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THESIS

EXPLORING THAI GRADE 10 CHEMISTRY STUDENTS' UNDERSTANDING OF ATOMIC STRUCTURE CONCEPTS AND THE NATURE OF SCIENCE THROUGH THE MODEL-BASED APPROACH

SUTHIDA CHAMRAT

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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This study aimed to explore the influences of teachers' implementing the Atomic Structure Instructional Unit (ASIU), on students' conceptions of the nature of science and atomic structure. Nature of science has become an important goal for science education internationally. Science educators agree that the nature of science promotes students understanding of scientific content. Furthermore, the nature of science is an essential feature of science literacy. It is also recognized that science curriculum is best taught in the context of inquiry-based learning that incorporates the nature of science. Such teaching-learning may result in the development of an intellectual approach to science that can have long-lasting effects on both science and society. Improved teaching-learning of atomic structure is one of those areas that is important for understanding the wider implications of connecting science and society. The study is premised on the notion that student's conceptions of the nature of science and atomic structure needed to be improved.

The ASIU was developed based on identifying key curriculum documents and using findings from phase I in this research: (1) current teaching and learning of atomic structure, (2) students' understanding of the nature of science and atomic structure, and (3) teachers' understanding of the nature of science. A model-based approach was used as the framework for instructional unit design in which learners participated in model and modeling activities such as constructing, comparing, contrasting, critiquing, and modifying models. Effects of the ASIU on students' understanding were explored through classroom observations, interviews, the Atomic Structure Concept Test (ASCT), the Nature of Science Questionnaire (NOSQ) and documentary data. The model and modeling activities encouraged students to shift from memorizing content without understanding to rational thinking for supporting their explanations. For example, students connected scientists' experiments to the atomic model being constructed. The reflection and discussion of the students' experiences in the lessons resulted in students' conceptualization of core aspects of the nature of science. For example, science relies on evidence, role of creativity and imagination in science, and observation and inference. Furthermore, it was found that students changed from passive learners to active participants by engaging in model thinking and modeling activities.

The overall findings of this study suggests that the designed instructional units, based on exploration of the current frameworks in teaching and learning atomic structure and the nature of science, coupled with a model-based approach, can be used to develop an informed understanding of the nature of science, and concurrently lead to an enriched understanding for concepts of atomic structure. However, there are key points that emerged in this study that need to be addressed: The teachers' teaching of atomic structure, with the integration of the nature of science, was influenced by their background and characteristics, their commitment to change, their understandings of the nature of science, and their dependence and familiarity of using lecture as a "reliable" method of instruction. Thus, these factors seem to be the most important determinants in developing student understanding for the nature of science. The outcome is that successful implementation of a model-based curriculum is critically dependent upon carefully planned professional development experiences for teachers.

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Student's Signature Thesis Advisor's Signature

ACKNOWLEDGEMENTS

Once, the modest but well-known scientists, Isaac Newton, had said that "if I have seen further it is by standing on the shoulders of giants." I had read this statement before, but I didn't perceive its actual meaning until I became the student in the Program to Prepare Research and Development Personnel for Science Education (RDSE). I would like to thank to my supervisors, Dr. Naruemon Yutakom, Dr. Porntip Chaiso, Dr. Nattamon Koonsaeng and Dr. Deborah J. Tippins for their continuous support for this study. I also would like to thank Dr. Norman Thomson, my supervisor when I was a student in exchange program with the Department of Mathematics and Science Education, the University of Georgia. I'm deeply appreciated on their patience and efforts to monitor and read my work. They provided me with valuable comments on this thesis. Without these great people, I might have not seen further how to complete this thesis.

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Suthida Chamrat
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CHAPTER I

INTRODUCTION

Significance of the Study

During recent years, some unrelated interesting events occurred. Some of these related to international issues while others to local phenomena. The following are some examples of these unrelated events described as brief stories:

1. On May 13^{th}, 2006, people who lived in Bangkok found a mysterious cylindrical object that was 15 cm long, jelly-like, and transparent. Many people believed that it was an alien, but other people thought that this object was a magic crystal that fell from heaven. A lot of people worshiped this object and some people even drank water from it. Most newspapers posted this story in their headlines for 3-4 days. It took more than a week for a formal announcement that said it was actually a fever relief gel. (Ministry of Science and Technology, 2006)

2. Since the 1990's, we have realized that increasing global temperatures are the result of the emissions of fossil fuel combustion gases. Up to the present, the world has faced the consequences of the greenhouse effect and these consequences appear to be more and more harmful (Burns *et al*., 2006).

3. By the end of the year 2006, the outbreaks of the highly pathogenic H5N1 avian influenza that began in South-East Asia in mid 2003 had already spread to a few parts of Europe. This was the largest and most severe on record (World Health Organization, 2007) of the spread of such a pathogen. From the beginning, the virus had gone global, spreading to over 40 more countries. A World Bank report outlined the dire economic effects avian influenza had on world poultry flocks and demands for the meat. The World Bank estimated that a severe avian flu pandemic among humans could cost the global economy about 3.1 percent of gross domestic product -

around US$1.25 trillion on a world gross domestic product of $40 trillion (World Bank, 2006).

The events described above are connected by the question “what kinds of people should we plan for our children to become or the people of tomorrow to be, in order for them to be able to handle unexpected phenomena like these?” Many scientists and science educators agree that people in this modern world will continue to have to meet new problems and challenges everyday. To cope with these, they should be “scientifically literate persons”. Mach (1898: 359-360) describes science literacy as:

> ...without at least an elementary mathematical and scientific education a man remains a total stranger in the world in which he lives, a stranger in the civilization of the time that bears him. Whatever he meets in nature, or in the industrial world, either does not appeal to him at all, from his having neither eye nor ear for it, or it speaks to him in a totally unintelligible language.

Without science literacy, it will be difficult to live a basic life, take care of ourselves, have quality of life, make intelligent decisions and problem solve. The more our world changes, the more we need to understand science and about science. On the macro scale, nations need scientifically literate persons to serve as human resources for developing the country and to be desired members of a knowledge based society (Institute for the Promotion of Teaching Science and Technology [IPST], 2002). Furthermore, when considering the entire picture on a worldwide scale, everyone in the world needs to know how to live a life of sustainability so problems like global warming, high rates of fossil fuel depletion, and the development of new viruses can be solved. Therefore, globally or locally, science is essential and necessary to every citizen. Science is not just facts, like remembering the name of subatomic particles and the sequence of the DNA double helix, it is also important that we understand the science of how these facts are determined and then use them for improving the quality of life and society as responsible citizens.

Understanding the nature of Science is a crucial component of scientific literacy. We cannot have science literacy without understanding the nature of Science. After completing school, former science students should be able to use their understanding of the nature of Science to distinguish science from pseudoscience and use logical thinking to solve the problems.

The question emerges though as to how we can do this. How can we educate individuals to enable them to comprehend the nature of Science? This dissertation will explore the answer to this question. It will start with the problems, it will outline the entire process of the study, point out possibilities of ways in which to promote students' understanding of the nature of Science with a specific-purpose approach, will give details of possible ways for promoting science concepts, the nature of Science and important scientific skills and modeling. Before beginning the study, terms and definitions employed in the research will be.

1. The Nature of Science

The nature of science has been emphasized in science education since people realized that teaching science is not effective if students don't really understand about science. Without an understanding of the nature of science, misunderstandings in science can result in a bad attitude toward science. The nature of science is really the characteristics of science from multiple views because science is a human activity. Science can be an occupation as well as the pursuit of understanding the world using human endeavors. To explain the activities of science, we need to consider the aspects that influence the ways science has been conducted for a long time, the aspects of how various societies of science relate and how they then relate to history, sociology, philosophy of science and psychology (McComas, 1998a).

Many contemporary science educators agree that encouraging students' understanding of the nature of science, its presuppositions, values, aims, and limitations should be a central goal of science teaching. Knowing how scientific knowledge is constructed, how it is justified, and how it changes will help individuals make informed decisions related to the validity and application of science-derived knowledge. Driver *et al.* (1996) suggested that the nature of science not only supports learning science content, but also enhances the appreciation of science as a major part of contemporary culture that they encounter. Furthermore, there is evidence, which indicates that the nature of science enhances the learning of science content, the understanding of science, an interest in science, decision making and instructional delivery (McComas, 1998a). A qualitative analysis of recent science education standards documents from several countries has demonstrated that there is a high degree of agreement about the elements of the nature of science that should be communicated to students (McComas, 1998a). Recent science education reform in many countries around the world has set the understanding of the nature of science as a goal of science education.

In Thailand, the National Science Curriculum Standards (IPST, 2002) emphasizes the nature of science as a vision for science learning and an aim of science teaching and learning. The nature of science is a core science standard in Strand 8: The nature of science and Technology of which all students should learn. To meet such standards, students should be able to use the scientific processes and have a scientific mind when doing investigations, solve problems using a scientific approach, know that most natural phenomena have definite patterns that are explainable and verifiable within the limitations of data and instrumentation during a period of investigation, and understand that science, technology and environment are interrelated. Ways to incorporate the nature of science into a science classroom are being continuously studied and developed among science educators, researchers and teachers. Teaching science with the aim to promote students' understanding of the nature of science will help those to achieve better science content and also better demonstrate the characteristics of science. Understanding what science is and how it works will also enhance science content learning. Understanding the strengths and limitations of science as well as the value of different types of scientific knowledge will also make students better able to understand the nature of science. Students' interest in science and better abilities in decision making are also consequences of understanding the nature of science (McComas, 1998a).

2. Student Difficulties in Learning Chemistry

A lack of understanding with respect to the nature of science could result in students perceiving science as a subject which is difficult and uninteresting, and they may be unwilling to learn it (Office of the National Education Commission [ONEC], 2001). Science should be portrayed by students as a human activity and a systematic way of developing life long education. This mistake in perception is likely because science teaching still emphasizes content more than its processes and critical thinking, especially in the fourth level (grade10-12) as the report, the Monitoring and Evaluation of Education Reform: six years from enact the Thai National Education Act of B.E. 2542 (ONEC, 2005) has stated. Besides this document, the Bureau of Education Testing (BET) also reported in the results of the national General Achievement Test (GAT) that students have low achievement in science, especially in chemistry: 49% of students in the academic year 2003 (the Bureau of Education Testing [BET], 2004) and 52% of students in the academic year 2004 (BET, 2005) needed to improve in chemistry. These reports were similar to that of the Third International Mathematics and Science Study or TIMSS from the International Association for Evaluation of Science Education Achievement (IEA). The results of the TIMSS-1999 indicated that Thai students had low achievement in chemistry content (Martin *et al.*, 2000). Thai students performed below the international mean, and were ranked 32nd out of 38 countries. Klainin (2001) suggested immediately that improvement was needed in the curriculum, along with more investment in education and teacher training. Improvement was also needed in teaching methods. All this would perhaps solve the problem of Thai students' weaknesses in learning chemistry content.

The students' low achievements in chemistry could be caused by misconceptions, especially in the fundamental principles of atomic structure. The understanding of chemical behavior at the atomic level appears important in understanding subsequent concepts in chemistry such as molecular structure, chemical bonding and chemical reactions (Ozmen, 2004). Furthermore, atomic structure is also a fundamental concept in contemporary sciences such as Nanotechnology, Genetics, and Electronics. On the other hand, any alternative conceptions that students hold about the fundamental concepts of atoms and molecules will impede further learning (Griffiths and Preston, 1992; Mamlok-Nahum *et al.*, 2004).

There are many researchers reporting that students usually have alternative conceptions pertaining to atomic structure topics (Ben-Zvi *et al.*, 1986; Bethge and Niedderer, 1996; Harrison and Treagust, 1996; Karen *et al.*, 1999; Harrison and Treagust, 2000b; Unal and Zollman, 2000; Nicoll, 2001; Tsaparsis and Papaphotis, 2002; Nakiboglu, 2003; Schmidt, Baumggartner and Eybe, 2003;). There are also studies in Thailand that have reported that students posses many alternative conceptions regarding atomic structure (Thirasiri, 1997; Suppavan, 2005). Most of the research has congruently reported that students had difficultly changing Bohr's orbit model to the more sophisticated electron cloud model based on quantum theory. Harrison and Treagust (1996) studied students' mental models of atoms and molecules. From a semi-structured interview, they found that most students in the study preferred the orbit model of an atom, but did not readily understand the orbital model.

These alternative conceptions appear to be resistant to change over time, despite increased chemistry education (Ozmen, 2004). A study was done regarding teaching the atomic structure in Thailand by Paungsombat (2004). He developed the computer-assisted instruction (CAI) in the topic of atomic structure. Buengsai (2005) also examined the effects of using multimedia using Constructivist Theory on the topic of "Atom" for Matthayomsuksa IV students. Suppavan (2005) developed an atomic diagnostic test to assess the Mathayomsuksa six students. The test consisted of four parts to identify students' learning weaknesses respectively: the discovery of the electron, the atomic model, wave and particle duality and quantum mechanics. Teaching atomic structure to develop students' understanding of the nature of science has never been studied in Thailand.

3. Core Nature of Science Aspects of the Study

Among the formulation of science teaching/learning standards, there is a desire to incorporate meaningful discussions about the nature of science into science curricula. However, there is a great deal of vagueness and variability with respect to what is meant by the nature of science and what kinds of instruction and curricula would best enable students to be engaged most effectively in the idea of the nature of science. Although the basic aspects or tenets concerning the nature of science are still an issue with contentious debate (Alters, 1997), there exists a great degree of agreement on some of its more basic tenets: Scientific knowledge is based on empirical evidence that is acquired from observation and inference (Akerson and Abd-El-Khalick, 2005), scientific ideas are affected by their social and historical milieu. Scientific knowledge is subject to change (American Association for the Advancement of Science [AAAS], 1996; McComas, Clough, and Almazroa, 1998). The processes of science can be defined and affected by human creativity and subjectivity (Songer and Linn, 1991; Lederman, 1999; Bell, Lederman and Abd-El-Khalick, 2000). There is no one way to do science (Weinburgh, 2003). Theory and law are both scientific knowledge and contribute to the understanding of our world (Dagher *et al*., 2004). Students who possess an adequate conception of the nature of science will have an understanding of the values and assumptions inherent to the development of scientific knowledge (Zeidler and Lederman, 1987) beyond the content knowledge it produces. This study emphasizes the aspects of the nature of science based on Strand 8: The nature of science and Technology in the National Science Curriculum Standard (IPST, 2002). These are accessible to students at all levels and relevant to their daily lives (Lederman *et al*., 2002).

4. Research on the Nature of Science

As current research casts doubt on previous teaching methods and suggests that in order for nature of science instruction to be effective, it must be taught explicitly through investigative activities and reflective discussions (Abd-El-Khalick and Lederman, 2000b; Schwartz and Lederman, 2002; Bartholomew, Osborne, and

Ratcliffe, 2004). There are a number of studies about understanding the nature of science in Thailand. Many studies at Mahasarakham University surveyed teachers' and students' comprehension concerning the nature of science (Boonmuangsaen, 1997; Pholthum, 1997; Sadao, 1997; Khantha, 1998; Boonwong, 1999). They found that teachers and students understood the nature of science with medium to sound understanding levels. TIMSS (Beaton *et al.*, 1996; Martin *et al.*, 1997; Martin *et al.*, 2000) reported that Thai students recorded average scores in assessing their understanding of the nature of science. These scores were similar to international average scores in both primary and middle school years in TIMSS-1995, but were lower than international averages in TIMSS-1999. Nevertheless, students' scores on understanding the nature of science had a higher ranking compared with their science content scores.

Results of a research survey reported very little about the current situation of teaching and learning the nature of science. These studies intended to label students' understanding of the nature of science as "adequate" or "inadequate" without clarifying how well they understood. Both studies and literature dealing with the nature of science in Thailand remains insufficient and limits the feasibility of drawing meaningful conclusions regarding learners' understanding of the nature of science. This also limits assessing the meaningfulness and importance of any gains in understanding the nature of science achieved by learners pursuant to various instructional approaches.

5. The Nature of Science as a Modeling Activity

Science should not be taught only through content; rather, the nature of science should be explicitly integrated into a science classroom. In order for students to learn and internalize both atomic structure content and the nature of science, a more authentic approach toward school science is necessary. Teaching and learning with models and model construction is suggested for science experiences to be authentic (Gobert, 2000). Instructional units using models and modeling in the context of atomic structure in attempt to encourage understanding of science content, nature of science and the model and modeling skills it is believed will have more success. Therefore the approach that will be used to address these goals is the model-based approach. The model-based approach is a way of teaching and learning that allows students to experience science in a more realistic and authentic manner. The model-based approach can be defined as a process of teaching and learning based on the known theory of models and modeling. Learning activities and instructional strategies intend to facilitate mental modeling both in individual and among groups of learners. As an integral part of the scientific process, models are used in a variety of ways within the science classroom. Teachers use models as aids to help explain scientific phenomena and students often make their own models to display their own understanding of same scientific phenomena. When engaged in a modeling activity, students are better able to understand scientific phenomena than when made to memorize and recite their understanding. Gilbert (1991) argues that students may better understand the nature of scientific knowledge by redefining science in the context of models. Furthermore, Justi and Gilbert (2000) suggested that teachers will be better able to introduce the dynamism of science into science teaching using a historical model of an atom. By emphasizing the role of distinct models in the history of science and of the role of progression between these models in the philosophy of science, an improved understanding of the nature of science would seem to be inevitable result.

In Strand 8: The Nature of Science and Technology in the Thai National Science Curriculum Standard, the constructing and use of models is emphasized as an important tool for conducting science which relates to all 13 standards of the section (IPST, 2002). According to the standards, understanding, constructing and using models is considered the best way to display an understanding of the nature of science and technology.

6. Conclusions Determined from the Presented Information

Many curriculum documents internationally value the nature of science, including Thailand, and indicate the importance of the nature of science in science education. They make a great effort to explain its importance to teachers and students, but the nature of science is rarely taught explicitly in a classroom. The nature of science is viewed of lower importance to scientific content in spite of the enormous amount of research that has found that the nature of science should be integrated and addressed in a science classroom. Aspects of the nature of science actually added greatly to the normal content-based science teaching and didn't impede students' learning of science, but rather, supported and enhanced it making the learning meaningful and provided them with an appreciation of science. This study's main focus was on the chemistry concept of atomic structure of which many students found to have great difficulty in learning. McComas (1998a) suggested that if students apply the underlining theory of the nature of science it will actually assist them in learning the science content, even difficult chemistry content like atomic structure.

Outline of the Study

Since the real setting of classroom is actually a social phenomena, to study this kind of milieu, researchers need more understanding of the meaning that people constructed and how they interact together in a classroom situation. The interpretive paradigm view believes that knowledge is acquired through social constructions such as language, consciousness, and shared meaning (Klein and Myers, 1999). In terms of methodology, interpretive research does not predefine dependent or independent variables, and does not set out to test hypotheses, but aims to produce an understanding of the social context of phenomenon and the process whereby phenomenon influences and is influenced by social context (Walsham, 1995). In this study, the researcher has no hypothesis to test, but aims to study social context focusing on the nature of science, atomic structure and a model-based approach and how they relate. This study is based upon the philosophy of interpretive research and is premised on the assumption that models and model methodology is the proper teaching strategy in which to get learners to understand and make their learning experiences more meaningful.

The study was divided into three phases, the first phase aimed to give an understanding of the current situation in teaching and learning atomic structure in chemistry and what students and teachers understand the nature of science to be. The second phase was the development of an instructional unit designed to enhance student's better understanding of atomic structure in chemistry and the nature of science by utilizing the model-based approach. The third phase was to investigate and explore how the Atomic Structure Instructional Unit promotes students' understanding of the atomic structure in chemistry and the nature of science. Multiple methods under the philosophy of interpretive research were used to collect and analyze the data.

Purposes of the Research

1. To explore the current situation in teaching and learning of the atomic structure in Chemistry and how it is integrated with the nature of science in Thai secondary school classrooms.

2. To explore teacher and student understanding of the concept of atomic structure in chemistry and the nature of science.

3. To develop a model-based instructional unit for teaching the atomic structure concept in chemistry that utilizes the aspects the nature of science

4. To investigate and explore how an instructional unit promotes students' understanding of atomic structure in chemistry and the nature of science.

Research Questions

Phase I Exploring the current situation in teaching and learning of the atomic structure in chemistry and the nature of science

Main Question:

What is the current situation regarding teaching and learning of atomic structure integrating this learning with the nature of science in 3 classrooms in Bangkok?

Sub Questions:

1. How and to what extent do Thai teachers' instructions typically reflect the nature of science in teaching atomic structure?

2. What are the teachers' perceptions of the problems of teaching atomic structure with the integration of the nature of science?

3. What are the students' understandings of atomic structure prior to the Atomic Structure Instructional Unit?

4. What are the teachers' understandings of the nature of science prior to the Atomic Structure Instructional Unit?

5. What are the students' understandings of the nature of science prior to the Atomic Structure Instructional Unit?

Phase II Designing and developing the Atomic Structure Instructional Unit integrated with the nature of science

Main Question:

What is the process of designing and developing of the instructional units to teach atomic structure with the integration of the nature of science?

Sub-Question:

1. How is the Atomic Structure Instructional Unit modified to take into account teachers' responses?

Phase III Investigating and exploring how the Atomic Structure Instructional Unit promotes students' understanding about the atomic structure and the nature of science.

Main Question:

1. How do teachers implement the Atomic Structure Instructional Unit?

2. How do the teachers' implementations of the Atomic Structure Instructional Unit influence students' understanding of atomic structure concepts and the nature of science?

Sub Question:

1. How do students understand atomic structure concept as sequences of the ASIU implementation?

2. How do students understand the nature of science as consequences of the ASIU implementation?

Anticipated Outcomes

1. Science teachers will be more concerned about their teaching of the atomic structure and how they integrate it with the nature of science and try to adapt instructional units into their own lessons.

2. The information of teaching and learning the atomic structure and nature of science using the model-based approach will be available to science educators for professional development in preservice and inservice education.

3. Science curriculum creators will concern themselves with integrating science concepts and the nature of science when designing and developing instructional units using the model-based approach.

Delimitations of the Study

1. Research Site and Participants

The research was conducted within three public secondary schools in Bangkok and sub-areas of Bangkok. The schools were public, underlying to Office of the Basic Education Commission, Ministry of Education. All three schools are categorized as “extra-large” schools with enrollments exceeding 2500 students and serving Grades 7-12. Three chemistry teachers and their Grade 10 students, participated in voluntary sampling with a total of 137 students (School A = 45, School B = 50, School C = 42) in the first phase and 143 students (School A = 42, School B = 49, School C = 52) in the second phase. The teachers from Schools A, B and C have taught chemistry for 25, 23 and 25 years, respectively. Three students from each school were selected by purposive sampling to be explored while they participated in the research. Whole classrooms were observed for contextual information and 9 students were explored in depth. All were science program students in that they had science experiences in Grades 7-9, but this was their first chemistry course.

2. The Atomic Structure Instructional Unit

The Atomic Structure Instructional Unit (ASIU) was a set of teaching lessons that emphasized the integration of the nature of science with the concept of atomic structure. The nature of science focused in the ASIU used the 8 aspects reviewed in a previous topic in this paper. The scientific content emphasized in the instructional units was the atomic structure covered in strand 3: Matter and Properties of matter. The ASIU consisted of 9 lesson plans which totaled 13 periods.

3. Data Collection

The data collection responses to the 3 research phases were divided into 3 intervals of time. In terms of phase I research, the data collection occurred during May-July 2006 (Academic year 2006). The second phase data collection took place during September 2006 - February 2007 with the design and developing of the ASIU. The data from focus groups and workshops was collected in May, July and October 2007. Lastly, the implementation of the ASIU and phase 3 data collection went from May-August 2007 (Academic year 2007).

Salient Terms Important to this Study

1. The Nature of Science

The nature of Science, which is integrated in the instructional units, emphasizes the eight aspects of science which are a blend between the nature of science and technology as defined by strand 8 in the National Science curriculum standards (IPST, 2002) and from the description of the nature of science generally accepted among international science educators. This description is appropriate for students at all levels and ensures that the vocabulary used is relevant to their daily lives. The core aspects of the nature of science in this study are: science is based on evidence, there are various methods in which to do science, science is subject to change, theory and law are both scientific knowledge and important for scientific development, scientific knowledge is constructed from both observation and inference, human subjectivity, social and culture milieu are affected by science, and lastly, creativity and imagination are important in science.

2. Atomic Structure Concept

The atomic structure concept in this study was based on the National Science Curriculum Standard of the fourth educational level, and as regarding to the school policy. Atomic structure is one of the topics of Strand 3: Matter and Properties of Matter that students have to learn in level 4 (grade 10-12). In this study, the atomic structure is part of the 10^{th} grade chemistry course. Its substances consist of 6 sub-topics namely, early atomic theory, Dalton atomic theory, Thomson's cathode ray tube experiments, Rutherford and gold foil experiments, Bohr's planetary model, the Quantum mechanics atomic model and electron configuration.

