: Understandings of the Nature of Science (14 Questions)

1. What, in your view, is “science”?
2. What, in your view, is “the nature of science”?
3. What makes science or scientific disciplines such as physic, chemistry, and biology different from other disciplines of inquiry such as religion and philosophy?
4. What do scientists do to get scientific knowledge?
5. What are the characteristics of scientists that support them to get scientific knowledge?

6. What do you think about the statement that “all scientific investigation must follow the steps of scientific methods because it is an only way to acquire scientific knowledge”? Please explain and give an idea.
7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence do you think scientists use to determine what a species is?
8. Is there a difference between scientific knowledge and opinion? Illustrate your answer with an example.
9. How scientific knowledge or scientific explanation will be accepted by other scientists?
10. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypothesis formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million year ago and let to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?
11. After scientists have developed a scientific theory such as atomic theory, evolution theory, does the theory ever change?

    If you believe that scientific theories do not change, explain why. Defend your answer with examples.

    If you believe that scientific theories do change: (a) explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.
12. Do scientists use their creativity and imagination during their investigation? Please explain and provide an example.
13. Some claim that science is infused with the social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that

science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced. Which claim do you agree with and explain why? Defend your answer with examples.

14. Do you agree with the statement that "science, technology, society, and environment are interrelated"? Please explain and provide examples.

Part III: Perspectives of the teacher about teaching science (9 questions)

1. In your opinion, how do students learn science?
2. What are the aims of teaching science?
3. How do you teach science to best support students' learning science?
4. What are the characteristics of science content teacher should teach?
5. How do you assess and evaluate the students' learning science?
6. What do you think are the most important things to emphasize in your teaching? Why?
7. What, in your mind, is the NOS? Did you teach the NOS? If yes, how? Why did you teach the NOS in that particular way? (If not, why?)
8. Do you think that teaching the NOS is important? Why? (or why not?)
9. Did your students learn the NOS? How do you know? Did you assess your students' understanding of the NOS? How did you do that?

BIOGRAPHICAL DATA

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CONFERENCES:	The Investigating Our Practices [IOP's]: 12th Annual Conference, University of British Columbia, Vancouver, Canada since 2009
	The 35th Congress on Science and Technology of Thailand [STT 35], the Tide Resort (Bang San Beach), Chonburi, Thailand since 2009
	International Conference on Teacher Professional Development: Searching for New Paradigms, Agendas and Networks, Rama Garden Hotel, Bangkok, Thailand since 2009
	The ASERA 2010: 41th Australasian Science Education Research Association Conference, Shoal Bay Resort and Spa Port Stephens, New South Wales, Australia since 2010