3. The Model-based Approach

The nature of science as a modeling activity is the theme of all teaching approaches employed in all the instructional units for this study. The philosophical concepts central to the units are explicit and reflective of the nature of science concepts, the use of model and modeling, the concepts of atomic theory, the history of science and the related technology.

The Thesis Overview

According to the National Science Curriculum Standard (IPST, 2002), there were attempts to identify a set of desirable learning outcomes for grade 1-12 science students. It was proposed that students who could master these learning outcomes would be considered scientifically literate - that is, they would be able to comprehend the principles and theories basic to science, understand the scope, limitations and nature of science, be provided with skills for discovery that would lead to the creation of science and technology and develop thinking processes, imagination, the ability to solve problems, data management, communication skills and the ability to make decisions. To achieve the outcomes of the National Science Curriculum Standard in Strand 3: Matter and Properties of Matter and Strand 8: The Nature of Science and Technology it is hoped these will support a student’s understanding of further concepts in science. This study aimed to develop the teaching and learning of atomic structure and the nature of science by exploring the teaching and learning of atomic structure and the nature of science and to use research findings to design and develop an effective instructional unit for teaching the nature of science, integrating it with the atomic structure content in a Thai context. The teaching and learning process investigated and explored how the instructional unit promoted student understanding of the atomic structure and the nature of science. This study used the model-based approach to reflect the nature of science in the classroom as well as an approach to teaching atomic structure. The findings described during the implementation of the atomic structure units integrated with the nature of science and consequences were available for the teachers and science educators to apply in their own classroom.

This dissertation consists of six chapters, and each chapter is divided into sections that contain topics and subtopics (figure 1.1). Chapter 1 provides the overview of the study. This chapter gives you a holistic view of the study. Chapter 2 presents a literature review that focuses on three main sections that shaped the theoretical framework of the study, the nature of science, atomic structure and the model-based approach. The development and implication of the ASIU are presented in chapter 4. This chapter also presented the findings from phase I because the ASIU was designed and developed based on the answers from the phase I questions. The findings from phase 3 were presented in Chapter 5. The results are divided into 4 sections. The first 3 sections describe the themes that merged from the ASIU implementation in the 3 schools. The last section of chapter 5, presents the common findings derived from the 3 school findings. Finally, chapter 6 summarizes and discusses the research findings and presents the possibilities of the implications for both practice and research in the future.

Structure of the Dissertation

CHAPTER I: INTRODUCTION

- Significance of the Study
- Outline of the Study
- Purposes of the Research
- Anticipated Outcomes
- Delimitations of the Study
- Salient Terms important to this study
- Research Questions
- The Thesis Overview

CHAPTER II: LITERATURE REVIEW

- The Nature of Science
  - What is the Nature of Science
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  - Students' understandings of the Nature of Science
  - The Nature of Science and Classroom Implications
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- The development of the ASIU
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CHAPTER V: THE DEVELOPMENT AND IMPLEMENTATION OF ATOMIC STRUCTURE INSTRUCTIONAL UNIT

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  - Themes of Research Finding from Schools A
  - Key Findings and Commentary on Results Derived from School A
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  - Key Findings and Commentary on Results Derived from School B
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    - Teachers' understanding and practices of the nature of science when teaching atomic structure concepts prior to ASIU
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  - Conclusion for Phase II Research question
    - The process of the ASIU development
    - The modification of instructional unit to take into account teachers' response
  - Conclusion for Phase III Research question
    - Teachers' implementation of the ASIU
    - Teacher's implementation of the ASIU influenced on students' understanding of the nature of science
    - Teacher's implementation of the ASIU influenced on students' understanding of atomic structure
- Discussion of the findings
  - Discussion of phase I findings
  - Discussion of phase II findings
  - Discussion of phase III findings
- Implications
  - Implications for Classroom Practice
  - Implications for Curriculum Development
  - Implications for Future Research

Figure 1.1 Structure of the dissertation

CHAPTER II

LITERATURE REVIEW

This chapter provides the information of research theoretical framework covering the learning theory underpinning this study, the nature of science and atomic structure concepts as the goal for science education and purpose of this research. The existing research involving nature of science and atomic structure will be portrayed for a whole picture of the study. In comprehend way, the review literature showed the theory and explanation that lead to the finding we want to uncover, that is, why and how we want students to know, understand, and be able to do science. There are three main topics contributed, to this work: the nature of science, atomic structure concept and model-based approach.

Nature of Science

1. What is the Nature of Science

In the early 20th century science educators, philosophers and people whose career were related in science education had been aware that just only science content was not enough for students anymore. Science as 'body of knowledge' was not the ultimate goal for science education. Rather, students should acquire science as a body of knowledge, process and nature of science. There was an attempt to incorporate nature of science into science classroom. Nature of science was recently emphasized in education reform in many countries. Many national curricula, for example The US; "Science for All Americans," (AAAS, 1990), "Benchmarks for science literacy" (AAAS, 1993) and the "National Science Education Standards," (National Research Council [NRC], 1996), also in Canada (especially Science for Every Student), and Europe (particularly those from UK, Denmark, and Spain) are giving increased prominence to students understanding of the nature of science (McComas, 1998a: xii). In Thailand, the National Science Curriculum Standards (IPST, 2002) emphasizes the nature of science as visions for science learning and aims of formulation of science teaching and learning. The nature of science is a core science standard as Strand 8: nature of science and technology which all students should learn. There are numerous definitions of the “nature of science”. It can be commonly defined as “...the values and assumptions inherent to the development of scientific knowledge...” (Zeidler and Lederman, 1987) or “Epistemology of science, science as a way of knowing, or the values and beliefs of scientific knowledge and its development” (Lederman, 1992). It may be defined as a complex multi-dimension as:

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

The basic aspects or tenets concerning nature of science, not different from its meaning, are still an issue with contentious debates (Alters, 1997). However, it does still exist a great degree of agreement on some of its more basic tenets. These include a summary as follows (Lederman, 1992; McComas *et al.*, 1998):

1. Science is an attempt to explain phenomena.
2. Scientific knowledge is tentative.
3. Scientific knowledge has basis in empirical evidence.
4. Scientific laws and theories are separate kinds of scientific knowledge and serve different roles in science.
5. Scientific knowledge is based upon observation and inference.
6. Scientific knowledge is created from human imagination, creativity, and logical reasoning.
7. Scientific knowledge is inherently subjective and based on interpretation.
8. Scientists require accurate record keeping, peer review and reliability.
9. Science is a human endeavor influenced by society and culture.

10. There is no one way to do science (there is no universal step-by-step scientific method).

11. People from all culture contribute to science.

12. Science and technology impact each other.

13. Scientific models are not copies of reality.

The aspects presented here are not limited of nature of science tenets. Alters (1997) suggested that it is not necessary to use one set of basic tenets but that some scheme might be developed wherein multiple sets of views from the philosophers could be organized into useful accurate criteria for the research in the field of nature of science, especially for measuring students' and teachers' conceptions. Before nature of science becomes a worldwide accepted goal for science education, the phrase "understanding of the nature of science" was not clearly stated. Some elements and characteristics of science were noted as goals worth pursuing in science teaching that appeared in historical perspective starting from the early years of the 20th century that are presented in table 2.1. (McComas, 1998a. From the beginnings of the interest in nature of science as an educational goal in science education up to the present moment, hundreds of researches in the field of nature of science have been conducted (Bell *et al*., 2001). Since a great number of studies have developed, those researches can be categorized into groups that Matthews (in McComas, 1998a: xii) had classified as follows:

1. To examine both teachers' and students' concepts of nature of science.
2. Instructional approach to teach about the nature of science.
3. Students' understanding of the nature of science.
4. Teachers' epistemologies and beliefs about the nature of science.
5. The impact of teachers' epistemology on their classroom practices.
6. The influence of students' epistemologies on their learning.
7. The history of the linkage between curricular definitions of scientific literacy and knowledge of the nature of science.
8. The classroom process whereby teachers' beliefs about the nature of science interact with curriculum and influence students' epistemology.

9. The justification, effectiveness, and practicality of nature of science course in teacher education programs.

10. The epistemological assumptions, or commitments, underlying various nature of science tests.

Table 2.1 The nature of science historical perspective

Year	Events
1907	The Central Association of Science and Math Teachers strongly emphasized the scientific method and processes of science in science teaching.
1916	Dewey argued that understanding of scientific method is more important than the acquisition of scientific knowledge.
1935	High school textbook 'New World of Chemistry' listed nature of science objectives such as willingness to swing judgment while experiments are in progress, willingness to abandon a theory in light of new evidence, and knowledge that scientific laws may not be the ultimate truth.
1945	James Bryan Conant delivered his famous Terry Lectures at Yale advocating a historical approach to science instruction. He suggested that all students must understand the tactics and strategies of science
1960	" Nature of science" was stated explicitly as a major aim of science teaching by the National Society for the Study of Education: pupils should acquire a useful command of science concepts and principles. Science is more than a collection of isolated and assorted facts . . . A student should learn something about the character of scientific knowledge; how it has been developed, and how it is used.

Many researchers devoted their work in the nature of science because they had a consensus view regarding the values of nature of science for teaching and learning. Driver *et al.* (1996) have suggested five additional arguments supporting the inclusion of nature of science as a goal of science instruction.

1. The utilitarian view: “an understanding of the nature of science is necessary if people are to make sense of the science and manage the technological objects and processes they encounter. . .”

2. The democratic view: people must understand the nature of science to make sense of socio-scientific issues and participate in the decision-making process

3. The cultural argument: understanding is necessary in order to appreciate science as a major element of contemporary culture

4. Moral: to understand the “. . . norms of the scientific community, embodying moral commitments which are of general value,”

5. Learning science contents: it “supports successful learning of science content”

Furthermore, there were evidences which indicated that the nature of science enhances the teaching, learning and application of science (McComas, 1998a). The nature of science enhanced the learning of science content. Evidence suggests that knowledge of the nature of science assists students in learning science content. Understanding how science operates is imperative for evaluating the strengths and limitations of science, as well as the value of different types of scientific knowledge.
The nature of science also increased the interest in science. Sensitivity to the development of scientific knowledge may also make science itself and make science education more interesting. The "democratic argument" for the nature of science instruction may be illustrated in a number of ways, but certainly having accurate views about how science functions is vital to inform decision making. A firm

grounding in the nature of science is likely to enhance teachers' ability to implement conceptual change models of instruction. Studying the process of historical conceptual development in science may shed some light on individual cognitive development.

2. Core Aspects of the Nature of Science

Nature of science has many aspects and changes over times. Like science itself, nature of science has evolved and changed along the time that we call paradigm shift (Kuhn, 1962). Recently, there have been debates among philosophers of science and between philosophers and other groups such as scientists and science educators about the nature of science. Thus, there are researches that study different aspects of nature of science. Smith and Scharmann (1999) questioned about what kind and level of understanding of the nature of science we should encourage students to achieve. The same question was addressed in the first and second phase of this study also, especially in Thai context that the nature of science becomes the core of eight strands in the National Science Curriculum Standard (IPST, 2002). Among the disagreements about aspects of nature of science, there are some characteristics of science that people in science education seem to generally accept as important for a basic understanding of the nature of science. Aspects of nature of science that seem to be appropriate goals for high school graduates have been addressed in curricular such as the AAAS Benchmarks for Scientific Literacy (AAAS, 1990) and the National Science Education Standards (NRC, 1996).

Eight aspects of the nature of science were selected to emphasize in this study because they are accessible to students at all levels and relevant to their daily lives (Lederman *et al*., 2002). McComas (2005) suggested that these lists of core nature of science ideas be appropriate to inform K-12 curriculum development, instruction and teacher education. These aspects are not only underpinning and relating to Thai aspects of nature of science in the National Science curriculum Standard (IPST, 2002) but also ready to integrate in particular science lessons. Each aspect of nature of science will be discussed in detail about the origin from history and philosophy of science perspectives and why it is important for the students to know and understand.

2.1 Evidence-based Characteristics of Science

Scientific explanations of natural phenomena or scientific knowledge are of value because they are based on two foundations: reliable empirical evidence and sound logical reasoning (Derry, 1999). This characteristic of science is predominant in the current research of both basic (science) and applied science. Scientists emphasize obtaining accurate data, which is acquired by observations and measurements taken in situations that range from simple setting, (e.g. plants) to completely constructed setting (e.g. laboratory) or even unreachable setting (e.g. other galaxies). Information comes from scientists' observation using their own senses and the extent of sense (e.g. instruments and techniques). The ways scientists observe may range from the lowest degree of manipulating, such as a complete observation of bird migration, a survey of the ecology of desert, a collection of samples such as soil, rock, water, to actively manipulating variables of which they want to know the relation between them; for example, studying the effects of temperature to the chemical reactions in particular catalysts.

This culture of empirical research is relatively in the history of science. School of thought that strongly relies on evidence to support the claims is well known as the group of people called 'empiricist'. The doctrine of empiricism was first explicitly addressed by John Locke in the 17th century but some characteristics of empiricism had appeared before that time. Back to the Greek era, Aristotle became increasingly dissatisfied with Plato's views that were very heavily dependent on a priori assumptions. Plato believed that real knowledge required rational mastery of universal principles. Aristotle developed an increasingly strict expectation for more explicit empirical confirmations for all inductions. Aristotle also stated the core empiricist tenet that human knowledge of reality is grounded in sense experience. He included observation and experiment to provide the material data for his rational scientific construction (Tsanoff, 1964). The knowledge claimed that came from a systematically observation or experiment later become a very important characteristic of science. The quality of the knowledge rests much on the evidence offered in support of the argument as it does on the logic. Accordingly, a consequence process of science is the evaluation of the quality of this evidence in order to analyze the validity of the argument. The need of quality evidence integrated with logical thinking confirms the validity of scientific knowledge. Scientists use this characteristic of science to confirm scientific knowledge. Thus the students have to achieve this tenet of science as well. In the world of science and technology, students have to evaluate between the science and pseudoscience; for example, to understand the claims of all sides in the debate over an ecologically related law, to decide whether a medical treatment they are considering is a hoax or is well supported by adequate research data (Smith and Scharmann, 1998). In this aspect of nature of science, it is not only the discussions about evidences that support scientific knowledge but also the questions about how we can justify those claims. For example, why should we believe a claimed statement? And what source, reference, or authority has warranted this claim?

We can also evaluate the possibility of the claims as Derry (1999) has discussed. The basic method to justify is using the basic knowledge. There is a certain amount of core knowledge and experience in science that can be used as a basic knowledge to evaluate new scientific claims. Probabilistic thinking and the use of numerical method are also used to justify knowledge claims. The developments of techniques and instruments in the field of science are much related with this aspect of nature of science. The senses of human are narrow and can deceive us; for example, human eyes can see only the visible region of electromagnetic radiation, and we have developed instruments that can interact with atoms or molecule in a microscopic level to study many of their characteristics. Telescope and microscope were developed in order to see further human eyes as Science for all American (AAAS, 1990) states that "...Because of this reliance on evidence, great value is placed on the development of better instruments and techniques of observation, and the findings of any one investigator or group are usually checked by others…". The need to confirm obtained evidence let scientists automatically communicate what they had discovered to the others. Any aspect of nature of science is related to each other in many ways. This aspect of nature of science is also related directly to the tentative tenet of science because when evidences are available, or we reach the technology that can let us get more information, scientific knowledge will be changed or modified.

2.2 Methods to Do Science

There are the notions that all of scientific studies follow the universal scientific method. If you do steps by steps of scientific method, you will obtain scientific knowledge. These methods are presented in the introduction of many textbooks. The steps listed for the scientific method vary somewhat text to text but usually include: defining the problem, gathering background information, forming a hypothesis, making observation, testing a hypothesis, drawing conclusion and reporting results. These steps have been portrayed to the students for a long time and this is one of the most common myths found in both teachers and students. One of the reasons of this belief comes from the way scientific journals generally published the result. The standardized style makes scientists follow a standard research plan in the real practice. Many researches about scientists' work show that no research method is applied universally (McComas 1998b: 53-70). Although there are discoveries following such series of steps, many others have not. Science is one of the human activities that is too wide-ranging, multifaceted and far too interesting for answer to suffice. Most great scientific achievements are the result of creative thinking, diligence, and many long years of dedicated research. Even the serendipity is also the method that contributes to the great scientific knowledge, for example, Wilhelm C. Roentgen and the discovery of X-ray, Frederick Kekulé and the structure of benzene, Edward Jenner and Smallpox vaccination (Derry, 1999). Another example about scientific discovery comes from looking for the patterns of an underlying coherence and regularity in nature with observation and experiment that becomes like the pieces of a jigsaw puzzle falling into the holistic from: The periodic table of the elements and the development of continental drift theory of Alfred Wegener (Roberts, 1989).

Sometimes, even though there are the systematic thinking and well-organized methods to do science; scientific ideas have to wait for other pieces of puzzle to complete a whole picture - the sufficient and necessary factors - evidences. This characteristic of science is very important to the students because it is incorrect to assume that all scientific investigations follow the same set and sequence of steps. Many science lessons may start with asking the questions that lead to investigations and experiments for seeking the conclusions. However, the teacher still needs to emphasize that there are many different routes to discover scientific knowledge (Crowther, Lederman, and Lederman, 2005). Teacher 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 results from the study of Lin, Chiu and Chou (2004) revealed that students are likely to perform better on conceptual problem solving if they have better understanding that there is no single scientific method. The methods used by scientists are dependent on circumstances and scientists are not compelled to use the traditional scientific method. Relating to other natures of science aspects, imagination and creativity are important factors that let the scientist investigate and think in different ways, and these different types of investigation to provide different information and evidence are responsible to the tentative characteristic of scientific knowledge.

2.3 Science is Subject to Change

Scientific knowledge is based on the process that depends on both on making careful observations of phenomena and inventing theories for making sense out of those observations. Such theories can be improved or changed when scientists get new evidences from the new observation. The Science for All Americans (AAAS, 1996) presents the idea about this characteristic of science as

> Changes in knowledge are 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, testing, 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 for the way it works.

Science is a way of developing answers, or improving explanations. This characteristic of science is also related to the openness to new ideas. Because one of the basic assumptions about science is scientific knowledge is that subject to change. Thus, scientists always seek for the new evidence to confirm or disprove their theory. The competition among ideas is a major source of tensions within science. Scientists modified, improved or changed their ideas according to new evidence. Besides these, skepticism as well as openness is scientific characteristics. The new theory always receives the attentions among scientists and community, but it is not widespread accepted in the early time. Evidences that they use to support the new theory will be justified and checked carefully. The questions as – "Is it consistent with the basic knowledge?, Can it explain better than the old or rival theory?, Does this theory lead to the new knowledge? will be raised". This process may be taken for several years. Skepticism and openness are the major factors for tentative characteristics of science as well as the reason for the advances of science.

Students can learn about tentative characteristics of science and understand this nature of science through the lesson designed on science topics or concepts that have changed over time. How and why scientific knowledge is very important for explicitly discuss in the classroom. For example, in August 24, 2006, the International Astronomical Union (IAU) formally downgraded Pluto from an official planet to a dwarf planet (International Astronomical Union [IAU], 2006). The reclassifying of Pluto could appeal to students' interest in science because it appeared in many publications and television channels. The teacher may use this opportunity to show students that scientific knowledge, in and of itself, is not static and that with new information, scientific theories can change. Besides this, what criteria the scientist use. How and why they change the knowledge about Pluto will make students understand more about nature of science and science concepts. However, while scientific knowledge is tentative, it is significant that both scientific laws and theories have still been used to explain natural phenomena currently. Although it is tentative, scientific knowledge has durable characteristics. The existing ideas were also disproved and confirmed before they became accepted. They may be modified several times until it survived by the rival theories. This is the reason why scientific knowledge is of value. We can use them to explain, predict and search for the new knowledge about a natural world. If we want students to understand how their own scientific ideas develop, students also have to understand how scientific knowledge has changed over time and it might enable learners to understand how their own scientific ideas develop (Solomon, 1991).

2.4 Scientific Theory and Law

The principal product of science is knowledge in the form of naturalistic concepts and the laws as well as theories related to those concepts. Unfortunately, the notion about theory and law is one of the most alternative conceptions that people held. Some people believe that when a theory has been supported by a great deal of scientific evidence, it becomes a law (Chiappetta and Koballa, 2004). There is the notion that laws were proven true and theories were tentative, either because not enough data are available or because scientists are unable to design experiments or apparatus to test theories (Lederman *et al*. 2002). Furthermore, there is the implication in the classroom that theories are lower status than laws because law is absolutely an idea (McComas, 1998b). The National Science Teachers Association (National Science Teachers Association [NSTA], 2000) endorses the proposition that a primary goal of science is the formation of theories and laws, which are terms with specific meanings.

Laws are generalizations or universal relationships related to the way that some aspect of the natural world behaves under certain conditions.

Theories are inferred explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws. However, not all scientific laws have been accompanying explanatory theories.

Theory and law are both scientific knowledge that can explain natural phenomena. Laws describe relationships, observed or perceived, of phenomena in nature. Theories are inferred explanations for natural phenomena and mechanisms for relationships among natural phenomena. Hypotheses in science may lead to either theories or laws with the accumulation of substantial supporting evidence and acceptance in the scientific community. Theories and laws do not progress into one and another, in the hierarchical sense, for they are distinctly and functionally different types of knowledge (Schwartz, Lederman and Crawford, 2004). McComas (1998b) presented the relations among theory, law, and hypothesis as figure 2.1.

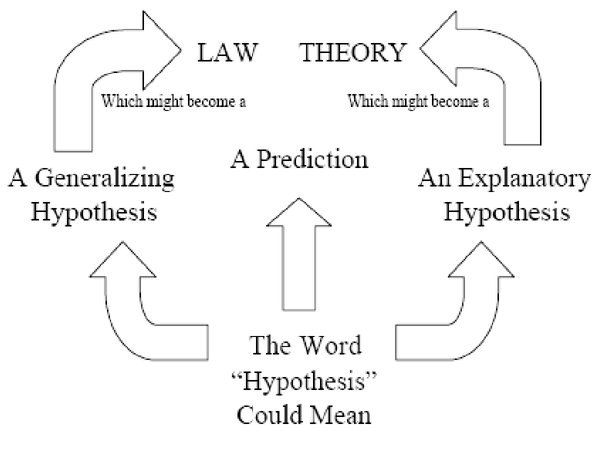


Figure 2.1 Illustration of hypothesis that turns to theory and law

In his ideas, hypothesis can lead to both law and theory with ability to predict phenomena. An explanatory hypothesis turns to theory based on a set of assumptions or axioms and posits the existence of nonobservable entities. A generalizing hypothesis becomes law because it described statements of relationships among observable phenomena. Theories, by contrast, are inferred explanations for observable phenomena or regularities in those phenomena. Both well-established laws and theories, even different kinds of knowledge, share the same characteristics. They must be internally consistent and compatible with the best available evidence; be successfully tested against a wide range of applicable phenomena and evidence and possess appropriately broad and demonstrable effectiveness in further research.

2.5 Observation and Inference in Science

As we know, one of the fundamental applications of science is to describe the natural world. To do this, scientists make many observations about natural objects and phenomena and attempt to explain what they observe. Constructing scientific knowledge can be based on both observation and inference. Schwartz *et al.* (2004) defined observation and inference as:

> … 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.

We developed many kinds of instruments and techniques to enhance our sense for observation. However, there are natural entities that we still cannot observe directly in spite of the technological advance of equipments. In this case, inference becomes the crucial role in science. Inferences are statements about phenomena that are not “directly” accessible to the senses. For example, many scientists study the invisible things, like atom, but are not able to see or observe it directly. How then are the scientists able to make claims about these particles without seeing them in their real state? The answer is that by collecting evidence, or data, scientists can piece together observable facts that can be used to explain things logically. When scientists use this approach to solve a problem, they are making an inference. For example; J.J. Thomson observed the cathode ray tube and made inference about its properties and behavior of electrons. Rutherford observed the alpha particle that hit the thin gold foil, and he inferred the existing of the nucleus of an atom. The process of making inferences based on observable evidence is one aspect of science that gives us the ability to apply our knowledge and intelligence to describe and explain the mysteries of the universe. Perspectives of current science and scientists guide us both observations and inferences. However powerful they may be in establishing scientific knowledge, inferences cannot be considered absolute truth because they are an interpretation, not a description of evidence. Every so often, inferences are later validated as being correct after technology is developed that makes direct observation of a specific object or event possible. Sometimes, a new technology or the discovery of contradictory evidence will reveal that a prior inference was incorrect. This does not mean that the science is flawed; it just means that science is an on-going process, and established knowledge will always be put to the test as new knowledge is developed. This is considered strength of the way in which scientific knowledge develops, because it allows for the acceptance of new knowledge as it becomes accessible, even if it is contrary to what was previously accepted.

2.6 The Human Subjectivity in Science

There was a philosophy of science perspective that science is objective-independent from the human factors. Scientists are careful in the analysis of evidence and in the procedures applied to reach the conclusions. At first, this notion seems to be valid, but with carefully considerate from both the philosophy of science and psychology perspectives it shows that it is impossible to have complete objectivity in science. There are at least three major reasons for supporting the ideas of the human subjectivity in science (McComas, 1998b). The first reason came from the Popper’s view (Popper, 1963). Such idea was called by Popper himself as conjectures and refutations. He believed that scientists had proposed laws and theories as conjectures and then actively worked to disprove or refute those ideas. If those laws and theories could survive from refutation or none of the contrary evidence existed, the confirmations of that scientific knowledge were cumulative. Thus, science never starts with neutral observations.

The second reason came from the psychological view. The inability of scientists to be objective is found in theory-laden observation, Scientists, like all observers, hold many preconceptions and biases about the way the world operates. The ways scientists work was affected by their theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations. These factors are held in the subconscious which influence everyone’s ability to make observation. These lead scientists to interpret the same data in different ways because it is impossible to collect and interpret facts without any bias as Schrödinger said, “Thus, the task is not so much to see what no one has yet seen, but to think what nobody has yet thought, about that which everybody sees”. This subjectivity in science is unavoidable, and it is another reason why scientific knowledge is subject to change. (Crowther *et al.*, 2005). Not only does individual theory-laden observation play a role to the subjectivity, but the issue of the allegiance play to the paradigm. From his groundbreaking analysis of the history of science, Thomas Kuhn (1962) suggested that scientists work within a research tradition or framework called a paradigm. The particular paradigm which scientists shared their work with a given discipline, provides clues to the questions to be asked, the issues for investigation, the basic knowledge and the hidden assumptions for conducting scientific research. The work that is shaped or directed by any given framework is necessarily limiting objectivity. It would be misleading to conclude a discussion of human subjectivity in science on a negative note, but the numerous examples in history of science show that the effects from different perspectives according to scientists’ views keep the track to the advance of science. Kuhn’s review of the history of science demonstrates that the causes of fundamental changes in the paradigm, called a scientific revolution, according to subjectivity in science, are responsible for far more successes in science than delays. The subjective aspect of nature of science influencing students’ attitude toward science was reported. When seeing scientists as people who grapple with complex ideas and struggle to integrate disparate information, students might be empowered to do the same (Eylon and Linn, 1988).

2.7 Science, Culture and Society Interaction

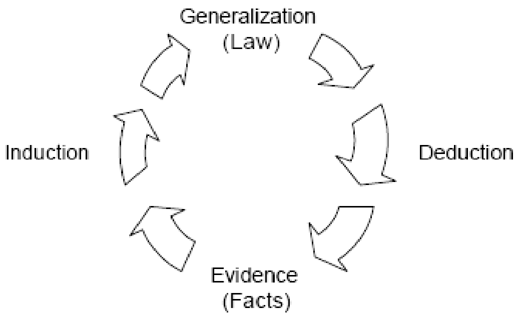
Science is human activities performed to understand the natural phenomena. This human endeavor is influenced by the society and culture in which it conducted. The values of the culture determine what and how science is conducted, interpreted, accepted, and utilized. The development of scientific knowledge cannot be isolated from the cultural context. The person who emphasized the effects of society to science in early time is Francis Bacon. In his ideas, the society would devote resources to science to hasten scientific progress because science contributes many practical benefits to society (Derry, 1999). In his time, he envisaged an ideal society that supported systematic scientific research to unlock the secret of nature and systematic scientific application of this knowledge to produce practical benefit. For the following three centuries, scientific research was still done by the low budget. The funding came from wealthy patrons, a few wealthy amateur scientists who supported themselves, a little from university, a few private foundations funded research in small scale. The funding from government was mostly limited to some practical research like agriculture. When technology became more commercial, company like Bell Telephone and General Electric started to conduct their research about their areas of interest with the industrial laboratory.

The changing occurred during World War II. There were the needs of the war for quick development such as radar, antibiotics, and the atomic bomb. The government of several countries valued the importance of science. A lot of money was turned to the funding of scientific research. Self-motivation of scientists generally came from their habit of mind, curiosity and the desire to understand the nature. More practically, the motivations of society to fund were taken into account. Citizens were usually are exited about the new result of scientific research, but this is a not single reason for spending their tax for scientific research. Economic prosperity, military security and better health are more often cited as reasons for society support of science. About the question, “Is science value-free?”, it turns too ambiguous if we refer to the over-all contexts within which science is done. In scientific community, scientists share a certain value. Scientific progress depends on the free and unimpeded flow of information from one scientist to another. A commitment to open communication of result is one of the bedrock values of science. The honesty is another value of science. Now, it is not just in science but for almost everyone. We do science with the assumption that other people who do science are giving us the honest information. In science community the penalty of fraud is very strong among scientist group because honesty is considered such an important scientific value. Curiosity and open-mind are also the general values of science. Curiosity, in science context, is the desire to understand nature more and better. This value is not only a personality of individual scientist, but it is also taken to be value of scientific community as a whole. Value is also used to determine whether one theory is better than another. Scientists employ criteria that can be considered as values. We normally prefer theories that have greater accuracy, and better consistency than the others, as well as a broader scope of application, a higher degree of simplicity and more likely to be in progress. These values are within scientific community. How about values held by a culture or society? Do they affect science or the results of science? Derry (1999) answered 'yes' for this question. He supported his ideas that our culture values regarding material prosperity influence the amount of effort. We spend time to study scientific questions that we think will contribute to our prosperity. Similarity, the questions concerning ethical issues in society limit the dimension of scientific inquiry or scientific research. This value is taking into account of using human subject in dangerous experiments, animal testing and the use of fetal tissue in research. Students have to understand this aspect of nature of science. Firstly, they have to understand that what they have learned about science is related in their life. Science is a human activity that they are engaged in everyday. Secondly, as a scientific literate person in the future, they have a voice to choose for their community, participating in making a decision what is advantage or disadvantage for them and their society. The American Association for the Advancement of Science suggests that all students whether science major or not "...should complete their science courses with an appreciation of science as part of an intellectual, social, and cultural tradition. Science courses must convey these aspects of science by stressing its ethical, social, economic, and political dimensions." (AAAS, 1990: 24). Curriculum needs not only students who know and understand that science as a human enterprise is practiced within, effects, and is affected by a social and cultural milieu, but students who also think that ethics and controversial issues should be discussed in science. The answers from this survey are uniforms among students at all levels participating in this study. They thought that discussions about philosophy and ethics make science curriculum more attractive. They also have a desire to understand and explore the moral issues of science as part of their course. (Institute of Education and Science Museum, 2003). The recommendation according to this survey corresponds with many researches which found that the relations among science, society, culture, economic and other issues in real life should not be hived off into occasional discrete topics but included throughout the curriculum.

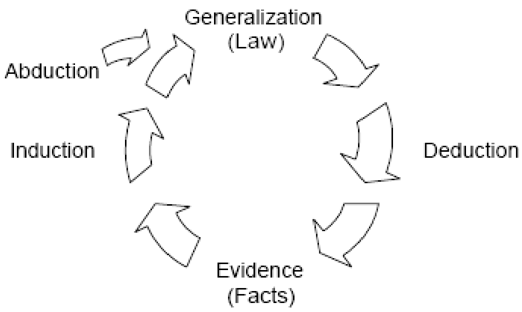
2.8 Creativity and Imagination

Although science is a systematic thinking relying on evidence and the development in science involves imagination and creativity science has been seen by students as uninteresting and difficult subject. They may be unwilling to learn it (ONEC, 2001). Scientists are described as bearded, balding, isolated and working alone in the laboratory, (Mead and Metraux, 1957); as boring, eccentric and dim (Oxford, Cambridge and Royal Society of Arts [ORC], 2006). There are many clever students who decided not to study science for their future careers because they are not given opportunities to see it as an exciting and creative pursuit (Tobias, 1990). It is necessary for students to understand that 'doing science' is far more than either rhetoric of conclusion of an existing body of knowledge or of following set procedures. By definition, scientific research requires creativity in the sense of going beyond existing knowledge and techniques to create new understandings (Hu and Adey, 2002). Hu and Adey (2002) defined scientific creativity as a kind of intellectual trait or ability producing or potentially producing a certain product that is original and has social or personal value, designed with a certain purpose in mind, using given information. This definition may be elaborated with a set of hypotheses about the structure of scientific creativity. Scientific creativity is different from other creativities since it is concerned with creative science experiments, creative scientific problem finding and solving, and creative science activity. Scientific creativity is a special kind of ability. The structure of scientific creativity itself does not include non-intellectual factors, although they may influence scientific creativity. Scientific creativity must depend on scientific knowledge and skills. Scientific creativity should be a combination of static structure and developmental structure. The adolescent and the mature scientist have the same basic mental structure of scientific creativity but that of the latter is more developed. Creativity and analytical intelligence are two different factors of a singular function originated from mental ability.

Creativity and imagination play an important role in scientific discovery - the most impressive and mysterious feature exhibited by modern natural science. Discovery of scientific theory can be seen as an invention. Theories are invented in order to explain the observational or experimental phenomena and to resolve anomalies. Discovery and invention embody both the structure of reality and human creativity. Inventions are sometimes discovered and discoveries are sometimes results of human inventiveness (Kantorovich, 1993). Not only for constructing theory, but for hypothesis formation, creativity and imagination is needed (Martin, 1997). There are no rules which guarantee, if we use them correctly, that we'll come up with a good hypothesis. It seems to be a matter of inspiration of creativity more than following the method or procedure. Considering with other aspects of nature of science, we will see the interrelation among them. The principle of each characteristic of science supports each other's. Drawing scientific knowledge needs some sort of creativity and imagination. The differences between observation and inference can be linked by creative thinking of scientists based on evidences which they obtained. The lack of single steps of scientific method for doing science is because of the creativity of the individual scientist. McComas (1998b) illustrated the role of creativity in the knowledge generation process (Figure 2.2 B) In this picture, the creative leap, or sometimes called abduction, is shown as a necessary element led from the evidence to the generalization. Comparing with a typical view of Baconian knowledge production (Figure 2.2 A), it illustrates Bacon's view of the production of new generalizations as we called induction, and deduction, or hypothetico-deductivism for the testing of such generalizations. The Baconian diagram does not imply that the laws produce new facts, but rather that a valid law would permit the accurate prediction of facts not yet known.



(A)



(B)

Figure 2.2 (A) Illustration of Bacon's view of the knowledge production (B) Illustration of the role of creativity in the knowledge generation

Although all sorts of imagination, creativity and thoughts may be used in coming up with hypotheses and theories, scientific arguments must unavoidably conform to the principles of logical reasoning - that is, to test the validity of arguments by applying certain criteria of inference, demonstration, and common sense (AAAS, 1990). This characteristic distinguishes scientific creativity and imagination from the other disciplines.

3. Teachers and the Nature of Science

The holistic view of research on nature of science was conducted in sequences as follows: research on students' understandings of nature of science, research on curriculum required to promote students' understandings of nature of science, research on teachers' conceptions of nature of science, research on the improvement of teachers' understanding of nature of science and research on the relative effectiveness of various instructional practices. The early research on nature of science started with assessing students' conception on nature of science. Many research findings indicated that students lacked understanding or held the misconceptions on nature of science. This result lead to the conclusion that science curriculum must be developed for addressing nature of science. However, the finding showed that many curricula trying to develop students' understanding of the nature of science were not reliable. Some were successful but many were not. At first, the connection of the nature of science and teachers was obviously not established. Later, teachers were considered to be an important factor and assessing teachers' understandings of the nature of science was conducted. Further studies were searched for the connections between teachers' understanding of the nature of science and their practice. More than 20 years of researching, Lederman and his colleague (Lederman, 2006) found that the teachers' understandings of nature of science did not mean that they would implement it in the classroom. There was no relationship between teachers' understandings of nature of science and their instructional behavior. Besides these, there was no direct relationship between teachers' and students' understanding of nature of science. However, teachers and their practices of instructions with the integration of the nature of science were subtle and complicated. Many factors influenced on the way teachers taught the nature of science, including how to bring it into effective professional developments.

The first research about teacher and nature of science was conducted after the systematic researches really began at the late 1950s or early 1960s. At that time, there were two assumptions that led to the way of research on nature of science. First, teacher could not expect to teach what they did not understand. Second, if the teachers could understand nature of science, they would reflect their behaviors in classroom. The research focusing on nature of science was based on these assumptions until early 1980s. Both assumptions were found to be invalids as discussed above. Research on teachers' understandings of nature of science comes with the development of the assessment to elicit their understanding. The attempt to develop instrument for assessing understandings of nature of science has been developed simultaneously. Research based on designing and developing methods, techniques, and instruments is the big area of nature of science research. There are many types of instruments depending on the aspects the researcher defined and the forms of instruments. From the early time that nature of science was concerned as a criticism of science education reform (AAAS, 1990, 1993; NRC, 1996) more than 20 standardized and convergent instruments have been developed to assess learners' nature of science view. Most of them are paper - and - pencil tests. Examples of such instruments and developers are presented in Table 2.2 (Alters, 1997; Taylor and Aldridge, 1997; Lederman, Wade and Bell, 1998; Good, Cummins and Lyon, 1999; Chen, Liberkin, 2001; Tairab, 2001).

Table 2.2 Examples of nature of science instruments and developers

Years	Instruments	Authors
1954	Science attitude questionnaire	Wilson
1958	Facts about science test (FAST)	Stice
1959	Science attitude scale	Allen
1961	Test On Understanding Science (TOUS)	Cooley and Klopfer
1962	Process of science Test	BSCS
1966	Inventory of science attitudes, interests, and appreciation	Swan
1967	Wisconsin Inventory of Science Processes (WISP)	Literacy research center
1968	Science Process Inventory (SPI)	Welch and Pella
1968	Science support scale	Schwirian
1968	Nature of Science Scale (NOSS)	Kimball
1969	Tests on social aspects of science (TSAS)	Korth
1970	Science attitude inventory (SAI)	Moore and Sutman
1974	Science inventory (SI)	Hungerford and Walding
1975	Nature of Science Test (NOST)	Billeh and Hasan
1975	Views of Science test (VOST)	Hillis
1976	Nature of Science knowledge scale	Rubba
1978	Test of science-related attitude (TOSRA)	Fraser
1980	Test of inquiry scale (TOES)	Fraser
1981	Conceptions of Scientific Theories Test (COST)	Cotham and Smith
1982	Language of science	Ogunniyi
1989	Views on science-technology-society (VOSTS)	Aikenhead, Fleming & Ryan

Table 2.2 (Continued)

Years	Instruments	Authors
1990	Nature of Science survey	Lederman and O’Malley
1992	Modified Nature of Scientific Knowledge Scale (MNSKS)	Meichtry
1995	Critical incidents	Nott and Wellington
1996	Philosophy of science survey (PSS or The Survey)	Alters
1997	The Beliefs About Science and School Science Questionnaire (BASSSQ)	Chen, Taylor and Aldridge
1999	Ideas on Natural Science(INS)	Good *et al.*
2001	Nature of Science and Technology Questionnaire (NSTQ)	Tairab
2001	Attitudes and Conceptions in Science (ACS)	Libarkin

It is noticed that the assessments in the early time used instrument comprising forced-choice, such as agree/disagree, Likert-type or multiple-choice items. Later, there were attempts to develop open-ended instruments, with emphasis on descriptive questions, together with interviews that allowed meaningful assessments of the individuals’ nature of science views, for example VNOS- form A, (VNOS-) form B and (VNOS-) form C (Lederman *et al.*, 2002). Recently, the use of classroom observation and interview are also employed to probe teachers’ concepts of nature of science. These kinds of eliciting enable teachers to get more in-depth understanding in their views. The results from assessing teachers’ understandings of nature of science are varying from holding the naive views or lack of understanding (Abd-El-Khalick and BouJaoude, 1997; Akerson and Abd-El-Khalick, 2003), to mixing views between traditional and constructivist (Haidar, 1999) and clear understanding (Lederman, 1999). However, the current view about teachers and nature of science is more complex than only teachers’ understandings of nature of science. This factor is necessary, but not sufficient for enhancing student's understandings of nature of science. The research about teachers and nature of science has to be taken into account of many factors to find the relative effectiveness of various instructional practices. The professional development programs are conducted to develop both pre-service and in-service understandings of nature of science and implementing into a classroom. However, experienced science teachers have developed an integrated set of knowledge and beliefs, which is usually consistent with how they act in practice before attending any professional development programs. Teachers' practical knowledge becomes an important factor that we have to consider before they are asked to put an innovation into their practices (Van Driel, Beijaard and Verloop, 2001).The new practical is not merely added to existing knowledge frameworks. Teachers need to restructure their knowledge and beliefs on the basis of teaching experiences, integrating the new information in their practical knowledge. Teaching the nature of science is a complicated reflection from teachers' thought. This is subtle and sensitive to consider. Bencze *et al*. (2003) used qualitative ethnographic and large-scale collaborative action research to study the factors from teachers that affect students' understandings of nature of science. They found factors that limited students from access to more contemporary views about realistic experiences with science. Those factors were (1) teachers were low in science self-efficiency (2) teachers in elementary level tended to teach as little science as possible (3) teachers concentrated on areas of science in which there confidence was high (4) teachers relied on kits, textbooks and worksheets (4) teachers emphasized expository teaching methods (5) teachers avoided all but the simplest hands-on work (6) teachers avoided using any apparatus that can 'go wrong' (7) teachers used outside 'experts' whenever possible (8) teachers were most comfortable working in the role as 'guide,' rather than as 'facilitator' of more students' controlled activities (9) teachers feared surrounding prospective implementation of the new science curriculum. The sort of agenda and prescription about learning outcomes and corresponding pedagogical approaches appearing in curriculum limited teachers from integrating alternative perspectives about science into their school science practices. Clearly, even the teachers hold 'contemporary' views about science but those factors were barriers to teaching and learning of achievements for compromising students' development of realistic conceptions about science and expertise for doing science. There are strategies providing for professional development that are necessary to promote changes in teachers' knowledge and beliefs. These are the examples of strategies reported to be used in the research; access to innovative classroom materials, opportunities to practice new ways of teaching, reflection on practical experiences, possibilities to discuss elements of the reform with others (peers, coaches, supervisors), supportive environment and so on (Haney, Czerniak and Lumpe 1996).

4. Students' Understandings of the Nature of Science

As we have discussed in topic 1.3, the research about nature of science started with examining students' understanding of nature of science, and it has been conducted for more than 50 years (Lederman *et al.*, 1998). The students' understandings of nature of science vary in research findings, its diversity finding is due to the aspects of nature of science emphasized in the study and the nature of questionnaires the researchers used.

The past methods to probe students' concepts of nature of science, including the findings, were doubted, especially the research in the 1960s and 70s using multiple-choice questionnaires which limited our deeper understanding. Recently, studies used open-ended questions, interview and observations to probe students' concepts. Those methods revealed that students' understandings of nature of science are complex and changeable as a result of differing situations and research probes, especially when extra-rational factors (emotions, values, etc.) were evoked in the learners (Johnston and Southerland, 2001). Because the clear understanding of students on nature of science can be greatly changed in different situations, they suggested that when we try to develop the understandings of nature of science by conceptual change theory, we need to further address the interaction of extra-rational factors on learning. The concept should not be determined solely by rational processes. However, it is useful to know what students understand before trying to develop their concepts of nature of science. Focusing on the core aspects of nature of science in this study, students' understandings of nature of science will be discussed as follows:

4.1 Evidence-based Characteristics of Science

Students of all ages find it difficult to distinguish between a theory and its evidence, or between description of evidence and interpretation of evidence (AAAS, 1993). Sadler, Chambers and Zeidler (2004) studied the students' conceptualizations of nature of science. The global warming articles were presented to the students and the questions were used to explore students' conceptions of the empirical nature of science by analyzing their comments about how data was used to support each position in those articles. The findings emerged into four hierarchy levels of conceptualizations. Level A responses revealed confusion over the nature of data. Rather than identifying and discussing data, these responses summarized the articles or described predictions made in the articles. There were 17 % of the students who answered the questionnaire in this way which made them unable to grasp the empirical nature of science. There were 30% of students that comprise level B and present very naive conceptualizations of data. Students with this level of understanding may be able to affirm that science is based on empirical evidence but probably do not fully comprehend the significance of this claim. It seems probable that only the students making up levels C and D (43 % and 10 %) possess enough requisite understanding of data and its use to apprehend conceptual aspects related to science's empirical nature.

When asked about how scientific inquiry may be different from other forms of inquiry, students responded that they viewed science as somehow different from other ways of knowing. The students couldn't tell what made science unique and why it was made so. They could not articulate what might distinguish a scientific way of knowing from others. They also understood that logic, curiosity, and imagination contributed significantly toward the scientific enterprise (Moss, Abrams, and Robb, 2001). Similar to Rannikmäe, Rannikmäe and Holbrook (2006), they found that students had difficulty in distinguishing the nature of science, although they recognized that pseudoscience is not science. The students tried to build their arguments around pseudoscience phenomena e.g. horoscopes. If students read horoscopes, they will be told about different stories depending on the author and hence horoscopes are not products of science. However, they did not attempt to explain what science is. Some researches suggest students can start understanding the distinction between theory and evidence after adequate instruction, as their early education (Roseberry, Warren and Conant, 1992).

4.2 Methods to Do Science

Many students believed that there is one single “scientific method” to do science (Griffiths and Barman, 1995; Lederman *et al*., 2002). The study of students in different country (Liang *et al.*, 2006) found that about 39- 48% American and Turkish students believed that there is a single, universal step-by-step scientific method that all scientists follow. However, when asked them that would scientists use a variety of methods, the majority of students in both countries also agreed. The students in large number (74-83%).) also thought that experiments were not the only means used in the development of scientific knowledge. This contradictory were solved when the open-ended sections revealed that the students viewed term “different methods” equal to different steps within the scientific method or different experiments. Even though they stated that scientists used different methods, they still hold the concepts that there is only scientific method that every scientist will follow. Very few students could provide examples of different types of scientific methods. They thought that experiment will be conducted by scientific method. The informed understanding that scientist can do science in different ways is important for learning science. Lin *et al.,* (2004) found that the students who said there are many methods to do science are likely to perform better on conceptual problem solving. While solving the molecular weight problem, the students who believe that there is no single scientific method and that the methods used by scientists are dependent on circumstances, are capable of retrieving related concepts of atom, molecule, atomic weight, and molecular weight and can integrate the knowledge of mathematical meaning of a ratio and the chemical concepts to solve the problem. On the other hand, the students who believe that the traditional scientific method is the only guide for inquiry can intuitively grasp the numbers available in the problem and focus on the formulas they memorized to do meaningless calculations. These results suggest that students' understandings about nature of science played a significant role in problem-solving.

4.3 Science is Subject to Change

Grade 5 and 6 Taiwanese students understand that scientific knowledge invented is changing (Huang, Tsai, and Chang, 2005). Almost of grade 11 and 12 students in the study of Moss *et al.* (2001) viewed scientific knowledge as both developmental and tentative in nature. When the researchers study more in depth about students' understanding of the tentative characteristic of science, they found that the students understand that theories can change as new evidence is brought to light or as new information is added. Old theory of science changes because information becomes more specific. Theories or concepts become more complex. Science is continually improving itself (Griffiths and Barry, 1991). However, students did not appear to understand that theories might also change owing to new perspectives of existing data (Bell *et al.*, 2003). The students also attributed changing in science to better technology rather than to changes in thought (Griffiths and Barman, 1995). There were students who believed that some kinds of scientific knowledge, such can change as theories and hypotheses. If scientists get more evidence, theory will change to facts and laws that are absolute (Brickhouse *et al.*, 2000; Griffiths and Barry, 1991).

Understanding tentative characteristic of science affects the way students learn science. There were the researches reporting that the students who had informed understanding that scientific ideas develop and change tended to learn science with understanding and made a relationship among scientific ideas. On the other hand, students who view science as static assert that science consists of a group of facts, thought that the best ways to learn science is memorization (Songer and Linn, 1991). It is possible ways to develop the sophisticated ideas about the nature of scientific knowledge. Some six graders were beginning to recognize that scientific knowledge is socially constructed and tentative in various ways at least after six years of engaged in repeated, explicit discussions of epistemological issues throughout the science instructions (Smith *et al*., 2000).

4.4 Scientific Theory and Law

When asked about theories and laws, students thought that theories and laws are the same kind of knowledge, separated only by the degree of certainty ascribed to them. Furthermore, they were often confused with scientific laws and facts and cited the common misconception that laws represent absolute knowledge (Bell *et al.*, 2003). Students considered facts as something that has proven. Despite a certain conception about facts, students had a difficulty to give a good example of scientific facts. Some students thought Darwin's evolutionary theory was a fact (Griffiths and Barry, 1991).

That belief is very hard to change, even though a significant amount of time in class is spent on discussing what theories are and how they relate to evidence, the students still held the misconceptions; for example, facts and laws are absolute, whereas theories and hypotheses are tentative (Brickhouse *et al.*, 2000). Students' understanding of law in Meyling's research fit into five categories (Meyling, 1997). First, laws were mostly periodically repeating phenomena in nature, such as ebb tide/flood tide, and day/night, the seasons. Second, laws were eternal. Unalterable laws within nature itself are independent of a man, for such as the gravitational pull of the earth. Third, laws were unquestionable and formulated by man. Nevertheless, exact copies of the laws are in nature. Laws of nature are not invented but discovered, for example, they describe the relationship between distance fallen and time elapsed. Fourth, laws were discovered by man but perhaps not exact copies of the laws in nature. Fifth, laws are only hypothesis about processes in nature made by man that possibly follow laws. Laws of nature are invented (most of the students think that laws are invented based on experiments, not by intuition). The students, whose beliefs fit into the first two categories, also understood that science cannot be tentative. There were 99 % of students in this study believed that laws are a part of scientific theories. Laws represent the necessary basis that permits the construction of the theory. Laws can be the result of a theory since a verified theory becomes a law. This notion can be found in many research reports. For example, when asking students about the Big Bang theory, they stated that "future technology will permit us to prove the basis of the Big Bang theory and make it a law" (Brickhouse *et al.*, 2000).

The hierarchy conception emerged when students asked to explain about the pathway of scientific discovery. Ignoring with the theory-ladden nature of science in observation, measurement, hypothesizing and inferring, students presented the pathway of scientific discovery as a series of hypothesis, experiment, observation, theory and law respectively. They also ignored the influence of contextual and constitutive values. Students were usually confused among the words theory, law, fact and hypothesis. They understood that laws don't change because they are facts (Bell *et al.*, 2003; Griffiths and Barry, 1991). The students tend to equate the testing and retesting of hypotheses with the status of a "proved" theory (Zeidler *et al.*, 2002). The research also found that it was very hard for students to understand that laws are invented link as theories (Chen, 2006).

4.5 Observation and Inference

There was a study reporting that before six years old, students neglect inference as a source of knowledge (Sodian and Wimmer, 1987; Ruffman, 1996; Varouxaki *et al.*, 1999). For the students, they believed that seeing is equal to knowing. In science, both observation and inference, directly and indirectly, contribute to construct scientific knowledge. Liang *et al*. (2006) found that there were 10% of students completely hold naïve views of observations and inferences and less than 46% of the students had an informed understanding of this aspect of nature of science.

Abd-El-Khalick (2002) used the activity in the context of teaching students about Rutherford's experiments and atomic structure to emphasize that inference should be based on and consistent with empirical observations. This activity was in the family of black box activity. Students used the data from observation to construct the hidden object in the box. The result from the activity indicated that many of students (35–55%) explicated a more tentative view of scientific knowledge and started to make the crucial distinction between observation and inference. The understanding of the role of both observation and inference is important for the students to know how scientists generate scientific knowledge. Another important thing is how students can generate scientific knowledge from the data they obtain. Students' understandings of the links between their laboratory tests, observations, and inferences can be promoted by the science writing heuristic as Keys *et al*. (1999) had reported. The instructions that used the science writing heuristic let the students think about how claims are supported with evidence in science. They also had a debate and discussion about the meaning of data. This activity led to the use of metacognition and reflection to understand the scientific knowledge growth. Reflecting on what students have done about scientific inquiry such as activities or experiment are found to be one of the successful approaches to convey concepts of nature of science that will be discussed in the topics 1.5.

4.6 The Human Subjectivity in Science

Students in the study of Bell *et al*. (2003) viewed science as completely rational and objective. When asked how it was possible to have different conclusions on the same evidence, the students mentioned on the different interpretations with their objective views by referring to incomplete or inaccurate data. They also suggested that some of the scientists were misinformed or even dishonest. In their opinions, none linked subjectivity in science to creativity, nor did they express understandings of the theory-laden nature of data interpretation. Some students thought that scientists would make the same observations because they were objective (Liang, 2006). This finding was consistent to the study of Halloun and Hestenes (1998). From the interview, they found that students thought that scientists are completely objective and logical people. They also thought that scientific knowledge is absolute truth. Griffiths and Barry (1991) found that there were only about one-third of the students in their study who understood that observation is theory-laden.

4.7 Science, Culture, and Society Interaction

Students' understandings about the interaction among science, culture and society are various. From the study of Huang *et al.* (2005), they found that, in average, students understood that science is related to the role of social negotiation in the development of scientific knowledge, but probably they did not strongly support the view that the cultural context had an essential impact on the development of science. Besides these, they still believed that the cultural context might not have played an important role in the development of science. While Moss, Abrams, and Robb (2001) found that the students understood this aspect of nature of science very well. They understood that science is influenced by societal needs, and is often driven by both governmental and private funding. They described science as not being 'pure', believing that 'it all comes down to money. Students' understandings about social embeddedness of science can be found as both a clear understanding of the influence of societal factors on science, and as a notion that science stands alone as a discipline insulated from other aspects of society (Sadler, Chambers and Zeidler, 2004).

4.8 Creativity and Imagination

Students' understanding of the role of creativity and imagination in scientific knowledge development is various. From the study of Rannikmäe, Rannikmäe and Holbrook (2006), they found that non-science undergraduate students poorly understood on the views that ingenuity and creativity play a role in the development of science. Students thought that scientists didn't use their creativity because they rely too heavily on instruments (Halloun and Hestenes, 1998). On the other hand, there were students who noted that scientists be intelligent and creative if they are going to try to figure out how to solve problems (Moss, Abrams, and Robb, 2001). Some students stated that imagination is beneficial to the process of science. Students usually ascribed some roles for creativity in the initial stages of scientific investigations. However, their responses indicated a failure to recognize creativity as inherent and necessary throughout all stages of investigations (Bell *et al*., 2003). Morover, Zeidler *et al*. (2002) found that by the time students reach the senior year in college, many perceive science as a rote and clinical process. The researcher commented that science experiences offered at the college level may confer or perpetuate the image of science to be an unimaginative process.

In summary, even though nature of science has been emphasized more than a half of century until now, there are still research reports about students' misconceptions and lack of nature of science, especially for non-science major students. Rannikmäe, Rannikmäe and Holbrook (2006) found that from 58 students, it appears that 50 students have a very limited understanding of the nature of science. The students came up with very divergent views. The dominant view is that science is the subject as taught in school that was broken down into Biology, Chemistry, and Physics. The idea held by non-science students that science is content or only experimentation is very strong. New branches of science such as molecule biology or gene technology were not mentioned. Furthermore, these views seem to be quite resistant to change. This indicated that the ways people think about science is directly and greatly influenced by the ways they had been taught during school years. This raises the questions like "What will happen if the major citizens in our society have a very limited understanding of nature of science?, What would happen if a citizen who didn't work in scientific career (or even in science career) could not distinguish between science and pseudoscience?, Do they understand their roles in making a decision in science topic dilemmas such as stem cell issues, or the responsibility in sustain natural resources?." These questions lead the researchers to develop students' understandings of nature of science which is one goal of science education. However, developing informed concepts of nature of science is subtle and related to many factors.

The understanding of nature of science also depends on age, gender and race. Huang *et al.* (2005) found that the 6th graders had more understanding that science was invented and changing than the 5th grader. Considered by gender, boys tended to express more constructivist views than their girl counterparts. Lastly, the aboriginal students in Taiwan tended to express less constructivist-oriented views toward the invented and changing nature of science and the role of cultural context than did non-aboriginal students.

Focusing on the approach to communicate nature of science, at first, many researches had been conducted under the assumption that if students were engaged in scientific activity such as inquiry or conduct experiments, they would come to understand nature of science implicitly. Nevertheless, recently, 1990s to early 2000s, it is clear that both teachers and students best learn nature of science if it is presented in a reflective, explicit manner (Lederman, 2006). He also pointed that teaching nature of science explicitly is not identical to direct teaching. Being explicit, in this sense, means the instructional approach that let the aspects of nature of science visible in a classroom. Students are engaged in scientific investigations that enable than to discuss and reflect on what they did. They also discuss about what implication these activities have for resulting knowledge and conclusions. This is a very fruitful context for promoting students' understandings of nature of science. Simply to let them do the investigation without explicit reflection is not effective.

5. The Nature of Science and Classroom Implications

In this section, the approach to communicate nature of science concepts will be discussed. Teaching and learning frameworks focused in this study were inquiry, constructivist, historical and model-based approach. The model-based approach was the dominant framework while the rest was integrated. In holistic view, what to be known currently about teaching nature of science is that it must be taught explicitly through investigative activities and reflective discussions in order to make it effective (Abd-El-Khalick and Lederman, 2000b; Bartholomew *et al.*, 2004; Schwartz and Lederman,2002). Lederman (2006) commented that there are strong emerging evidences that an explicit approach to the teaching of nature of science is more effective than implicit approaches, but there has been virtually no research comparing the relative effectiveness of the various explicit approaches. It was still unclear these the various approaches were equally effective or not, they will be discussed in this topic to search for the feasible and appropriate ones for Thai students that are who congruent with the Thai National Science Curriculum Standard (IPST, 2002). The details of each teaching approach are as follows:

5.1 Constructivist Approach

The constructivist approach is effective to let students understand the nature of science. There are many studies of using a constructivist teaching approach to develop students' understandings of the nature of science. Smith *et al*. (2000) studied two sixth-grade classes, one taught using a constructivist approach and the other taught using a textbook and lecture approach. The researcher found that the students in the constructivist classroom showed significantly greater understanding than that of scientific beliefs, needed to be evaluated by a complex set of criteria. The constructivist students were better able to delineate the nature and purpose of scientific experiments. These students also mentioned that social interaction is a key component of conducting science more often than the students in the comparison classroom. Smith *et al*. (2000) noted that the constructivist classroom was designed to include substantial group work and provided many opportunities for an exchange of views and the development of shared norms. Besides these, Lin and Chen (2002) showed that students' understandings about the nature of science were enhanced by learning through the students-centered historical instructional method for teaching. This strategy based on constructivism provided many activities to students: discussion about scientists' original debates, project assignment, small-group discussion, role-playing and hands on experiment that stimulated scientists' work. For teaching chemical concepts and the nature of science to enhance students' long term understanding, Clough and Clark (1994) indicated the needs of appropriate teachers' behaviors and strategies. They discussed that students cannot rush through laboratory activity nor should teachers direct students' laboratory approaches. Students must be responsible for solving a lab problem. Furthermore, some essential teachers' behaviors are needed for facilitated-answer questions, questions that require students to elaborate on their idea, by spending time. They also needed responding behaviors that accept rather than judge students' ideas, encouragement rather than praise and a great deal of teacher's observation and listening. They also concluded that the constructivist model forces students to be actively engaged in learning and only the teacher can ensure that the proper environment exist to activate this teaching model.

5.2 Inquiry Teaching Approach

Scientific inquiry refers to the methods and activities that lead to the development of scientific knowledge. According to the National Science Education Standard (NRC, 1996)

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

Abilities to do scientific inquiry include identifying and posing questions, designing and conducting investigations, analyzing data and evidence, as well as using models and explanations, and communicating findings. Understandings include knowledge of how scientists conduct their work and concepts related to the nature of science. The National Science Education Standard (NRC, 1996) further suggested that inquiry-based instruction will be a powerful vehicle for students to learn scientific content. There are many studies about the inquiry teaching approach which may provide a viable context for discussion and reflection on the nature of science conceptions. Inquiry approaches to enhance students' understandings of the nature of science have varied in effectiveness. Schwartz *et al.*, (2004) studied developments in the nature of science conceptions during a science research internship course for preservice secondary science teachers. Interns' nature of science views were assessed in a pre/post format using the Views of the nature of science questionnaire, [VNOS-C] and interviews. The results indicated that most interns showed substantial development in their nature of science knowledge. Three factors were identified as important for the nature of science development during the internship: (1) reflection, (2) context, and (3) perspective. The science research component provided a context for reflection. In conclusion, they discussed the significance and challenges to teachings about the nature of science within inquiry contexts.

Kenyon and Reiser (2005) suggested that integrating explicit, reflective discussions about the nature of science into an inquiry curriculum shows some success in shifting students ‘conceptions of the nature of science. However, Keys and Bryan (2001) suggested including teachers’ voices in the design and implementation of inquiry-based curriculum. The perspective of cognitive and sociocultural constructivism, cultural models of meaning, the dialogic function of language, and transformational models of teacher education need to be considered in the next research.

Furthermore, computer technology and internet are opening up new possibilities in science education. New computer technologies are creating new opportunities for students to engage in serious inquiry (Krajcik *et al.* 2000). Hawkey (2001) pointed that technology can provide a new opportunity to reconsider fundamental questions about what it means to be scientifically literate, about the nature of science and the relationship between practicing scientists, their work and the public.

5.3 Historical Approach

Among various strategies attempted to develop students’ conceptions of nature of science, historical approach is one of the most accepted approaches that had been studied for developing students’ including preservices’ and inservices’ understandings of both nature of science and subject content. Conveying how science is done and engaging students in the process of discovery for themselves are aspects of teaching what science is. The important role of history and nature of science has been recognized, for example, the National Research Council's National Science

Education Standards (NRC, 1996) specify standards for learning science as a human endeavor, history of science and nature of science .

Matthews (1994) summarized the reasons for the inclusion of history of science in instruction. He pointed that history of science promoted better understanding of scientific concepts and methods as well as an understanding of nature of science with cultural-intellectual validity. The integration of science history into a science lesson humanized scientific contents and reduced formalism. It counteracted scientism and dogmatism which is common in science education. History of science also connected the development of individual thinking with the development of scientific ideas while presented integrative and interdependent nature of human achievements. There are some important advances in science that have long-lasting effects on science and society which the US National Science Content Standard (NRC, 1996) suggested that they should be used to express the historical perspective of scientific explanations and to demonstrate how scientific knowledge changes by evolving over time. One of the examples of such advances includes atomic theory, the content of which students were found to hold misconception. Atomic theory also has other aspects of nature of science that Niaz *et al*.(2002) had shown that freshman students' conceptual understanding of atomic structure (based on the models of Thomson, Rutherford, and Bohr) were facilitated by arguments, counterarguments, and discussions about how those scientists conducted the historical experiments and interpreted the data. Further more, Psaros (1998) argued that from the cultural point of view chemistry indeed offers a field of interesting questions ranging from the reconstruction of its epistemological objects to the elucidation of the semantic functions of term like 'atom' or 'molecule' . He also argued that the philosophical reflection upon chemistry has important consequences for the didactic, the history and even the ethics of this science. Thus it made philosophy to a partner of chemistry in fulfilling its purposes in human society. In addition, Harrison (2002) explored possible ways to use the history and epistemology of science to enhance the teaching and learning of particle concepts. Studying the history of the atomic theory should, therefore, help students demonstrate the outcome that "knowledge atomic/molecular theory" according to the policy of AAAS (1990).

He also stated that "…informative histories of the intellectual victories that make science so interesting and relevant. And, I believe, chemistry will prosper as a result." (Harrison, 2002)

Historical approach has no more to be suspected whether it is effective or not but for those whose skepsis what "characteristics" of this approach lead to goal aspects of nature of science and to facilitate science content. At this stage literature is briefly reviewed to show what research had been already known and what direction the researcher will head for the future study. Learning with only the historical facts is not necessary to enhance students' nature of science views. Students did not gain nature of science concepts even though they had been studied in history of science course. It is because the specific nature of science aspects had not been addressed. It is clear that historical approach must stress aspects of nature of science on learning activities (Abd-El-Khalick and Lederman, 2000b). History of science is available for teachers to explicitly present in a classroom. Niaz and Rodriguez (2001) claimed that history and philosophy of science are already 'inside' chemistry and teachers can grasp this perspective to facilitate students' conceptual understanding such as in the case of atomic structure. In later study, they showed that textbook presentations based on history and philosophy of science perspective can arouse students' interest in the subject and hence to greater conceptual understanding. Besides these, historical reconstruction of an atomic model can provide students an opportunity to appreciate scientists' work and science progress (Niaz and Rodriguez, 2004). Lawson (1999) recommended the way to teach nature of science with historical approach. In his idea, the history of science has much to offer to help teachers identify "natural" routes of inquiry, routes that past scientist had taken and routes that present students can also take, routes that should lead to scientific literacy. That is, to students who know what science is and how to do it.

Unfortunately, there are a few textbooks presenting history and philosophy of science perspectives, such as atomic structure (Niaz, 1998), elementary electrical charge (Niaz, 2000a), kinetic theory (Niaz, 2000b), covalent bond (Niaz, 2001a), and stoichiometry (Niaz, 2001b). Scientific models in textbook are also lacking of historical perspective. Justi and Gilbert (2000) analyzed 12 high school textbooks (9 from Brazil and 3 from UK) with respect to the representation of atomic models within a history and philosophy of science perspective. It was found that most textbooks use "hybrid" models of which the compositions drawn from several distinct historical models, which, by their very nature, do not allow the manifestation of the different history and philosophy of science aspects.

However, teachers can develop their 'historical material' as the study of Toa (2003). He developed 'The science stories' based on the notion of science as a narrative human story or 'science as narrative stories'. The science stories he developed are the story of penicillin, the story of smallpox, Newton's Law of Universal Gravitation and the cure of stomach ulcers. These science stories were presented to grade 1 students to let them debate and discuss through the peer collaboration strategies. As the results, the conflict and co-construction arising from the collaboration could lead to be adequate as well as inadequate views of nature of science. Without guidance from the teacher, students tended to make sense of the stories in idiosyncratic ways and extended to aspects of the stories that matched their inadequate views of nature of science. An implication is that in addition to using the peer collaboration strategy, the teacher should also actively scaffold students' understandings. The teacher can do this by holding whole-class discussion after each story during which they query students' views and direct their attention at the various aspects of nature of science presented by the story.

The teacher must be aware of the complexity of students, learning in the classroom. Using historical approach, teachers have to concern about the learning process of students. Lin and Chen (2002) showed that students' understandings about the nature of science were enhanced by learning through the students-centered historical instructional method for teaching. This strategy that was based on Constructivism provided many activities to students: discussion about scientists' original debates, project assignments, small-group discussions, role-playing, and hands on experiment that stimulated scientists' work. This study corresponded to the finding of Bell *et al.*, (2000) that the teacher, who has adequate views of nature of science, need not teach effectively in a practical classroom. Teachers' pedagogical content knowledge is also important.

The worries and the fear of those who doubt about pupils' grasp of essentials in the introduction of curriculum material and about the time for discussing of nature of science may be reduced by the study of Irwin (2000). The results show that there is no difference in understanding of contemporary science content between the first students who studied a unit in which a substantial amount of historical material was incorporated and the second group who studied a unit covering identical scientific content but without any reference to history. Moreover, the students from historical class showed more nature of science understanding. The teaching strategy used in this research is tracing the development of atomic theory from the Greeks to the present students with historical material that is related to the content in the unit. For example, in the article, "Empirical Foundations of Atomism in Ancient Greek Philosophy", a list offers elements and atomic weights available to Dalton at that time (around 1807). Other experts also suggested the best ways to incorporate history and philosophy of science materials in instruction (Galili and Hazan, 2001) for example, the reproduction of historical experiments i.e. Rutherford's experiments (Abd-El-Khalick, 2002); the presentation of original historical texts i.e. historical short story (Clough and Olson, 2004); the infusion of stories during regular instruction, the science stories (Toa, 2003), vignettes, science stories, historical case studies, scientific narratives, and thematic approaches, story line, Dialogues (Stinner *et al*., 2003); systematic incorporation of historical materials i.e. Kafai and Gilliland-Swetland (2001) conducted case study that used and discussed the feasibility and benefits of using historical source materials, as well as the implications for selecting and preparing historical source materials in digital format for teaching. Lastly, the historical references (dates and names) were required.

In summary, there are some kinds of essential notions of historical approach about nature of science and the ways to convey it to students,. First, the nature of science should be integrated in science curriculum explicitly and the historical approach could be used to convey aspects of nature of Science. The teacher should not worry about the time for discussing history in the class. With the same level of science content understanding, students in historical approach class gaining more understanding in nature of science than students who studied a unit covering identical scientific content without any reference to history. Most importantly, in teaching historical approach, teachers must regard that learning about nature of science is long-term proposition so that it of science should not be conducted only in the beginning of the course and then be discarded. The teachers must ensure the students with historical activities and let them have hands-on and minds-on. The teachers have to be aware that using of high-tech machines such as computer and video-disc players does not replace actual hands-on, minds-on inquiries (Lawson, 1999). Teachers should keep in mind that students' discussion may lead them to misconception of nature of science. Furthermore, media, science-textbook, author as well as teacher can lead to the misunderstanding too. Teaching with historical approach, or other approaches should start with a familiar topic and expand to another (either micro or macro scopic). Lastly, teachers must make sure that they prepare historical material systematically before using it in a classroom.

5.4 Model-based Approach

The model-based approach dominated the design and development of the Atomic Structure Instructional Unit (ASIU). However, characteristics of constructivist, inquiry and historical approach will be blended in the 12 hours-long instructional units. Students will have opportunities to reflect the ideas about science by modeling activity into the study of the atomic structure and the nature of science. Model-based approach is discussed in the topic 3 in more details.

Atomic Structure

The atomic structure is one of the topics in Strand 3: Matters and Properties of Matters in the National Science Curriculum Standard (IPST, 2002) that students have to learn in level 4 (grade 10-12). Its substances consist of 7 sub-topics namely: Early atomic theory, Dalton's atomic model, Thomson's atomic model, Rutherford's atomic model, Bohr's atomic model, Electron cloud atomic model and Electron configuration in atom. An understanding of molecular structure based on atomic structure and bonding is crucial to subsequent understanding of chemical reactions. Since the concepts of molecular structure and chemical bonding are built upon the fundamental principles of atomic structure, this understanding of chemical behavior at the atomic level appears important in understanding subsequent concepts in chemistry (Ozmen, 2004). The details of each subtopic are presented as follows.

1. Evolution of Atomic Theory

1.1 Early Atomic Theory

The earliest concepts of atom have been introduced in the ancient Greek era for more than 2500 years up to now (Wynn and Wiggins, 1997). Leucippus (480-420 B.C.) and his students Democritus (460-370 B.C.) believed that atom must exist. But the idea that dominated the study of matter at that time was from Aristotle (384-322 B.C.). He hypothesized that matter was continuous and could be subdivided indefinitely. This concept influenced the learned societies and academies for almost 2000 years until the experimentation became the test of credibility of a hypothesis during 1500s-1600s.

1.2 Dalton's Atomic Theory

The first atomic theory based on the experiment came from the English chemist, John Dalton (1766-1844). Dalton used atomic theory to explain the Law of Constant Composition. From evidences Dalton relied on, he finally proposed the atomic theory that can be summarized as: (1) elements are made of tiny particles called atoms. (2) All atoms of a given element are identical (3) the atoms of a given element are different from those of any other element. (4) Atoms of one element can combine with atoms of other elements to form compounds. A given compound always has the same relative numbers of types of atoms. And, (5) Atoms cannot be created, divided into smaller particles, nor destroyed in the chemical process. A chemical reaction simply changes the way atoms are grouped together.

1.3 Thomson's Atomic Model

In 1897, Joseph John Thomson (1856-1940) used gas discharge to study the glowing ray that was emitted within the tube when the electric current was turned on. These rays were called cathode rays because they came from the negative terminal called a cathode. Later, Thomson called these negatively charged subatomic particles "electrons." Since the electrons were negatively charged, the rest of the atom had to be positively charged. Thomson believed that the electrons were scattered in the atom like raisins in positively-charged bread dough, or like plums in a pudding. Although Thomson's "plum-pudding" model was not correct, it was the first attempt to show that atoms were more complex than just homogeneous spheres.

1.4 Rutherford and Gold Foil's Experiment

In 1896, Ernest Rutherford (1871-1937), conducted an experiment using the alpha particles. He set up a piece of thin gold foil with photographic plates encircling it. He then allowed alpha particles to hit the gold. Most of the alpha particles went right through the gold foil, but a few of them did not. A few alpha particles were deflected from their straight course. Furthermore, some even came straight backward. Rutherford wrote that it was so surprising as if one had fired a bullet at a piece of tissue paper only to have it bounce back. Rutherford concluded that since most of the alpha particles went through, the atoms of the gold must be mostly empty space, not Thomson's space-filling plum-pudding. Since a few of the alpha particles were deflected, there must be a densely packed positive region in each atom which he called the nucleus, with electrons being distributed throughout most of the space occupied by the atom and orbiting the nucleus.

1.5 Bohr's Atomic Model

Niels Bohr (1885-1962) realized that the idea of a quantum of energy could explain how the electrons in the atom are arranged. He described the electrons as being "in orbit" around the nucleus like planets around the Sun. Electrons in the atom could not have just any orbit. There were only certain distances that were allowed by the energy that an electron had. If an electron of a particular atom absorbed the precisely right quantum of energy, it could move farther away from the nucleus. If an electron farther from the nucleus emitted the precisely right quantum of energy, it could move closer to the nucleus. These values could be determined by a process called atomic spectroscopy. An atom was heated so that all of its electrons were moved far away from the nucleus. As they moved closer to the nucleus, the electrons would begin emitting their quanta of energy as light. The spectrum of light produced could be examined using a prism. This concept leads to the conclusion that an atom composes of nucleus and electrons orbit around it in the certain energy level precisely equal to the quanta energy of light.

1.6 Electron Cloud Atomic Model

The current accepted model of an atom is described by the wave function based on the quantum mechanics theory. Instead of exact location, electrons are described by the probability to be found in a region around the nucleus. The probability of electrons is represented by a region of the cloud of them, the denser a region of the cloud, the greater the probability of finding the electron in that region. The densest regions correspond to where electron's wave intensity is greatest.

1.7 Electron Configuration

Electrons travel around the nucleus that may differ in size, shape, or orientation in space. The difference will be determined, by the set of quantum numbers. From those quantum numbers, we can define the region of each electron that moves as a wave in a specific sub-energy level which is the in particular main energy level.

2. Students' Understandings of Atomic Structure

There are many researchers who found that students usually hold misconception in atomic structure (Ben-Zvi *et al*.,1986; Bethge and Niedderer ,1996; Harrison and Treagust, 1996; Karen *et al*.,1999; Harrison and Treagust, 2000b; Unal and Zollman , 2000; Nicoll, 2001; Tsaparsis and Papaphotis, 2002; Schmidt *et al.*, 2003; Nakiboglu, 2003). Most of the researches congruently reported that students difficultly change Bohr atomic model or orbit model to the sophisticated model based on quantum theory or electron cloud model. Harrison and Treagust (1996) found that an atom is often described as a round, solid, and hard sphere. They also found that students generally produced four categories of models: the atom as a sphere, a solar system atom, a neutral atom (positive charges of the nucleus equal to negative charges of the electrons), and the atom as a nucleus surrounded by an electron cloud. According to their research, many students represented an atom as a simple circle within a large circle. Even after teaching, there was a certain degree of confusion among students about the terms used: not only particle, atom, molecule, but also orbitals, shells and orbits (Nicoll, 2001; Nakiboglu, 2003). For some students, the number of electrons, protons and neutrons is the same for a given atom (Tsai, 1998). The quantum model of the atom gives birth to the representation of the electron cloud. However, the fact that the students are willing to use this representation is not a guarantee that they understand its meaning. Harrison and Treagust (1996 and 2000b) showed that, for students, the electron cloud is considered as a matrix in which electrons are embedded (as water drops in a cloud). Tsaparlis and Papaphotis (2002) reported that upper secondary Greek students (grade 12) had greater difficulties in understanding of the concept atomic orbital.

3. Teaching Atomic Structure

Karen *et al*. (1999) studied how chemistry teachers related their pedagogical content knowledge with teaching strategies incorporating computer visualization models to teach quantum science. Nicoll (2001) pointed out that teaching students to understand more advanced concepts, they have to let the students grasp the fundamental concepts and emphasize the transitions between the symbolic, macroscopic and microscopic level in students' mental model. Harrison and Treagust (2000b) found out that effective model-based learning will be benefited from knowing much more about students "proximal zones of development," especially the types of models they find easy or difficult to negotiate. Furthermore, Treagust, Chittleborough and Mamiala (2003) noted that the abstract nature of chemistry and the need for the learner to develop a personal understanding of the submicroscopic nature of the chemical nature of matter necessitated the use of an extensive range of symbolic representations such as models, problems and analogies.

Model-based Approach for Teaching Atomic Structure and the Nature of Science

Model and modeling play an important role for a long time in history of science. Scientists generally use models, for example, to figure out what the world is, or to explain and predict the natural phenomena. Scientific practice involves the construction, validation and application of scientific models, so science instruction should be designed to engage students in making and using models (Hestenes, 1996). In classrooms, models have been familiar to students more than the real target that they represent. Students learn with enormous models not only in a science classroom but also in other disciplines. Model is not only products of science, the process of model constructing, modeling, is very important to scientific enterprise. One of the science landmarks is the use of explanatory model as an explanation of entities. Modeling is the core of scientific inquiry and theory development (National Center for Improving Student Learning and Achievement in Mathematics and Science [NCISLA], 2000). Many education standards set the ability to understand, construct, interpret, revise and critique models as a goal of science education. Ability to use a model and modeling in scientific inquiry is considered integral parts of scientific literacy (Perkins, 1986; Gilbert, 1991; Gilbert, 1993a; Linn and Muilenberg 1996; Gilbert and Boulter, 1998;). Like science itself, models reflect many aspects of nature of science when teacher engages students into the well-designed lesson. In that state, comprehension of science both in content and in nature of science will finally be the result.

1. What is Model?

When thinking about a model and classroom implication, individual may have different perspectives about this. One may think about the physical model which is used for curriculum material. It may be a scientific model like the double-helix DNA model that appeared in the textbook. Even the explanatory theory such as Natural Selection is considered to be a model. Furthermore, the conceptual models in student's mind are also models, as we call them a mental model. A model in science is set of ideas that describe a natural process initially produced for a specific purpose. Such set of idea can be an object, an event, a process, or a system (Gilbert and Boulter, 1998). The specific purpose for which any models are originally produced in science or in scientific research is link a simplification of the phenomenon to be used in inquiries to develop its explanations. There are many forms of models. Models can be only a particular part of system, such as, model of a heart of the blood system which is also a part of body system. A model of an object can be either smaller than the phenomenon which it represents (e.g. of a space shuttle) or bigger (e.g. of a virus). It can be the same size as the object (e.g. of the human body). Presenting a model in different sizes depends on the purpose of using. In general, models are far simpler and contain less information than their targets, but so often, models are seen more complicated than the targets.

There are a lot of documents that try to classify models in various typologies based on the criterion of classification. In this section, some classification will be given to show a variety of types of model and the terms frequently used in both science and science education. Laing (1985) classified model into seven groups from a full-scale reproduction of physical processes to purely mathematical formulae. Classifications of models and examples will be given in the Table 2.3.

Table 2.3 Classifications of model and examples

Classification of Model	**Comment**	**Example**
Pure Physical	Real full-scale model	'reconstruction of the crime' using real people and objects
Physical Geometric	Geometrically scaled model retaining the general physical characteristics of the full-scale version	A model of building designed to study strength of the structure, etc.
Interpretive Geometric	Geometrically scaled but with different physical characteristics to the original	A scaled model human dummy, the design which entails the use of mathematics
Interpretive Analogue	Model is unlikely to physically resemble the original but is likely to give an analogous effect	A shape designed to indicate an effect, such as ball bearing of different weights and sizes designed to simulate the movement of a human body under shock waves
Computational Mathematics	Mathematical estimation based on observation and mathematics which are not especially complicated	The determination of the coefficients of an equation for a market share model by analysis of observations
Pure Mathematics	Mathematics models using pure and applied mathematics	The Newtonian laws of physics

Harrison and Treagust (2000a) presented and explained a conceptual typology of models for the teachers to select. The types of models were classified into ten types according to their characteristics and functions for using in a science classroom. Scale model are used to depict external physical properties of a target in proportions but not necessary to show internal structure, functions and use. The materials for constructing scale models can be different from the target. Pedagogical analogical models are broad definition even they can include others types of model, such as scale models. This type of model shares information with the target. The word 'pedagogical' was used because teacher crafted explanations that make abstract concepts like atoms and molecules accessible for the students. Iconic and symbolic models, mathematical models and theoretical models are both considered to be pedagogical analogical models. All of them were used to build conceptual knowledge. Chemical formulas and equations are examples of iconic and symbolic models as compare to compound compositions and chemical reactions. This type of models needs to be interpreted when using to explain the phenomena. Physical properties and processes represented by mathematics equation and graph are examples of mathematics models. They depicted conceptual relationships. Theoretical models are human constructions used to describe well grounded theoretical entities.

Maps, diagram and tables are other types of models that share some characteristics with concept process models and simulations. They depicted multiple concepts and/or processes. Mental model shares some characteristics with synthetic models in the way that they are both personal models of reality, theories and processes. The examples of all ten types of model presented by Harrison and Treagust are summarized in 2.4.

Table 2.4 Conceptual typology of models and examples

Classification of Analogical Models	**Examples**
Characteristics/Functions: Scientific and teaching models	

Table 2.4 (Continued)

Classification of Analogical Models	Examples
1. Scale models	Toys or Toy-like
2. Pedagogical analogical models	Balls and sticks in molecular models
Characteristics/Functions: Pedagogical analogical models that build conceptual knowledge	
3. Iconic and symbolic models	Chemical formulas and equations
4. Mathematical models	Boyle's law, exponential decays
5.Theoretical models	Kinetic theory's explanation of gas volume
Characteristics/Functions: Models depicting multiple concepts and/or process	
6. Maps, diagrams and tables	Periodic table, phylogenetic trees, weather maps, circuit diagrams, metabolic pathways, blood circulation, pedigrees, food chain and webs
7. Concept-process models	Multiple models of acids and bases, redox and chemical equilibrium
8. Simulations	Simulation of aircraft flight, global warming, nuclear reactions, accidents, population fluctuations, computer games, computer-based interactive multimedia
Characteristics/Functions: Personal models of reality, theories and processes	
9. Mental models	Mental representation, analogue representation which individuals generate during cognitive functioning

Table 2.4 (Continued)

Classification of Analogical Models	Examples
10. Synthetic models	Student's alternative concept e.g. electron shells were protective structures like egg and clam shells and that an electron cloud was a matrix in which electrons were embedded

Gilbert (2000) classified the ontological status of models into the followings: a mental model, an expressed model, a consensus model, a scientific model, a conceptual model, a historical model, a curricular model, a teaching model, a hybrid model, and a model of pedagogy.

A mental model is private and personal cognitive representation. It is formed by an individual either on their own or whilst within a group. An expressed model is placed in the public domain by an individual or group, usually for others to interact with, through the use of one or more modes of representation. The relation between any one mental model and the apparently corresponding expressed model is complex. Any reflective person who has set out to express a mental model will be aware that the act of expression has an effect on a mental model: expressing or changing it. Different social groups, after discussion and experimentation, can come to an agreement that an expressed model is of value, thereby producing a consensus model. In particular, scientists produce a wealth of expressed models of the phenomena which they are investigating. An expressed model which has gained an acceptance by a community of scientist following formal experimental testing, as manifest by its publication in a refereed journal, becomes a scientific model. It then plays a central role in the conduct of scientific research for a length of time which is governed by its utility in producing predictions which are empirically supported. Like a conceptual model, a consensus model is a precise and complete external representation that are coherent with scientifically accepted knowledge created by researchers, teachers, engineers, etc., that facilitates the comprehension or the teaching of systems or states of affairs in the world. Those consensus models produced in specific historical contexts and later superseded for much research purposed are known as historical models. That version of an historical or scientific model which is included in a formal curriculum, often after some further simplification, is a curricular model. As the understanding of consensus, historical, and curricular models (as well as the phenomena that they represent) is often difficult, teaching models are developed to assist in that process. Teaching models can be developed by either a teacher or a student. A hybrid model is formed by merging some characteristics of each of several distinct scientific, historical, or curricular models in a field of enquiry. It is used for curriculum and classroom teaching purposes as if it were a coherent whole. A model of pedagogy is used by teachers during the planning, practical management, and reflection on, classroom activity and is concerned with the nature of science, the nature of science teaching, and the nature of science learning.

The classification can be more simplified as Georgia Framework for Learning Mathematics and Science (GIMS) (1997) viewed models. Models can be as a vehicle for understanding and doing science. Thus can be physical, conceptual or mathematical. Some physical models are devices that behave like the real thing, e.g., a model car or airplane. Other physical models, referred to as "manipulative" are used to simulate situations-for example, gumdrops and toothpicks to simulate the atoms and bonds in a molecule. Conceptual models explain the unfamiliar by comparing it to something familiar and are understood through imagery, metaphor, or analogy. For more conceptual about the model and modeling, the concept map (figure 2.3) is provided here to illustrate the types of model and how people construct them.

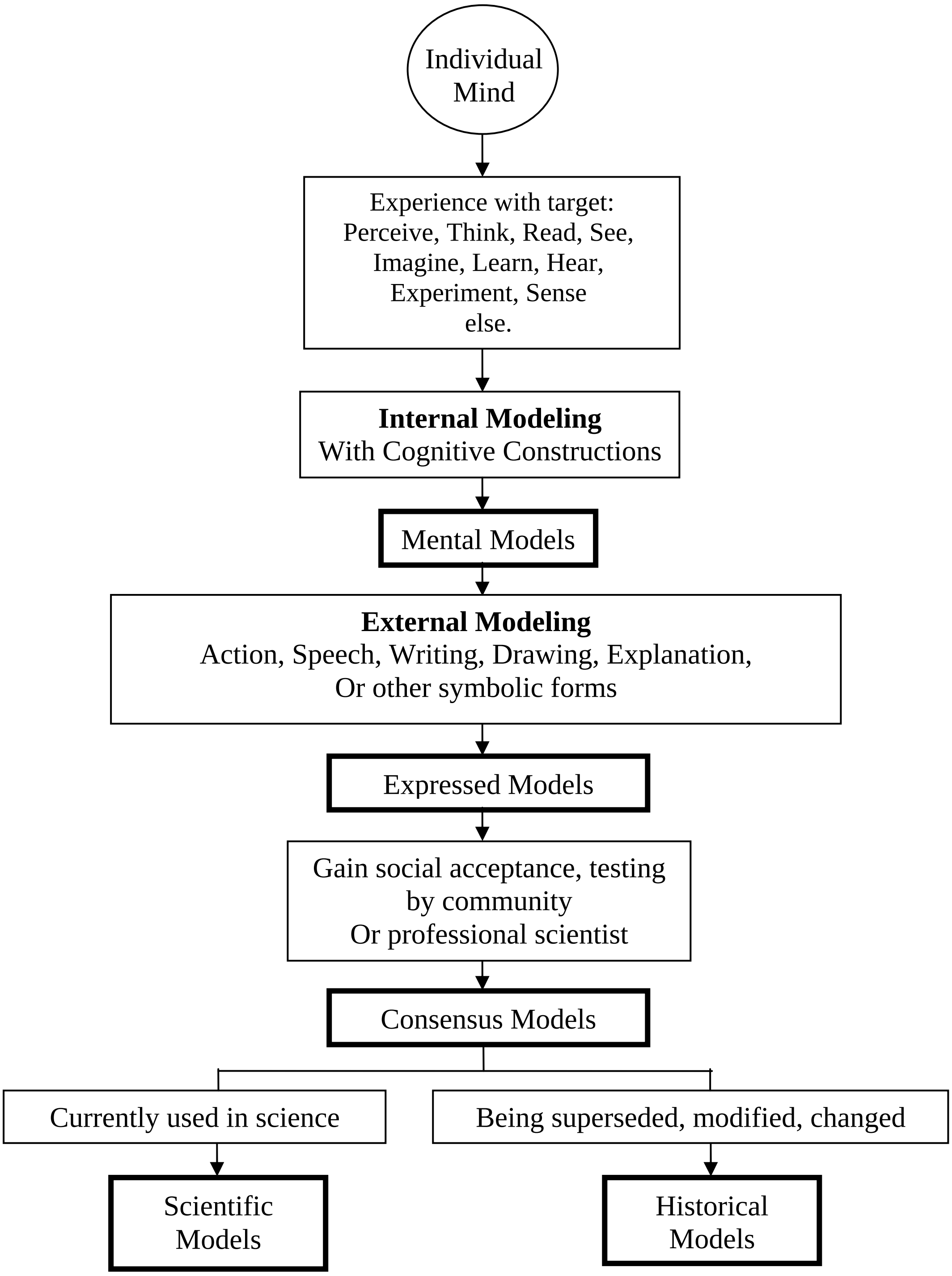


Figure 2.3 Types of models and modeling concept Map

Because there are many types and definitions of a model, they can be overlapped in some sorts. One model can be categorized into several types of model. One target can also be represented by the various models. In scientific enterprise, scientists use models to explain and predict natural phenomena. Besides, models are important in scientific research both in formulating hypotheses to be tested and in describing scientific phenomena (Gilbert, Boulter and Rutherford, 1998). Scientists also use models to guide for the future research. In many fields of science education, models are of value; for example, they can be used to 'make sense of abstract, difficult and non-observable science concepts to accommodate the explainer, the audience, the content and the context' (Treagust and Harrison, 1999). Indeed, scientific models are often the only way to explain an abstract scientific theory. Scientists' consensus models are taught as fact persuant to being the accepted model of a scientific theory, e.g., the model of the atom. Teachers can use a model and modeling as an approach to engage students to know, do and understand science.

Even though there are many types of model, all models have the same characteristics that Gilbert and Ireton (2003) has described. These characteristics are important because they underline both our thinking and the expressions of our thoughts. By their very nature, all models are:

- Artificial: All models are human constructs, even if they make use of existing a system or object. For example, if we use an orange to model the roundness of the Earth, we give the roundness of the orange a special meaning, a meaning that it does not normally possess. Because we give the meaning to the orange to make it model, the model is artificial, even if the orange is not. However, the term "artificial" does not mean "false". It simply means something that is created rather than naturally occurring.

- Utilitarian: Models are constructed to serve particular purposes. Usually models are not intended to represent all elements in particular system, but rather to reveal some of its narrower aspect. Information is often deliberately omitted from a model in order to reveal the desire target. For example, a classroom model of the Earth may be useful for geographic relationships, but not useful for a geologic process. We hold ideas and choose models for communication that best suit our purposes, not because they are right in any absolute sense.

- Simplified: Models are generally far simpler and contain less information; a model lacks the effects of variables- or attributes- that may be present in its targets. The best models do their job with little interference from irrelevant features. When we construct mental models, our models usually do not contain all possibilities - only those that serve our needs and purposes.

- Interpreted: All models must be understood and interpreted on their own terms, Some require more interpretation than others. A scale model is generally pretty clear on its face, but a road map, for example, requires the user to consult the map's key to make sense of scale, road types, town sizes and so forth.

- Imperfect: Models should never be considered perfect or complete representations of their targets. Only the target can be perfect. Models are right or wrong only in relation to criteria that define their "goodness of fit". Models imperfectly and probabilistically represent their targets. There are always errors in relation to their fit. When we construct models, we can determine their usefulness by certain criteria not the least of which is "goodness of fit" to the target for our purposes. The fit of a model is assessed according to a number of factors.

- Relatedness: To other models, especially models of the same targets, how well does it fit with other models? We are likely to reject or at least hold in abeyance a model that is too different from accepted models. Another term for relatedness is consistency.

- Transparency: It is a measure of how obviously the model fits the target. Some models are very transparent or obvious, while others are rather opaque. When a model is opaque, we don't really get a good sense of what it is being represented. Consider the metaphor inherent in using the term "string" to describe the smallest entity in the universe. Because the concept is mathematical, the use of this physical metaphor is probably opaque to many people.

- Robustness: It is measure of how insensitive the model is to changes in assumptions. In general, the more assumptions need to link the model to the target, the greater the likelihood that the model need will be changed or discarded later. The model is robust if it requires few assumptions to be understood.

- Fertility: It is measure of how much the model explains. The best models explain more about their targets than lesser models targeting the same system. The most fertile models give rise to new understanding and broad insight.

- Ease of enrichment: A measure of how easy it is to add to and extend the model. All other things being equal, better models are easier to extend and enrich. We can add to and extend the best models with relative ease.

In summary of this topic, models have several types used in scientific inquiry and school science. Models could be simple or complicated ranged from a merely individual mental model to the most abstract mathematical model invented by intellectual understanding of natural phenomena. The understanding of what is a model and its functions lead to the comprehensive employed in science education which this study defined as a model-based approach.

2. What is Model-based Approach?

In the past decades, the value of models and modeling to science education has been increasingly recognized among the science education reform movements (NRC, 1996; AAAS, 1993). The people who work in the areas related to science education are specially appealed by the words models and modeling with many reasons. Numbers of research in the field of models and modeling have been conducted. In many terms used by people who make an effort to bring a theory of models and modeling into a science classroom, we still do research, how model and modeling should be approached. From various documents, the researchers call their work differently; for example, a model and modeling (Gilbert, 2004); Modeling instruction (Halloun and Hestenes, 1987); Modeling Method (Wells, Hestenes and Swackhamer,

1995) ; Model-based instruction (Gary *et al*., 1999); Modeling approach (Cartier, 2000a, 2000b; Passmore and Stewart, 2002); model-based teaching and learning (Gobert, 2000); Model-centered instruction (Raghavan, Sartoris and Zimmerman, 2002; Steel, 2003); Model-based pedagogy (Coll, France and Taylor, 2005).

There are researchers who emphasize the construction of mental models of phenomena which they call Model-based learning (Clement, 2000). This field of research is closely related with constructivist view because mental models are personal internal representations of the target system being modeled. How people construct mental models and how we can use this theory implementing in a real science classroom, will be discussed in the next topic. Personal mental models are constructed from all the information assimilated and understanding is conveyed via each person's expressed model (Gilbert *et al.*, 1998). Harrison and Treagust (1998) found out that effective model-based learning will be benefited from knowing much more about students "proximal zones of development," especially the types of models they find easy or difficult to negotiate.

Model-based approach can be defined as the process of teaching and learning based on the theory we know about a model and modeling. This theory underpinned and found information resources, learning activities and instructional strategies intended to facilitate mental model-building both in individuals and among groups of learners. As an integral part of the scientific process, models are used in a variety of ways within the science classroom. Teachers use models as aids to help explain scientific phenomena and students often make their own models of scientific phenomena to display their understanding.

Students don't learn science from looking at a scientific model. Rather, they learn more from building the model and from manipulating it. Introduce students with only a model on without any reflection on models is not considered to be model-based approach. Students, if they have opportunities, learn with a model to build their own mental model. Learning how to use a model explaining phenomena and evaluate of the model may lead the students to develop ability to use the logical thinking as we call model-based reasoning. NCISLA (2000) presented the features of the modeling classroom for teaching and learning atomic structure.

- Instruction must emphasize students' use of scientific models to understand, illustrate, and explain key atomic theory and data.

- Students from a scientific community learn, present, and discuss about atomic models with their peers. Students collaboratively observe and gather data, discuss and present scientific arguments for critique.

- Students hone their reasoning skills through judging their own and other students' explanatory models. Students evaluate models for their fit with data, their predictive power, and their consistency with other scientific models or concepts.

- The teacher assumes the role of co - inquirer in the classroom, engaging the students in scientific inquiry and invigorating their investigations through questions and class discussions.

- The teacher continuously assesses students' understandings to determine the direction of instruction. Through literative, ongoing assessment of individuals and groups, the teacher gives students constructive feedback to direct their learning.

Implementing model-based approach, teacher must be aware that models do not share all of features and functions with the targets. Model is neither a copy of reality nor the toys or miniatures of real-life objects (Harrison and Treagust, 1998). The project "Modeling for Understanding in Science Education (MUSE)" (National Center for Mathematics and Science, 2002) at the Wisconsin Center for Education Research focused on the idea that a central goal of scientists is the development of explanatory models that can be used to explore the natural world. In this research, students have diverse opportunities to be engaged in collaborative, investigative activities, which involve the development, the use, the revision, and the assessment of central explanatory models that are at the core of various scientific disciplines. Cartier

(2000a, 2000b) discussed the implications on the use of modeling as an approach to teach students about the structure of scientific knowledge and the nature of science as a modeling activity. Focusing on Genetics concepts, in the setting like communities of scientists, students construct their own explanatory models, share and justify their models with other groups. Likewise, Harrison and Treagust (1998) found that whenever the social learning environment is supportive and multiple models are used, students can become competent multiple modelers, and they can realize that knowledge is relative and contextually. The roles of communicating expressed a model in group work were well documented by Coll *et al.* (2005). The notions that focus on individual doing science like a real scientist have shifted to that one that focus on social context and the nature of interactions between scientists.

3. Model-based Approach and Constructivist Teaching

Science educators embracing constructivism believe that learning is an active process that requires students to construct their own personal schema to assimilate new concepts. Constructing mental models are such an internal individual representation of reality that people use to understand specific phenomena. Before engaging to a scientific concept, according to constructivist's view, students already had mental models in their mind. Learning science is to reconstruct students' mental model. Those processes depend on the capacity of students to form and express mental models that will be enhanced by providing explicit opportunities to become aware of their mental models and are given explicit opportunities to express those models (Gilbert, 1993b). Teaching with model-based approach is sharing eight characteristics of the constructivist environment which Jonassen (1991) identified as follows:

3.1 Constructivist Learning Environments Provide Multiple Representations of Reality

In a model and modeling classroom, one reality can be represented by multiple models. When models are used to represent atom, they can be multiple forms. Models can be a physical model e.g. VAST model (Chamrat, 2007), 3D paper model (Pringle, 2004), pictures that can be found in common chemistry textbooks, images of atoms (Wright, 2003), animation and visualization or computer simulation (Gilbert, 2005), or even alphabet and mathematical like electron configurations that represent electrons behaving in an atom. There are empirical studies in secondary science classes which have shown that it is possible for students to learn to think in sophisticated ways at an earlier age than previously thought (Harrison and Treagust, 2000b). In this study, 11^{th} grade chemistry students who became creative multiple modelers realized that no model is wholly right. They appreciated that science is more about process thinking than object description. Corresponding with Saari and Viiri (2003), they found that the use of multiple models may be one reason for the positive learning effect of the teaching sequence.

3.2 These Representations Represent the Complexity of the Real World

Models are representations of the complex entity even in the simpler or more complicated form. In learning about atomic structure, students are difficult to imagine how atoms are, because an atom and subatomic particles are particular abstract which are, difficult, and non-observable science concepts. To facilitate students' constructive processes, models are the experiences that students can get involved in both hands-on and minds-on. Treagust and Thapelo (2003) provided examples of the use of symbolic and submicroscopic representations in explaining the macroscopic nature of chemical phenomena. They also found that the abstract nature of chemistry and the need for the learner to develop a personal understanding of the submicroscopic nature of the chemical nature of matter necessitates the use of an extensive range of symbolic representations such as models, problems and analogies.

3.3 Knowledge Construction is Emphasized over Knowledge Reproduction

In teaching with models should be aware that models teachers can only act as aids to memory, explanatory tools, and learning devices if they are easily understood and remembered by students (Harrison and Treagust, 1998). Students generate their mental model by participating with a particular well-designed instructional unit. Interacting with experiences offered by a teacher and participating group activities, students constructed and revised their mental model.

3.4 Authentic Tasks are Emphasized in Meaningful Context

In the study of Mayer (1989), there were evidences that conceptual model, defined as words or diagram, can be used as tools for meaningful learning. Students were also able to engage in systematic thinking better when they learned with models. The conditions for meaningful learning can be addressed by answering the questions: Is a material potentially meaningful? Does learner need help? Does model help learner to select key concepts? Does model help learner to organize concepts? Does model help learner to integrate concepts? And, does a test evaluate meaningful learning?. From the result, learners can predict a pattern, in which students who learn with concrete models recall more conceptual information, perform less on verbatim retention of information, and generate more creative solutions on transferring problems, as compared to students who learn without models.

3.5 Real World Settings or Case-based Learning is Provided

Teacher can use various models in teaching with real situations. Constructing and using models to answer particular questions or engage them into specific cases can implement in a science classroom. Passmore and Stewart (2002) found that by engaging students in the examination of the metaphysical assumptions of various models (Paley’s model of intelligent design, Lamarck’s model of use inheritance and Darwin’s model of natural selection) and by requiring them to use those models to explain natural phenomena, there is enormous potential to deepen and broaden students’ understanding of evolutionary biology.

3.6 Thoughtful Reflection on Experience is Encouraged

Model and modeling are the powerful ways to let students reflect their experiences in science. Recent research has shown that some pedagogical approaches to model use have enabled students to develop a metacognitive awareness as well as providing the tools to reflect on their own scientific understanding (Coll *et al.*, 2005). The evaluation and critique of both scientific and mental models let students develop their understanding of scientific concepts. The teaching strategy 'Student-centered instructional design' developed by Wells *et al.* (1995) had a modeling method called a modeling cycle which engaged students in all phases of model development, evaluation and application in concrete situations. In the evaluation phase, students validated a scientific model through comparison with empirical data. In a model and modeling classroom, the state of reflections on students' own mental model is widely used (Cartier, 2000a, 2000b; Coll and Treagust, 2002; Taylor, Barker and Jones, 2003).

3.7 Enable Context - and Content - Dependent Knowledge Construction

Knowledge is context and content dependent, so learning should occur in contexts to which it is relevant. To understand and do science, students have to be engaged in the context like scientists do. One of the roles of scientists in scientific practice is model builder (Lakhtakia, 1996). Many times, students are introduced into experiments, likewise scientists have done. There is also a general agreement among science educators that inquiry should be of value because this is the way real scientists do in their work. Focus on teaching implications of using models to frame inquiry, there are many reasons for students to undertake inquiries into larger context of scientific model building (Gilbert and Ireton, 2003). Student's understanding and practicing with a broader framework of science can be provided by model building. Inquiry is not just only to have a purpose of a lab activity but also to create an intellectual satisfying and persuasive model of the target system based upon observation and inference, present the model to others and to defend it). This process portrait the spirit of science than does inquiry in isolation. Students in the classroom are often asked to complete labs lacking a context that gave the process of exploration and inquiry in a broad and more satisfying meaning. They may be required to fill in tables with data and provide "right" answer to preset questions. Science is thus reduced to the completion of particular tasks. Model building gives inquiry more form and substance in context and content of particular science concepts.

3.8 Support Collaboration and Social Negotiation among Learners

When focusing towards constructivist philosophy, learning science requires students to take ownership of an idea or concept, to reconstruct it, to internalize it and to explain or communicate it to others. Models are served as invaluable tools in this process. Coll *et al.* (2005) suggested that model-based teaching and learning strategies provide opportunities for science education research to examination of the wider social aspects involved in learning science. They also commented that the community aspect of the classroom and the role of peer discussion assist students to learn science. A discussion with peers has the potential to provide students with alternative models of scientific phenomena and to introduce criteria as well as evidence to help them distinguish among scientific models. Such an activity is enhanced with the utilization of cooperative learning strategies.

In modeling activity, the communication among the community of practice of scientists or students in the classroom is very important because expressed models of individual or group of people become a scientific model when it gains social acceptance, tested by community or professional scientist. Thus, every model-based classroom has to acknowledge the social construction of knowledge by defining consensus models as expressed models that have been developed, tested, and agreed among groups of learners.

4. Model and Modeling in Science Education

Among the researchers who are interested in using the theory of model and modeling to develop students' understanding and ability to do science, there were a number of strategies implemented in the researches. Many of the research reports present those strategies in the pattern of cycle and step. There were modeling lessons that emphasize in students' constructing of concrete model, Gilbert and Ireton (2003) presented seven steps for building a model. Those steps are based on scientific inquiry. First, the learners who conducted the research-based inquiry had to know the questions they wanted to know. It might be the hypothesis that they had to address earlier. Second, the students observed and recorded what they knew about their hypothesis. This gave a mental model to their initial sense. Third, students stated the purpose of the research or named the title of their model. This would help them focus the model and think about the process of investigation clearly. Fourth, students analyzed the task and figured out how to construct the model. This step was to design, for example, the way to collect the data and how to record them. Fifth, students identified the variables that they were interested in. The variables were important to the model they wanted to construct. Sixth, there was practice working with the model after they assembled it. The data from testing the models would help students ensure their validation. In this step, students had to document their work carefully because these data would be presented to others or peer. And, seventh, students used the model as the purpose and collected the data to draw the inference. This step was a part of model building. Testing and revising had to be conducted. The students put their work into the form that was ready for peer review.

Núñez-Oviedo and Clement (2004) discussed the model process 'Macro Cycle' that was used to teach a small group of student and 'Micro Cycle' which was used to teach the large group of students. Micro Cycle has five steps: introducing the topics, detecting Students' Ideas, building on students' ideas, comparing the student and the scientific models and adjusting the student model. For Micro Cycle, it refined the step 'building on students' ideas' into three steps: focusing on a preconception in the students' model, producing dissatisfaction in the model element and modification of the model element.

In teaching physics concepts with computer-based modeling, Sins, Savelsbergh and Joolingen (2005) emphasized on the reasoning processes specifically associated with modeling. There were five steps in reasoning process. The first was Analyzing; students analyze and decompose the phenomenon, they were studying. The students also identified the elements of the model they were interested in order to implement such model. The second step, Inductive Reasoning; the students used it when they conjectured or how model elements interact and on how the model should behave. The student also constructed the hypothesis and engaged in the complex process of elaboration on the relationships between the model structure and the behavior of the phenomenon being modeled. The third step, Quantify; the students could express their idea of preliminary model they constructed in the form of an executable mathematics format. This could let them think about their model precisely. The students also experienced that quantities in the model were specified with a starting-value and relations were worked out in equations. The next step, Explain; the students documented the reason and clarified why model elements were related and why factors caused changes in another. Those reasons were discussed among students. The last step, Evaluate; the students used results from the experiment connecting to the output from their model in order to evaluate and ultimately test their model. To evaluate the model, students determined whether their model was consistent with their own beliefs, with data obtained from experiments and with descriptions of behavior about the phenomenon being modeled. This step also led to the revision and modification of the models.

Taylor *et al.* (2003) studied about model-based reasoning by using the mental model-building strategy. In this strategy, there were five phases to teach intermediate school students(Years 7–8) in New Zealand. The steps consisted of pre-phase/preparation: phase 1: focus on the mental models, phase 2: mental model building and critiquing, phase 3: using the mental model to solve problems and phase 4: reflection. In the processes of constructing models (mental or physical model), there were some parts of sharing model cycle. The lesson usually started with the existing student’s mental model. If the lessons were not started with probing student’s pre-mental model, it would not have appeared in very early of the class. Model constructing from observation or experiment gave the students an opportunity to reason why those data fit with model they had constructed, or why model could represent the target being modeled. The students could critique their model comparing with a scientific model or peers' model. Students pointed the functions of the model used to represent the target as well as its limitations. Communicating a model to the others is a very important part of the lesson. The students have to reflect their mental model, discuss and revise it until it is accepted by the community, or it fitted with phenomena. The development or model is a cyclic process (Saari and Viiri, 2003).

5. The Nature of Science as a Modeling Activity

There are many researches indicated that teaching and learning with models and processes of constructing them promoted students' understandings of the nature of science. Gilbert and Ireton (2003) concerned about the loss of money and lives that happened because people, even scientists, cannot distinguish between science and pseudoscience. Some pseudoscience occurs because people ignore principles, of scientific inquiry and standards of evidence. It might have been caused by the weak evidence. Students, whatever they will be in the future, have to be intelligent "consumers" of science and avoid the pitfalls of pseudoscience. The strategy they proposed in the books was the use of analyzing and categorizing a model to differentiate the knowledge, which is science, and the knowledge that came from other sources, such as religious, political, or fictional literary models. To know the different kinds of knowledge is to understand how knowledge was constructed. Taylor *et al.* (2003) suggested that students' understanding of the nature of science might be promoted by a mental model building intervention. While learning astronomy, student accessed the three aspects of the nature of science. Firstly, science is a process which has been constructed by people. Secondly, science is influenced by the social and cultural frameworks in which scientists work. The third nature of science aspect is that science understanding changes over time'.

Cartier (2000b) found that if students understand the day-to-day practice of scientists in particular disciplinary settings, it will promote understanding of nature of science. As scientists study important concepts in a particular discipline, students should develop an understanding of the types of questions scientists in that discipline ask: the methodological and epistemological issues that constrain their pursuit of answers to those questions, and the ways in which they construct and share their explanations. In Thailand, the National Science Curriculum Standard (IPST, 2002) states explicitly that student's ability to use model and modeling for setting up the hypothesis and for pointing out trends of data that they gathered from investigation are considered to reach the standards of strand 8: nature of science and technology.

Summary of the Chapter

It is widely accepted about the value of teaching the nature of science and science concepts to reach the ultimate goal of science education. Nature of science is viewed as a basic assumption for the people in a particular paradigm about how scientific knowledge was constructed and how we can justify them. Students, the prospective scientifically literate citizen, should at least have basic scientific concepts, scientific skills, understanding of nature of science including good attitude toward science. The goals are clear in science curricular but the ways to reach those goals are still under developing. There are many teachers, researchers, science educators and people in the field of science education devoted their career for uncovering how we can educate our children to know, understand and be able to do science. Model-based approach is the teaching pedagogy in which students engage experiences for constructing, analyzing, evaluating, revising, and commutating models to understand atomic structure concepts. There are several types of model including physical, conceptual, and methodical models. An analogy and metaphor are considered to be a model. In addition, from this literature review, teaching approaches embedded in a model-based approach were inquiry, constructivist and historical approach. These several types of teaching and learning strategies aimed to promote the diversity of activity of the ASIU.

CHAPTER III

RESEARCH METHODOLOGY

In this chapter, the theoretical framework used to inquire the understanding of the classroom phenomena is described. The research paradigm held by the research and the way researcher viewed the world is communicated to the audience. This chapter is very important because it advocates the credibility for knowledge claim of this study. It's to be noted that the strength of qualitative research is the thick description not only the findings but also the process of such an inquiry. It's easy to make an understanding of this chapter. The chapter is divided into two parts. The first part discusses about the theory used to set the methodological framework of this study, including the principle of how to ensure the quality of the study. The second part portrays the method of the study. The research approached, collecting data techniques and data analysis methods are also described. All the data of this chapter will be presented on the thick description to portray the most accuracy to the audience.

Research Paradigm

1. Interpretive Research

The way to understand the world we are within is to interpret the meaning. The next question is – what is the meaning we're looking for? In the sense of doing research, most of the meanings are acquired through social constructions such as language, consciousness, and shared meanings (Klein and Myers, 1999). Interpretive paradigm has emerged when the way we view the world has changed. Relevance to constructivism, emphasis on the socially constructed nature of reality, interpretive research acknowledges the intimate relationship between the researcher and what is being explored, and the situational constraints shaping this process. In terms of methodology, interpretive research does not predefine dependent or independent variables, does not set out to test hypotheses, but aims to produce an understanding of the social context of the phenomenon and the process whereby the phenomenon influences and is influenced by the social context (Walsham, 1995). The study of human and society are different from the study of natural world. The paradigm of interpretive research distinguished itself from those of a reductionist, hypothetio-deductive model employed in the natural sciences (Dawson, 2002). The use of interpretive framework to study human science included ethnographic, qualitative, participant observational, case study, phenomenological, symbolic interactionist and constructivist research. In this study, interpretive research allowed researcher to answer the questions in detailing the nature of practices in science classrooms. As Gallagher (1991) had discussed, interpretive methodology allows us to examine (1) science classroom as socially and culturally constructed environment for learning (2) the nature of teaching as one feature of that learning environment and (3) the way in which teachers and students make sense of, and give meaning to, their interactions as the central element of the educational process.

2. Data Collection Technique

From research questions and the theory used in this study, five techniques were selected; observation, interview, open-ended question, multiple choice diagnostic test and documentary data. Characteristics and nature of each technique were discussed to support why they were used and to make the confidence that they are the appropriate technique to inquire the data.

2.1 Observation

Certain kinds of research questions can best be answered by observing how teachers or students act or how things happen in the classroom. For example, researchers would like to know how students behave during class discussions of lesson issues. An accurate indication of their activities would probably be obtained by actually observing such discussions while they are taking place. Observations are carried out using a carefully developed set of steps and instruments. The observer is more than just an onlooker, but rather comes to the scene with a set of target concepts, definitions, and criteria for describing events (Westat *et al.*, 2002). While in some studies observers might simply record and describe, in the majority of observations, their descriptions are, or eventually will be, judged against a continuum of expectations. According to Fraenkel and Wallen (2003), there are four different roles that a researcher can take, ranging on a continuum from complete participant to participant as observer, to observer as participant and to complete observer. The degree of involvement of the observer in the observed situation diminishes accordingly for each of these roles. In participant observation studies, the researchers actually participate as an active member of the group in the situations or setting, he or she is observing. In nonparticipant observation studies, the researcher does not participate in an activity or situation, but observes from the sidelines. The most common forms of nonparticipant observation studies include naturalistic observation and simulations. A simulation is an artificially created situation in which subjects are asked to act out a certain role. Before observation, researchers had to consider observation techniques. The equipment was used such as audio-video recording. Field note is also the data collection supplement to observation. Furthermore, the researchers have to prevent observer's effect and bias that were discussed in the topic of ensuring the quality of the research.

2.2 Interview

Interview becomes the most common technique to obtain data when the research paradigms shift from quantity to quality in basis for decades (Fraenkel and Wallen, 2003). Although it is not easy to conduct and it needs time and competency of an interviewer, interviews are used widely by several reasons especially when rich details about the perspectives of participants are desired. The use of the interview as a data collection method is based on the assumption of people viewing the world. It is meaningful and complicated but can be interpreted and understandable. An interview is suitable to use when the researcher wants the data that insights into people's biographies, experiences, opinions, values, aspirations, attitudes and feelings. Among the diverse interview typology, they are generally selected by the purpose of the researcher. In this study three types of interview were selected because of situations on each phase. Formal interview let the researcher ask teachers with the same set of questions about their understanding and teaching of nature of science. Informal interviews take information while the researcher had opportunities to talk with teachers in various situations; such as before and after implementing the lessons. During 3 workshops, focus group as one type of interview was used because three teachers participated and discussed together.

2.3 Formal Interview

Formal interview is verbal questionnaires. They consist of a series of questions designed to elicit specific answers on the part of respondents. Often they are used to obtain information that can later be compared and contrasted. For example, a researcher who was interested in how the characteristics of teachers in inner-city and suburban schools differ might conduct a structured interview (i.e., asking a set of structured questions) with a group of inner-city high school teachers to obtain background information about them - their education, their qualifications, their previous experience, their out-of-school activities, and so on - in order to compare this data with the same data (i.e., answers to the same questions) obtained from a group of teachers who teach in the suburbs. Structured and semistructured interviews are best conducted toward the end of a study. However, rather than at the beginning, as they tend to shape responses to the researcher's perceptions of how things are.

2.4 Informal Interview

Contrast with formal interview, informal interview does not tend to use prepared questionnaires or interview schedules. However, they will have a number of themes or issues which they aim to explore. The questions asked will be more likely to be open-ended, with the participant providing responses in their own words. The respondent might have more control over the conduct of the interview in that they are often allowed to discuss issues as they like and not necessarily in an order predetermined by the interviewer. The result of this more open-ended approach is a richness of data, which is unbiased by any interpretation which the interviewer might have placed on it. The main difficulties with unstructured interviews are that it is time consuming, and perhaps more importantly, the data collected from different respondents will obviously be different, and therefore, they can not be compared. This might raise issues of reliability and validity for data collected in this way.

2.5 Focus Group

Dawson (2002) has described focus groups which also - discussion groups or group interviews as an interview that number of people are asked to come together in a group to discuss a certain issue. For example, in market research this could be a discussion centered on new packaging for a breakfast cereal, or in social research this could be to discuss adults' experiences of school. The discussion is led by a moderator or facilitator who introduces the topic, asks specific questions, controls digressions and stops break-away conversations. She makes sure that no one person dominates the discussion whilst trying to ensure that each of the participants make a contribution. Focus groups might be video-recorded or tape-recorded.

2.6 Open-ended Questionnaire

In general, there are two types of questionnaire, closed-ended and open-ended. Both have the advantage and disadvantage over each other. Making a decision what to use depends on what kind of data the researcher wants. Open format questions are good for soliciting subjective data or when the range of responses is not tightly defined. An obvious advantage is that the variety of responses should be wider and more truly reflect the opinions of the respondents. Closed format questions usually take the form of a multiple-choice question. They are easy for the respondent to give their answer. It doesn't need time too much to complete this kind of questionnaire. Open-ended questionnaires are used in qualitative research, although some researchers will quantify the answers during the analysis stage. The questionnaire does not contain boxes to tick, but instead leaves a blank section for the respondent to write in an answer. Whereas closed-ended questionnaires might be used to find out how many people use a service, open-ended questionnaires might be used to find out what people think about a service. As there are no standard answers to these questions, data analysis is more complex. Also, as it is opinions which are sought rather than numbers, fewer questionnaires need to be distributed. Using of an open-ended questionnaire to elicit students' understanding of nature of science aims to decrease the degree of force-choice questionnaire. Tracing back to the first time 'nature of science' term emerged about the mid of nineteen century when nature of science became an important goal for science education, the attempt to develop instrument for assess understanding of nature of science has been developed simultaneously.

In the early time, that nature of science has been concerning as a criticism of science education reform (AAAS, 1990, 1993; NRC, 1996) many standardized and convergent instruments have been developed to assess learners' nature of science view. Most of them are paper-and-pencil test. Those instruments comprised forced-choice, such as agree/disagree, Likert-type or multiple-choice items. Lederman *et al.* (2002) noted that there are three criticism issues of using standardized and convergent paper-and-pencil instrument. The first, these instruments assumed that respondents perceive and interpret an instrument's items in a manner similar to that of the instrument developers. Second, standardized instruments usually reflected their developers' views and biases related to the nature of science and the third, these instruments were mainly intended to label participants' nature of science views as "adequate" or "inadequate without elucidating and clarifying such views. As criticism, several researchers have attempted to develop open-ended instruments, with emphasis on descriptive questions that allowed meaningful assessments of the individuals' nature of science views. Lederman *et al*. (2002) developed such a questionnaire, focusing on several aspects of nature of science. The authors stressed that the uses of open-ended questionnaire were proper to investigate student's understanding of the nature of science.

2.7 The Two Tier Multiple Choice Diagnostic Test

Diagnosing the students' misconception is an important and complex task in science classroom. There are many diagnostic methodologies for science misconception, including concept mapping, interview and paper and pencil test. To avoid the shortcoming of the paper and pencil test and take advantage of interviewing and concept-mapping, two-tier diagnostic test was proposed by Treagust (1985, 1988). The two-tier multiple choice diagnostic test is different from tradition multiple choice test in several degrees. First, the two-tier diagnostic test question is comprised of two tier items. The first tier of each item is a multiple choice question related to propositional statement and it is part of the concept map as well. The second tier of each item consists of a multiple choice set of reasons for the answer related to the first tier item. Second, two tier test multiple-choice test items included responses with known student alternative conceptions, and also required students to justify their choice of option by giving a reason (Tamir 1971).

Tregust (2006) summarized the development of two tier test and its contribution to science education. The means whereby two-tier items have been designed has been well documented by Treagust and other researchers who have implemented the approach. In brief, there are three major aspects to developing these items: (a) the content is defined by the identification of propositional content knowledge statements of the topic to be taught and the development of a concept map that accommodates the propositional statements; (b) information about students' conceptions is obtained from the extent research literature, where available, and where not available by having students provide free response explanations to their answers and conducting unstructured interviews with students who have previously been taught the content/concepts; and (c) the development of the two-tier multiple-choice diagnostic items.

2.8 Documentary Data Gathering

Documentary evidence is one of the important data sources for research.

Existing records often provide insights into a setting and/or group of people that cannot be observed or noted in another way. This information can be found in document form. As individual or public, documents are integrated in every part of our daily life and public concern. In classrooms, much data basically are available in the form of document. A broad definition of a document is a written text. Lincoln and Guba (1985) defined a document as "any written or recorded material" not prepared for the purposes of the evaluation or at the request of the inquirer. Documents can be divided into two major categories: public records, and personal documents (Guba and Lincoln, 1981). Sources of documentary data include teacher documents such as lesson plan, anecdotal, as well as students' work.

3. Provision of Trustworthiness

Since the epistemological assumptions of interpretive research are different from those of quantitative research, the new criteria to judge quality of interpretive research emerged. The trustworthiness of the research refers to reliability and validity in quantitative research and is attained by the following strategies. Lincoln and Guba (1985) describe criteria that are frequently cited for evaluating qualitative studies. They address the criticisms leveled at naturalistic research and determine that quality rests in trustworthiness of the study and its findings. They agree with others that conventional criteria are inappropriate for qualitative studies and that alternate criteria do exist. These criteria are (a) credibility, (b) transferability, (c) dependability, and (d) confirmability. These authors go on to recommend activities the researcher might undertake to ensure that these criteria will be inherent in the study. In particular, to make credible findings more likely, they recommend that prolonged engagement, persistent observation, and triangulation be done. Further, they recommend to peer debriefing about the study and its methods, opening the researcher and the methods up for review. They also recommend analyzing negative cases to revise hypotheses; testing for referential adequacy, by building in the critical examination of findings and their accompanying raw data; and conducting checks of data, categories used in analysis, interpretations and findings, with members of the subject audience. Lincoln and Guba (1985) provide a similar level of helpful suggestions in the area of ensuring confirmability. They recommend triangulation with multimethods and various sources of data, keeping a reflexive journal, and, most powerfully, conducting a confirmability audit. In their book, they include detailed descriptions of the steps in conducting an audit and recommend the following categories of data that can be used in the audit, including raw data, products of data analysis, products of the synthesis of data such as findings and conclusions, process notes, personal notes about intentions, and information about how instruments were developed. In the tradition of Lincoln and Guba (1985), Erlandson *et al*. (1993) describe the following techniques for ensuring the quality of a study.

Table 3.1 Establishing trustworthiness: a comparison of quantitative and qualitative research.

Criterion	Quantitative Term	Qualitative Term	Techniques to Establish
Truth value	Internal validity	Credibility	Prolonged engagement Persistent observation Triangulation Referential adequacy Peer debriefing Member checks Reflexive Journal
Applicability	External validity	Transferability	Thick description Purposive sampling Reflexive journal
Consistency	Reliability	Dependability	Dependability audit Reflexive journal
Neutrality	Objectivity	Confirmability	Confirmability audit Reflexive journal

Source: Erlandson *et al.* (1993)

Research Method

1. Design of the Study

1.1 Research Framework

This study bases on the research philosophy of interpretive research described in previous section. The study was divided into three phases, as figure 3.1, the first phase aimed to make an understanding of the current situation in teaching and learning atomic structure as well as how and what teachers and students understood the nature of science. For answering the research question in the first phase, four instruments were chosen to be the appropriate data collecting techniques. Observation was selected first because inquiry into the natural setting is the keystone of interpretive research. The researcher randomly observed classroom 3 times per teachers while they taught atomic structure topics. Classroom observation was conducted during teacher implemented their own atomic structure lesson plan in the first semester of academic year 2006. When atomic structure lesson finished, the Nature of Science Questionnaire (NOSQ) and Atomic Structure Concept Test (ASCT) were administered to the students. These methods were selected because the nature of open-ended question allows students to answer in their own words. While the nature of multiple choice diagnostic test as ASCT was developed base on the limit of time and schooling period as well as teacher's the familiarity. The disadvantage of forced-choice item selection of a normal multiple choice test was developed into two-tier format that more focus on student's conceptual understanding. After their classrooms were observed, the teachers were also interviewed about their understanding of the nature of science, how they reflected the nature of science on their classroom and the problems of teaching the nature of science in atomic structure concept. The second phase was the development an instructional unit designed to enhance student's understanding of atomic structure and the nature of science by mean of modeling activity described in chapter 2. Besides the relevance documents such as the national science curriculum standard (IPST, 2002), teacher handbook, IPST textbook, findings from the first phase were used to design Atomic Structure Instructional Unit (ASIU).

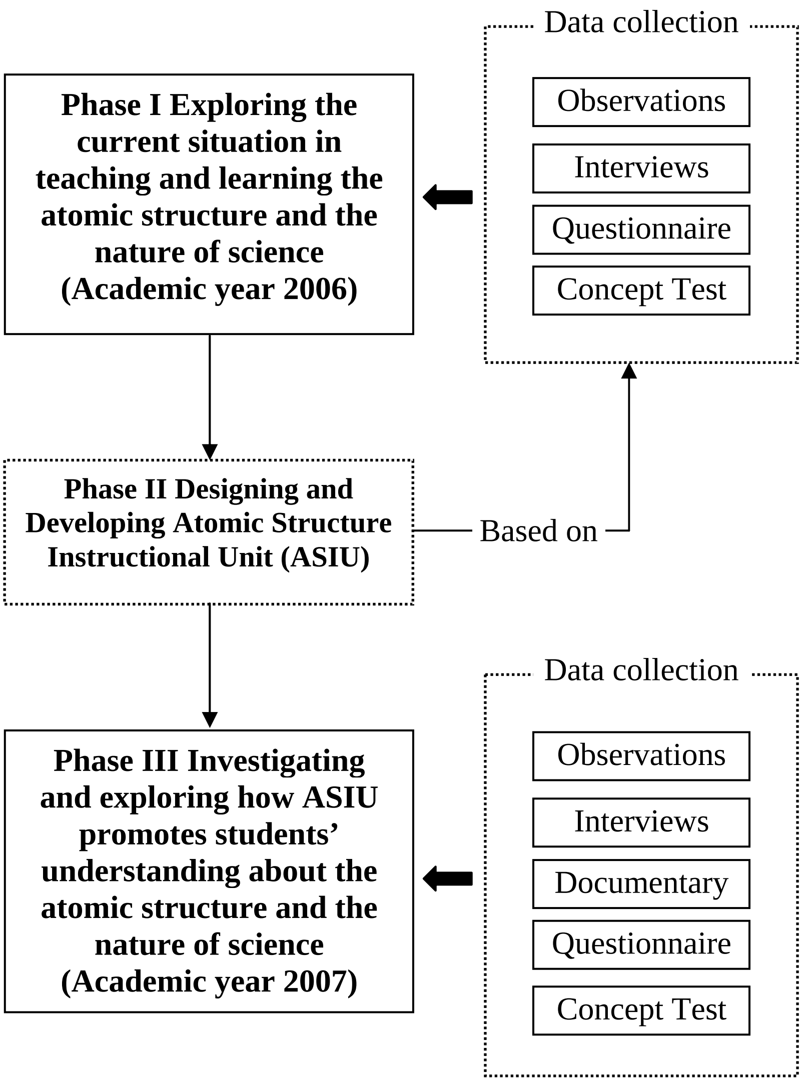


Figure 3.1 The overview of the research

The three workshops were set for the teachers before the implementation of ASIU in the first semester of academic year 2007. The first workshop was set before the beginning of the semester. The second workshop was set while teachers were implementing the ASIU. The last workshop, as the conclusion of the program, was finally set to give an opportunity to the teachers to reflect their feedback and evaluation of the instructional units. To investigate how ASIU enhance students' understanding of atomic structure concepts and the nature of science in the third phase, five selected methods under the philosophy of interpretive research were used to collect the data. NOSQ and ASCT were administered to the students before and after they engage in ASIU experiences. The time period of the second phase started from May to August, 2007. To study in-depth in the real setting, the researcher appeared in every single classroom of three teachers when they implemented the lesson. The total time of the ASIU implementation for all three schools was 72 hours. The details of each instrument for collecting the data and the development of ASIU will be discussed in details later in the next topics. The phases of the study, research questions, instruments, and timeline are summarized in Table 3.2.

Table 3.2 Summary of research framework

Phases of Study and Research Questions	Participants	Data Sources	Timeline
Phase I Exploring the current situation in teaching and learning the atomic structure and the nature of science			
Main Question:			
What is the current situation about teaching and learning atomic structure integrating with the nature of science of 3 classrooms in Bangkok?			
Sub Questions:			
1. How and to what extent do Thai teachers' instructions typically reflect the nature of science in teaching atomic structure?	3 teachers from 3 schools in Bangkok	1. 10 classroom observation VDO recording 2. 3 teacher interviews	May-July 2006 (Academic year 2006)
2. What are the teachers' perceptions of the problems of teaching atomic structure with the integration of the nature of science	3 teachers from 3 schools in Bangkok	1. 10 classroom observation VDO recording 2. 3 teacher interviews	May-July 2006 (Academic year 2006)

Table 3.2 (Continued)

Phases of Study and Research Questions	Participants	Data Sources	Timeline
3. What are the students' understandings of atomic structure prior to the Atomic Structure Instructional Unit?	137 secondary participant students from 3 schools in Bangkok	Atomic Structure Concept Test	May-July 2006 (Academic year 2006)
4. What are the teachers' understandings of the nature of science prior to the Atomic Structure Instructional Unit?	3 teachers from 3 schools in Bangkok	3 teacher interviews	May-July 2006 (Academic year 2006)
5. What are the students' understandings of the nature of science prior the Atomic Structure Instructional Unit?	137 secondary participant students from 3 schools in Bangkok	Nature of Science Questionnaire	May-July 2006 (Academic year 2006)

Table 3.2 (Continued)

Phases of Study and Research Questions	Participants	Data Sources	Timeline
Phase II Designing and developing the Atomic Structure Instructional Unit integrated with the nature of science			
Main Question:			
What is the process of developing of the instructional units to teach atomic structure with the integration of the nature of science?	1. 3 teachers 2. Researcher	1. 3 focus group discussions 2. researcher's planning journal note 3. researcher's concept map 4. researcher's note about curriculum standard and review literature 5. sample lesson plan	September 2006 – February 2007

Table 3.2 (Continued)

Phases of Study and Research Questions	Participants	Data Sources	Timeline
Sub-Question: How is the Atomic Structure Instructional Unit modified to take into account teachers' responses?	1. 3 teachers 2. Researcher	1. 3 focus group discussions 2. researcher's planning journal note 3. researcher's concept map 4. researcher's note about curriculum standard and review literature 5. sample lesson plan	May 2007 July 2007 October 2007
Phase III Investigating and exploring how Atomic Structure Instructional Unit promoting students' understanding about the atomic structure and the nature of science			
Main Question: 1. How do teachers implement Atomic Structure Instructional Units?	3 teachers from 3 schools in Bangkok	1. 18 classroom observation videotape recording 2. 18 classroom observation field notes 3. 18 Teacher pre-instructional conversational interviews	May-August 2007 (Academic year 2007)

Table 3.2 (Continued)

Phases of Study and Research Questions	Participants	Data Sources	Timeline
		4. 18 Teacher post-instructional conversational interviews	
Main Question: 2. How do the teachers' implementations of the Atomic Structure Instructional Unit influence students' understanding of atomic structure concepts and the nature of science?			
Sub Questions: 1. How do students understand atomic structure concept as sequences of the ASIU implementation?	3 students from 3 schools in Bangkok	**Primary sources** 1. 18 classroom observation videotape recording 2. 18 classroom observation field notes 3. 54 students' informal interviews **Secondary source** 4. The Atomic Structure Concept Test (ASCT)	May-August 2007 (Academic year 2007)

Table 3.2 (Continued)

Phases of Study and Research Questions	Participants	Data Sources	Timeline
2. How do students understand the nature of science as consequences of the ASIU implementation?	3 students from 3 schools in Bangkok	**Primary sources** 1. 18 classroom observation videotape recording 2. 18 classroom observation field notes 3. 54 students' informal interviews **Secondary source** 4. The Nature of Science Questionnaire (NOSQ)	May-August 2007 (Academic year 2007)

1.2 The Setting and Participants

The study was conducted in three public schools located in sub-areas of Bangkok. All three schools are categorized as "extra-large" schools with enrollments exceeding 2500 students and serving Grades 7-12. Three chemistry teachers and their Grade 10 students, participated in voluntary sampling with a total of 137 students (School A = 45, School B = 50, School C = 42) in the first phase and 143 students (School A = 42, School B = 49, School C = 52) in the second phase. The teachers from Schools A, B and C have taught chemistry for 25, 23 and 25 years, respectively. Three students from each school were selected by purposive sampling to be explored while they participated in the research. The whole classrooms were observed for the contextual information meanwhile 9 students were explored in depth. All were science program students in that they had science experiences in Grades 7-9. However, this was their first chemistry course.

2. Data Sources of the Research

The term data sources refer to the evidences of investigation to answer research questions. Understanding of the current situation in teaching and learning atomic structure and the nature of science according to basic assumption of this research cannot be brought simply by just only one method. To prevent the superficial interpretation, seven methods of data sources were used to acquire the information that met the research questions. Those methods were divided into 2 types of data sources, primary and secondary. Primary data source was used as the main information to explore the teachers and particular participants which were aimed to enrich in the details of what was going on during the implementation of ASIU. Primary data sources consisted of classroom observation and VDO recording, informal interview, Teacher Interview Protocol (TIP), focus group and documentary Data Gathering. Meanwhile secondary data source was sought to understand the situation and the context of the setting that reveal the holistic view of the study which was Nature of Science Questionnaire (NOSQ) and Atomic Structure Concept Test (ASCT). Each will be described their purposes of using, the development, administrations to the participants including process of the data collection.

2.1 Classroom Observation and VDO Recording

An inquiry into the real situation in classroom is a key research instrument to explore the usual contexts. The way teacher teaching reflects their view of nature of science. Classroom observation is considered to be an instrument which can portray the current situation about teaching and learning atomic structure integrating with the nature of science. In this study, observations were conducted in the classroom in the setting in which teaching and learning normally occurred. The process of observations moved from broad observations to specific ones. The broad observations were used for a general view of the classroom situation as a background of the study. Specific observations were used when it is necessary to focus on special or unexpected aspects. Field notes were used to collect the data during an observation. Field notes were separated into two columns. The right column was for writing what the researcher has observed. The left column was for observer's reflections such as comments or questions of the researcher about those situations. Field notes were used throughout classroom observations so that a wide range of data could be collected from a variety of situations. In addition videotapes and audio tapes were also used for reviewing.

Classroom observation was used in both two phases. In the first phase, the researcher observed during atomic structure lessons (May-June) in the first semester of academic year 2006. It's randomly observed for 3 hours per school. The total of observation in the first phase was 11 hours. For the second phase, there were 72 hours of three teachers' implementing to be observed. The researcher observed and made VDO recording in every class.

2.2 Informal Interview

The purpose of an informal interview is to get information about the effects of ASIU implementation on the teachers and students. It was informal because the questions asked were generated constantly. There were no predetermined questions been asked, in order to remain as open and adaptable as possible to the interviewee's nature and priorities .The purpose of the interview was to acquire the meaning, interpretation, opinion of the teachers and students while they participated in implementation ASIU. This interview also gave them a chance to reflect in and on what's happened in the classroom or why they did that way. Even they were not considered and planned in advance, the questions focused on what the teachers and students had done or were doing, what the teachers and students thought about their experiences, how the teachers and students felt, what they have learned from engaging in a particular activity and how they knew. Besides these, student's background or demographics was asked if necessary.

The teachers were interviewed informally during the meeting before ASIU implementation. The interview was not strict; it was subjected to the teachers' schedules. Normally, the conversations with participant teachers were conducted for 30 minutes before the ASIU implementation in each class. For the students, the researchers had the opportunities to talk to them during and after class. Furthermore, after ASIU implementation, the informal interviews with students conducted outside the class had to be permitted by the teachers with an appointment beforehand.

Students who were interviewed were chosen to investigate their interest and response to learning and teaching. After the interviews, the researcher noted the aspects that the audiotape recorder could not document, such as atmosphere, students' and teachers' behaviors during the interview.

2.3 Teacher Interview Protocol (TIP)

Teacher Interview Protocol was designed to explore the current situation in teaching and learning atomic structure integrating with nature of science from teachers' perspective. This interview could be categorized as formal interview because there were set of questions existed before conducting the interviews. According to the National Science Curriculum Standard (IPST, 2002) there are two sub-strands related to this study. The first is the strand 3: matters and properties of matters. This standard requires student to know and understand structure of an atom, constituents of an atom, and properties inside atoms that cause the macroscopic properties of elements and compounds. The second important standard is strand 8: nature of science and technology. This standard requires students to know and understand what science is and how it works via the scientific inquiry such as observations and experiments. There are some researches reported internationally that students usually held the misconceptions in both atomic structure and nature of science. Not surprisingly, teachers difficultly communicate those science contents and nature of science to their students even they know and understand nature of science (Abd-El-Khalick and Lederman, 2000a; 2000b). The interview in this study will probe teachers' teaching atomic structure and nature of science. The strategies and activities teachers reflect nature of science, were asked. The problems and difficulties were explored in order to use this information to design an instructional unit in phase II. Because there were many views on nature of science, the teachers were interviewed about their understanding nature of science. There were 5 steps to develop interview protocol. Each step was carefully followed because the qualities of the instrument rely heavily in the development: Step 1 set the appropriate level of structure, Step 2 write question, Step 3 order questions, Steps 4 write the scrip in an interview, Step 5 limit length of an interview.

The interviews were conducted in the first semester of academic year 2006. The process of data collecting began with sending the informed consent letter to the teacher. After the permission from the school principal, the appointments were made and notified each participant ahead of time to schedule an interview, explaining its main purpose and importance. After that, the researcher contacted each participant personally to schedule the interview at convenient time and confirmed the interview. The interviews were conducted via telephone. With the permission of the participants, there were audiotape the interview and take brief notes on a copy of the interview protocol. The average time for interviewing was 60 minutes.

2.4 Teacher Focus Group Discussion

During the three workshops set for the teachers to discuss about Atomic Structure Instructional Unit, the focus group discussion allowed the researcher to collect the data. The questions of focus group aimed to take into account teachers' response to modify the instructional unit. Teacher focus group discussion also was a part of data sources to develop atomic structure instructional unit integrated with the nature of science. There were no predominant questions but the discussion was about the activities in the instructional units, lesson plans, textbook, the student handbook and the research finding in phase I. Because the second and the third workshop were set after implemented lesson plan 1-6, the conversation among teachers and teacher-researcher were focused on the consequences of instructional unit implementations.

The data from teacher focus group discussion were collected from three workshops. The first workshop was on May 11, 2007, which was before the starting of the first semester of 2007 academic year. The second and the third workshop were on June 29, 2007 and September 28, 2007 respectively.

2.5 Documentary Data Gathering

Researcher-generated documents were used in all phases in order to enhance the trustworthiness of data from other primary sources. The aim of investigation was to explore teachers' and students' views and interpretations of the learning that occurred before and during the implementation of the instructional units. The documents were personal ones generated by students during the study. Teachers' recordings of student summative assessment were collected. Other data sources includ photocopies of student work, worksheets, and student journals. Photographs were taken during the learning and teaching and were used as a data source. When teacher or students were presenting to the whole class, documentary data producing during implementation sometimes was recorded as field notes when it was impossible to photocopy the originals, such as, blackboard notes, cardboard notes.

Data from students' and teachers' documents were collected concurrently with the implementation of ASIU. Personal documents generated by students during the study were copied from the teachers'. All of documentary data were permitted by the teachers before it was collected.

2.6 Nature of Science Questionnaire (NOSQ)

Before the development of the Nature Of Science Questionnaire (NOSQ), literature review was made to find out what is the most effective method to elicit student's concepts and understandings of nature of science. Nature of Science Questionnaire for this study was conducted in the form of open-ended question and adapted as Lederman *et al.* described (2002). Starting review relevant documents such as National science curriculum standard, reform curriculum and existing instruments, nature of science aspects were identified as the crucial characteristics and functions of science needed by the students at the 4^{th} grade level. The questions were constructed and sent to experts for validations. Questionnaire was tried out in paper form followed by students' interviewing. The data from both questionnaire and interview were analyzed using thematic approach. The data from interview were acquired to check against those from questionnaire as data sources triangulation. The procedure of the questionnaire was shown in Figure 3.2.

The Nature of Science questionnaire (NOSQ) was used three times in this study. The first data collected by NOSQ was conducted in the first semester of academic year 2006, after the students completed their atomic structure lesson. The aim of this data collection was to answer research question in phase I study. It's used to explore the students' understanding of the nature of science in current situation of the traditional instruction. The next two data collections were conducted during the first semester of academic year 2007 to the different group of students from academic year 2006. This time, NOSQ was used as an instrument to investigate the effectiveness of ASIU that influenced their learning and understanding of the nature of science.

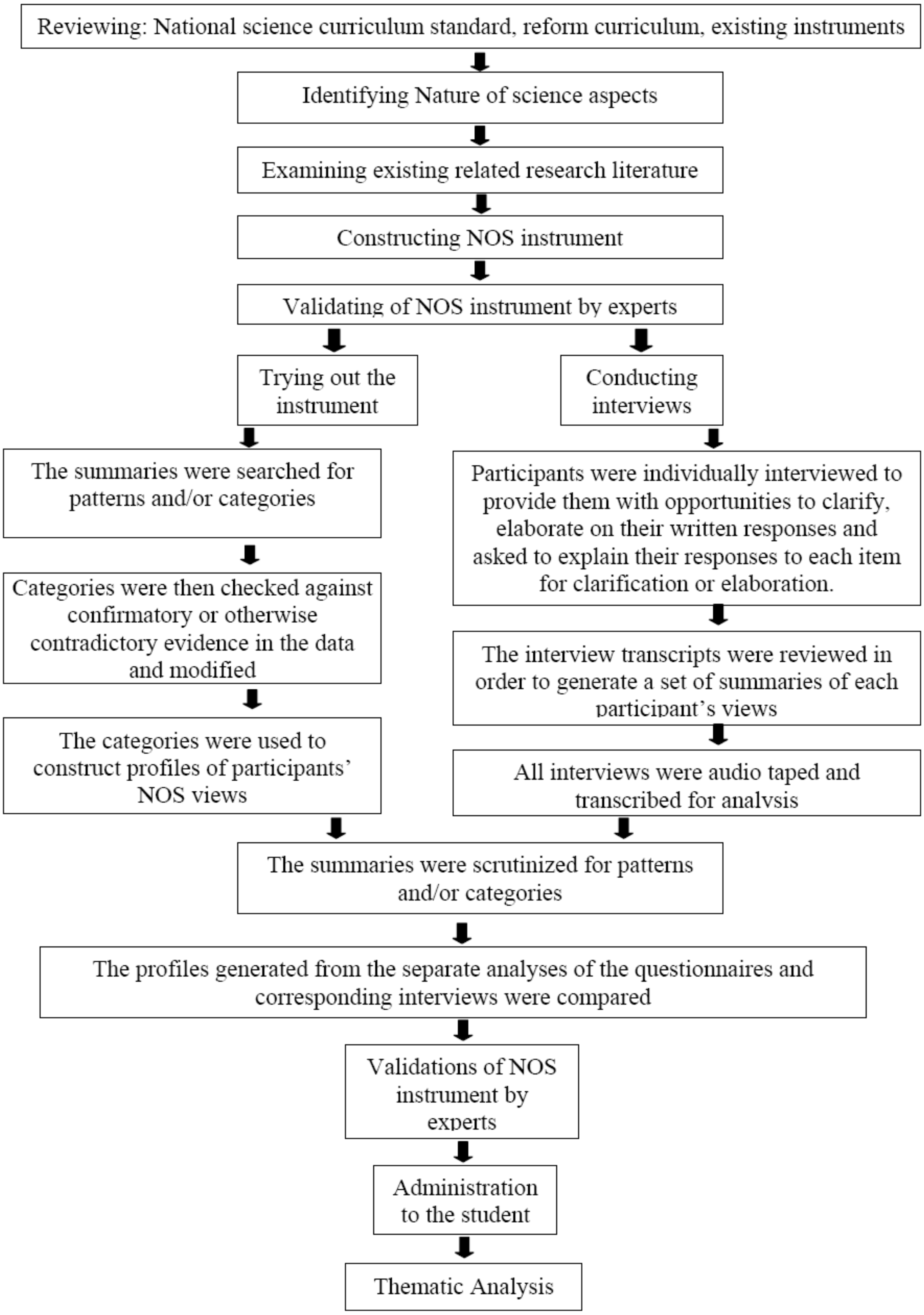


Figure 3.2 Flow chart illustrating the NOS-Instrument developing procedure

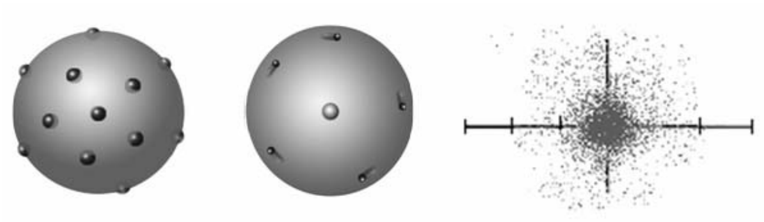
2.7 Atomic Structure Concept Test (ASCT)

Atomic Structure Concept Test was developed in the format of a two-tier diagnostic test for assessing students understanding of the atomic structure concepts which required by the National Science Curriculum Standard (IPST, 2002).The two-tier diagnostic test is a multiple-choice instrument. Each item of the ASCT was composed of the first tier which consists of a content question with two or three choices. The second part of each item is open-ended questions for the justification of answers to the first part. The example of item which is the item number 1 is shown below.

Instruction

For each of the following questions, choose the ***one best answer*** with ***one best reason*** to support your answer, and mark it on your answer sheet.

1. These are examples of atomic model presenting in the IPST Chemistry I textbook



(IPST Chemistry Textbook 1, 2002)

What is the significance of image or atomic model?

A. To support atomic theory
B. To explore the constituents of an atom
C. To study the smallest past of the matter
D. To explain macroscopic properties of matter and its change

How do those atom image and atomic model come?

A. By computer
B. By scientist's imagination
C. By inferences from experiment and observation
D. By seeing through powerful equipments such as electron microscope

The two-tier multiple choice diagnostic instrument on atomic structure concepts was developed in three phases using procedures defined by Treagust (1985, 1988) and Tan *et al*. (2002). The concept test was divided into 3 phases. The flowchart of instrument developing is presented in figure 3.3.

The first phase started with reviewing the related documents which were national science curriculum standard (IPST, 2002), the IPST chemistry textbooks and the IPST teacher handbook, after that the propositional knowledge statements were identified to define the content framework of grade 10 atomic structure with a concept map (figure 3.4). Three science educators and one scientist reviewed the concept map and a list of propositional knowledge statements to make an agreement that the concept map and the propositional knowledge statements were accurate and relevant to grade 10 atomic structure concepts.

The second phase involved the identification of a students' alternative concept of atomic structure. Students' alternative conceptions information was obtained from literature review. Some existing atomic structures and relevant concept tests were adopted and revised to fit for the propositional knowledge statements. The data collection from the first and second phases were contributed to the development of the first version of the two-tier multiple choice instrument, the Atomic Structure Concept Test (ASCT). Twenty four questions were analyzed item by item again to check whether each question matched the propositional knowledge statement or not. The first version of Atomic Structure Concept Test was checked and revised before trying out with 53 students of grade 10 who were similar to the students participated in this study both from academic year 2006 and 2007. After trying out with the students, SPSS version 14 and developed scripts run on Microsoft excel were used to analyze the result. The ASCT was corrected by the science educators, chemistry professor and the consultant in chemistry assessment who focused on developing instruments for student testing at a university level. Each item was considered to be correctly answered if a student correctly responded to both parts of the item. The final version of the ASCT consisting of seven key areas with different numbers of items in each area reflecting the emphases on the propositional knowledge needed to be understood by the students. The key area of concepts and items are identified in Table 3.3. The concepts of propositional knowledge statements of each item are shown in table 3.4.

The data collection via ASCT was conducted at the same time with NOSQ. The first time ASCT was administered to students after they finished an atomic structure lesson in the first semester of academic year 2006. The next academic year, ASCT was used again to collect the data from grade 10 students before and after they engaged the ASIU.

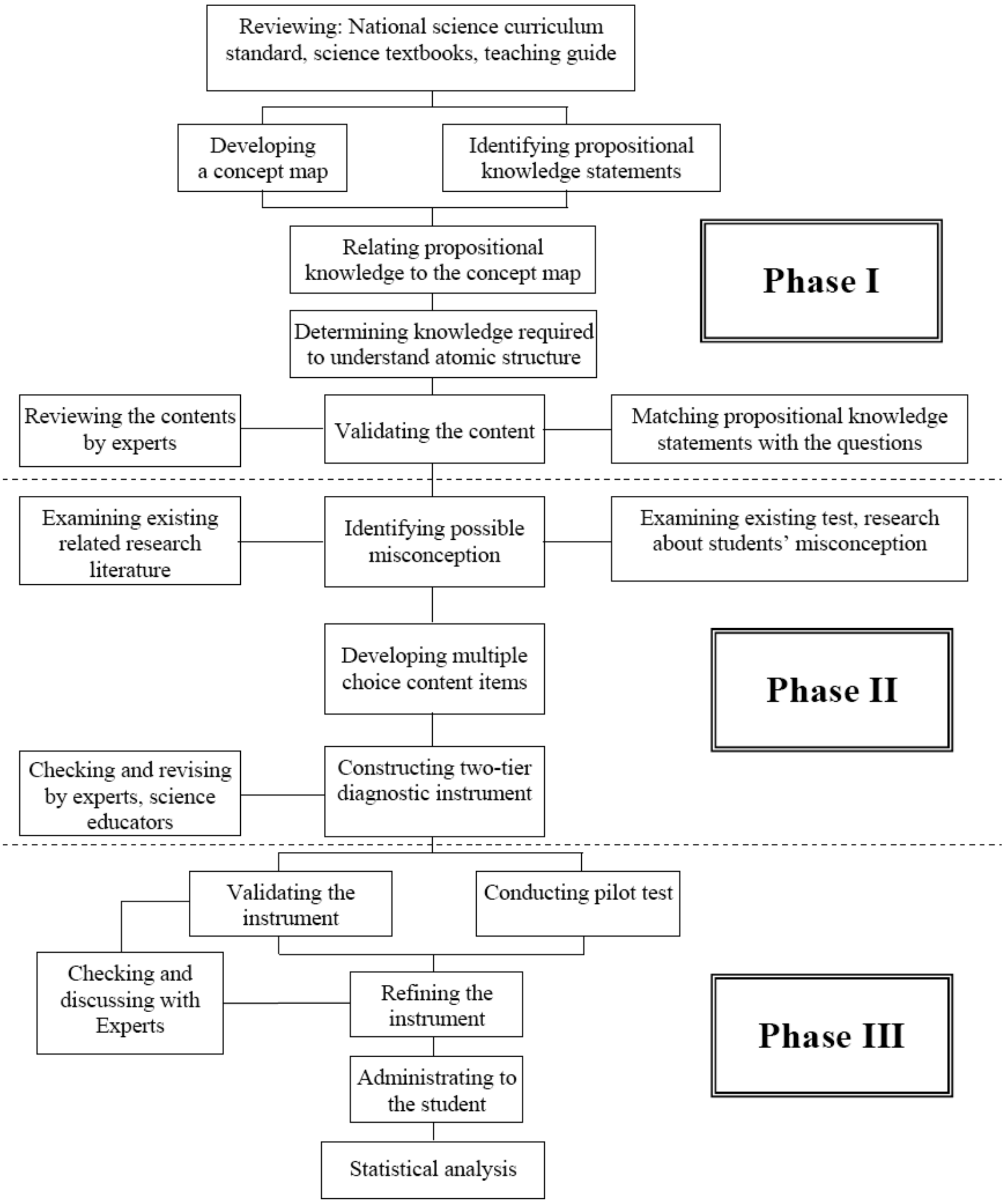


Figure 3.3 Flow chart illustrating the concept test developing procedure

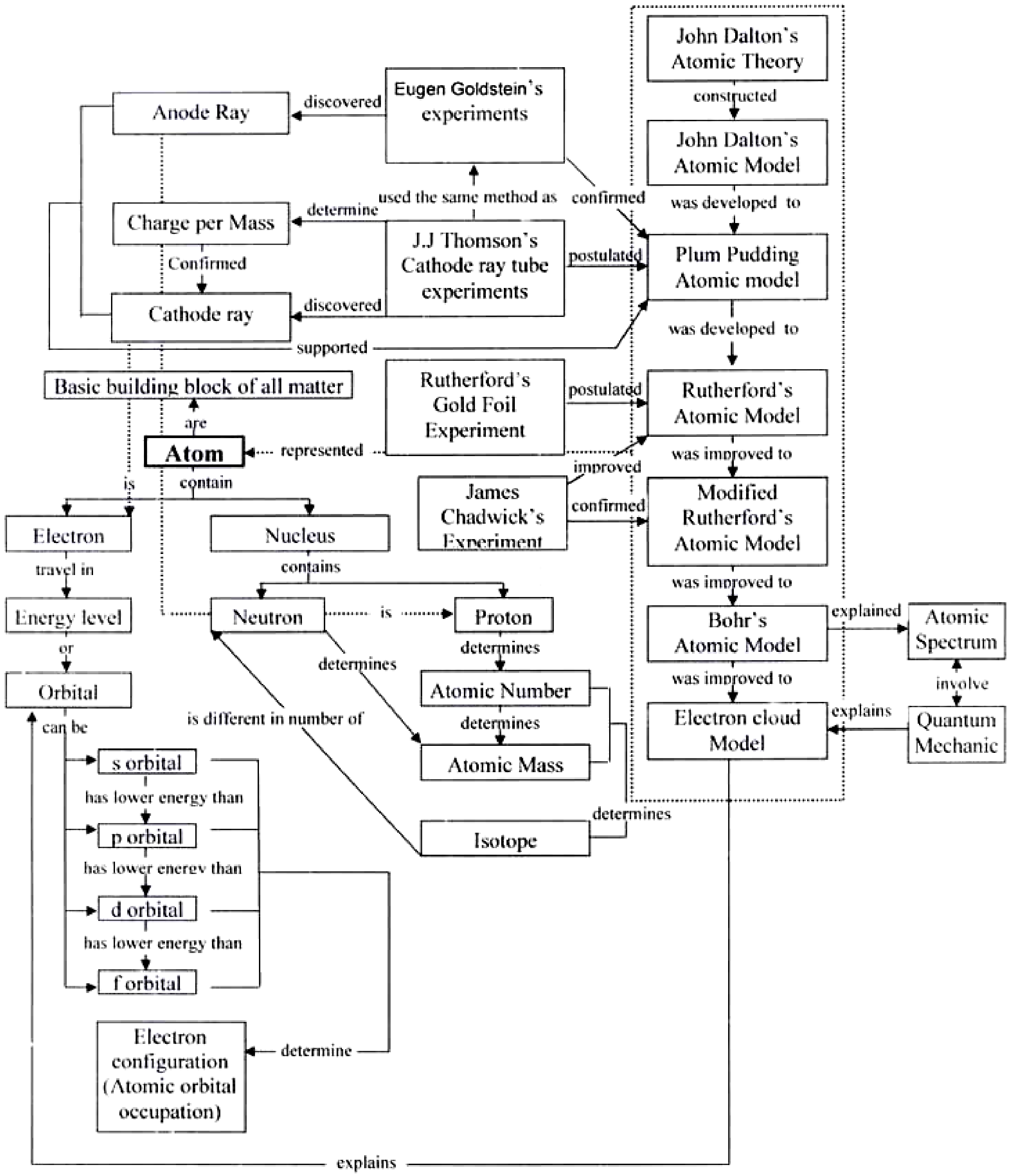


Figure 3.4 Concept mapping shows concepts in atomic structure topic

Table 3.3 Key areas of atomic structure concepts, number of items, and percentage on the ASCT.

Key Area	Number (items)	% Number of Item
Model and atomic theory	2 (1,2)	8.33
Dalton's atomic theory	1 (3)	4.17
Thomson's atomic model	3 (4,5,6)	12.50
Rutherford's atomic model	6 (7,8,9,10,11,12)	25.00
Bohr's atomic model	2 (13,14)	8.33
Electron cloud atomic model	2 (15,16)	8.33
Electron configuration in atom	8 (17,18,19,20,21,22,23,24)	33.33
Total	24	100

Table 3.4 Main atomic structure concepts of propositional knowledge statements in each item of ASCT

Item	Concept	Item	Concept
1	The role of model in atomic theory	13	Atomic spectrum
2	Characteristics of model	14	Bohr's atomic model
3	Dalton's atomic theory	15	The probability of electrons in an atom
4	The nature of cathode ray tube	16	Quantum mechanics model
5	Observation and inference of cathode ray experiments	17	Atomic orbitals
6	Thomson's atomic model	18	Energy level of an atom
7	Gold foil experiment	19	Sublevels in energy level
8	Constituents of an atom	20	The nature of atomic orbital
9	Atomic number	21	Aufbau principle
10	The relevance of atomic number and mass number	22	Pauli exclusion principle
11	Isotopes of an element	23	Hund's rule
12	Nuclear symbol	24	Valence electron

3. Data Analysis

3.1 Thematic Approach

Thematic analysis was used to analyze the data from audio-video transcripts from classroom observation, interviews, documentary data and Nature Of Science Questionnaire (NOSQ). Field notes and the audio-video tape transcribed from interviews and observation were coded and related to intellectual schemes or ideas of the thematic structures of the effectiveness of the ASIU in learning and teaching the atomic structure. These were captured from primary data sources which addressed teacher's teaching and students' learning the atomic structure and their reflection about atomic structure concept and the nature of science when implementing the ASIU. Documentary data was used in order to support the trustworthiness of data from classroom observations and informal interviews. Braun and Clarke (2006) provided steps for analyzing by thematic approach which was also modified and used by this study shown below.

1. Familiarizing with the data: Transcribing all electronic data to hard copy or electronic documents (Word processor), reading and re-reading the data, noting down initial ideas.

2. Generating initial codes: Coding interesting features of the data in a systematic fashion across the entire data set and collating data relevant to each code.

3. Searching for themes: Collating codes into potential themes and gathering all data relevant to each potential theme used as the evidences to support each theme.

4. Reviewing themes: Checking if the themes work in relation to the coded extracts and the entire data set and generating a thematic 'map' of the analysis.

5. Defining and naming themes: Ongoing analysis to refine the specific of each theme and the overall story of the findings and generating clear definitions and naming each theme.

6. Producing the report: Taking the final opportunity for analysis, selection of vivid, compelling extract examples. Final analysis of selected extracts, interpret each theme by relating back of the analysis to the research questions and literature producing and a scholarly report of the analysis.

3.2 Reflective View on Nature Of Science

VDO recordings from first phase observation were analyzed by an assessment rubric for science teaching evaluation instrument called Reflective View on Nature Of Science (RVNOS). This rubric was provided for analysis to find out how and to what extent the teachers use nature of science to teach. It integrated aspects of nature of science in this study with the strand 8: nature of science and technology in The National Science Curriculum Standard (IPST, 2002) and Science and Technology Teacher Standard (IPST, 2002).

Reflective View on Nature of Science (RVNOS) divided teachers' teaching into four levels. Each level was described in eight focusing aspects of the nature of science in this study. Table 3.5 portrays an example of RVNOS in the aspect of science relying on evidence. The full version of RVNOS is presented in appendix B.

Level 1 - deficient: A lack of activity to do science and no mention about the target aspects of the nature of science or misconceptions given.

Level 2 - implicit: Implicit teaching by only doing the nature of science and no address to the target aspects of the nature of science in their lesson.

Level 3 - didactic: Concentrating on teaching science content and making a simple didactic explanation of certain aspects of the nature of science.

Level 4 - explicit and reflective: Having students expose to reflective discussions on the nature of science and to assess students' understanding of the nature of science

Table 3.5 Reflective View on Nature Of Science (RVNOS)

More teacher orientation ⟷ More student orientation

Aspect of the Nature of Science	Deficient Level	Didactic Level	Implicit Level	Explicit and Reflective Level
Science relies on evidence: Scientific knowledge based on natural phenomena, evidence, data, information, and observation (Sc.8: Students should be able to use scientific process and scientific mind in investigation and in problem solving).	Lack of activities or mention on the concept that science needs evidence to support.	Explaining that the body of scientific knowledge which students have learnt must be based on evidence, prediction, and logic to the natural world.	Engaging students to record or collect the results and data and then use them from investigations to provide the evidence to support explanations and conclusions.	Encouraging students to discuss the importance of keeping records of observations and investigations that are accurate and understandable on a particular activity they are engaged.

3.3 Atomic Structure Concept Test

The criterion for the correct answer was that the student could choose both correct answer and reason. The descriptive statistics was used to analyze the data. The SPSS program was used together with the scripts developed by the researcher to run on Microsoft Excel. For analysis of students' understanding of atomic structure, the researcher used the percentage of the students who correctly answered both tiers of an item compared with that of the students who correctly answered only the first tier of an item. On scatter plot, students' conceptions were divided into three zones according to Conceptual line (Figure 3.5).

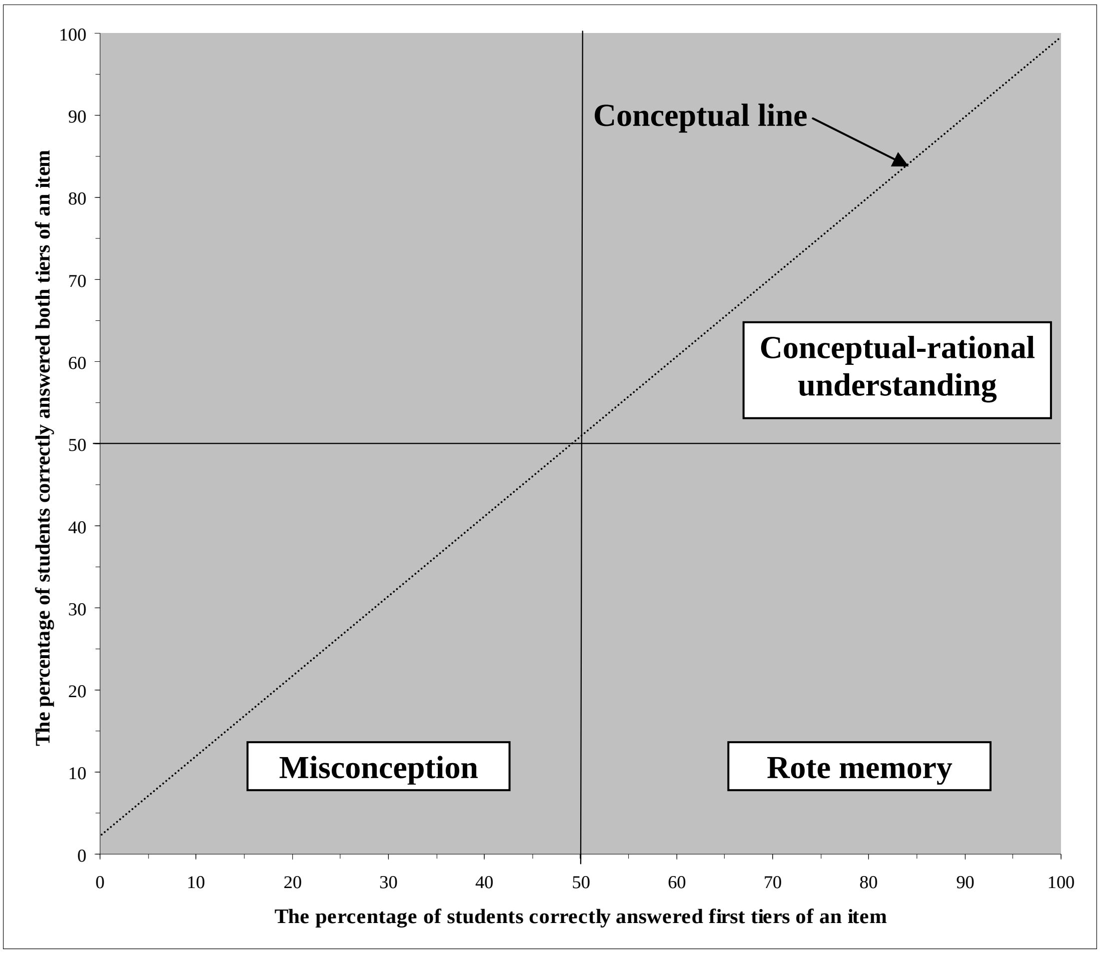


Figure 3.5 Graph for scatter plot shows the 3 zones of students' understanding of atomic structure concept test.

The three zones are:

1. Conceptual-rational understanding: students could give the correct answer, in the first tier. They also successfully match the correct reasons with the right answers. It indicated that they hold the conceptual understanding so their percentage of answering ASCT fell into this zone which was high in the first tier and both tiers.

2. Rote memory: students tended to remember the content about atomic number, without understanding the concept of the atomic number. They could obtain the right answers for the first tier, but had difficulty giving a correct reason in the second tier.

3. Misconception: students were not reflecting conceptual understanding even in the first tier. They could not give the correct answers. Therefore, the percentage of answering the ASCT fall into this zone which was low both in the first and both tiers.

4. Ensuring Trustworthy Data Collection and Data Analysis

As to be explained in the previous topics, the ways to establish the trustworthiness of the research data have to emphasize the process of data collection and data analysis. To ensure the quality of the research the following strategies were established. Summarized in Table 3.6, there are four criteria that the research needs to emphasize and explicitly report. In every data source, primary and secondary, there must be a process of ensuring the trustworthiness. The details were addressed as followed. During the process of data analysis, some research findings had been continually presented at the conferences. It allowed the researchers to discuss about them with impartial colleagues experienced in qualitative methods.

Table 3.6 Strategies for ensuring the trustworthiness of the study

Strategies for Assessing the Criteria	Particular Action Taken by Researcher
Credibility	- Triangulation of methods (observation, field note, interviews, documents, concept test and questionnaire) - Triangulation of the data sources (multi data sources were used in this research) - Prolonged engagement - Persistent observation - Member checking - Peer examination (Discussion of the research finding with impartial colleagues experienced in qualitative methods) - Reflexivity (the researcher assessed own biases and bracketed them) - Findings were presented at two international conferences for peer evaluation
Dependability	- Triangulation of data sources (primary and secondary data sources) - Independent coder assisted with categorization and coding - Peer examination
Transferability	- Thick descriptions of the research methodology, literature control and verbatim quotations taken from the narratives - Purposive selection of the samples
Confirmability	- Thick descriptions of the research methodology, literature control and verbatim quotations taken from the narratives - Purposive selection of the samples

4.1 Classroom Observation and VDO Recording

Before collecting data by observation, the researcher prolonged rapport with teachers for 1 semester. During that time, pilot observation and VDO recording were made to stabilize classrooms (the second semester of Academic year 2005). Pilot observation can reduce threats such as attitude of subject threats that participant tried to change their practices while they were observed (Fraenkel and Wallen, 2003). Persistent observations were also used to promote the credibility of the data.

4.2 Informal Interview

The data from informal interview was triangulated by the data acquired from observation and documentary data. The data from informal interview also triangulated between participants such as teacher-teacher, teacher-student and student-student. Furthermore, time triangulation was used. The conversation with teachers and students which were kept throughout the study made the data more credible. In the second and third workshop with the teachers, member checking was employed. The data from informal interview was presented and discussed.

4.3 Teacher Interview Protocol (TIP)

In case of TIP, the series of questions were constructed before the interviews. The interview protocol was sent to science educators to check whether those questions meet the purpose of interview or not. After revising the protocol, the pilot was conducted. The interview was separated into two individuals similar to target respondents. Each individual was told about the purpose of the pilot to be sure that the questions were easily understood and ordered sensibly. Each individual was asked to respond to each question as if he/she were in the evaluation and also to comment on the clarity of the questions. At the end of the interview, each individual was asked for feedback on the entire experience of taking the interview. Interview protocol was revised according to the respondents' feedback and researcher’s own experience of using the protocol and recording responses. The final interview protocol was approved from science educators before administering to three interviewees. The data from the TIP interviewing was triangulated with classroom observation. Interview transcribed was sent to the teachers for member checking.

4.4 Teacher Focus Group Discussion

The information shared in workshops and focus groups provided greater teachers' responses about the instructional units. In this activity, the researcher could show research findings to them and received participants' responses in turn. The quality of focus group interview was acquired by time triangulation because the workshop was held 3 times in the role - before during and after the instructional unit implementation. Furthermore, the conclusion of the former discussion was also the topic to address in focus group discussion. This member checking confirmed the interpretation of the research about the development of Atomic Structure Instructional Units. Reflexive view of researcher during the workshop also eliminated researcher's biases on teacher's responses on the units as well as how they used the lesson plan.

4.5 Documentary Data Gathering

There are four criteria for assessing the quality of the evidence available from documentary sources; authenticity, credibility, representativeness and meaning. The document met the first three criteria because it is the primary document taken from the teachers and students directly. All documents were constructed by the participants not by the researcher. For example, one teacher usually took a picture while her students were getting involved in hands-on activities. The pictures were asked to collect as an evidence of the teacher's interests. Some documents which were the student' works would be the evidence of how they were influenced when engaging in activities of ASIU. Meaning, the last criteria, was ensured by the presence of the researcher in the classroom that it could change and the use of words varied. Social contexts were understood by the researcher. It assured the clarity and comprehensibility of the document.

4.6 Nature of Science Questionnaire (NOSQ)

It was necessary that in the construction and development of nature of science questionnaire, the instruments be appropriate to get the correct data both in language and in format. Above all, the validity and reliability are the most important things for constructing the instruments. After constructing the questionnaire, trying out the instrument is crucial for ensuring the quality of the NOSQ. This topic aims to describe the method of trying out the nature of science questionnaire and the example of data analysis. The results of trying out are used for revising the nature of science questionnaire and also for testing the method of analyzing the data. The nature of science questionnaire tryout version was administered in the second semester of the academic year 2005. There were 8 students who completed this questionnaire. The steps of trying out were:

1. To complete the latest version of the nature of science questionnaire, it had to be revised by science educators, and then printed into hard copy.

2. To write the formal letter for permission to the school principal to collect the data. The letter was signed by the chairman of The Program to Prepare Research and Development Personnel for Science Education and by the Dean of the Faculty of Education respectively.

3. To make an appointment with the teachers about trying out the instrument.

4. To administer the nature of science questionnaire with 8 students of high, average and low academic achievement students. The time to complete the questionnaire was approximately 55 minutes.

5. To analyze the data, the researcher read the students' answers carefully and made summaries. The summaries were searched for patterns and/or categories. Categories were then checked against confirmatory or otherwise

contradictory evidence in the data and modified. After that, the categories were used to construct profiles of participants' nature of science views. The summaries were scrutinized for patterns and/or categories. The patterns emerging from the data represented the students' understandings of the nature of science.

6. To interview the students in the next week after administering the questionnaire. The students were asked for the answers to express their ideas about nature of science item by item.

7. To record the interviews and take note. The researcher asked the student about the questionnaire in terms of format, language, time and their understanding in what the question intended to ask

8. To transcribe the records verbatim before analyzing it in the same way as data from the questionnaire.

9. To support the data from Semi-structured interview or dispute the pattern of students' understanding about nature of science.

10. To conclude the result of trying out the nature of science questionnaire.

11. To revise the nature of science questionnaire before sending to science educators.

The results from trying out were:

1. The average time to complete NOSQ is 48 minutes. Mode of completing the questionnaire was 50. It was appropriate for finishing nature of science questionnaire.

2. After reading students' answer carefully, confirmatory or otherwise contradictory evidence was searched for the details and examples the students use were useful for interpreting their ideas.

3. The format of questionnaire was changed because it gave too much blank space for the answers. The students felt discourage to write. The questionnaire was changed into 2 set of items- the questions and the answer sheets. Students could answer as they wanted and they need not necessary to answer in order of the items.

4. The bold print was used to emphasize the question because it's too long

4.7 The Atomic Structure Concept Test (ASCT)

The development of ASCT concerned much on the quality. Several techniques to establish the trustworthiness were used in each phase of the procedure. Those strategies were addressed as follows:

1. In every phase of ASCT construction, the test was checked, discussed, revised and reviewed by experts (3 science educators, 2 science professor and a consultant in chemistry assessment)

2. All of the 24 items had to be checked and revised in both questions and responses to make sure whether the students answered the questions correctly or wrongly because of their understandings not because of the problematic items. The problematic items are also called "bad" or "misfitting" ones. To eliminate or avoid the problematic items, constructing of the test had to be aware that: (1) Some items might be poorly written and they could cause students to be confused when responding to them. (2) Graphs, pictures, diagrams or other information accompanying the items might be unclearly depicted or might actually be misleading. (3) Some items might not have a clear correct response, and a distractor could be potentially qualified as the correct answer. (4) Some items containing distractors that most students could see

easily, were obviously wrong. They could increase the odds of students to guess the correct answer. (5) Some items might represent a different content area than that measured by the rest of the test (also known as multidimensionality). (6) Bias for or against a gender, ethics or other sub-group might be present in the item or the distractors. In the overall validating, the Atomic Structure Concept Test was revised corresponding the suggestions and commendations from chemistry professor and the consultant in terms of unclear items, languages and grammars , ambiguous questions, options and reasons, pictures, symbols or diagrams and time to complete the ASCT.

3. After completing the Atomic Structure Concept Test, 6 students were conveniently selected for the interview. They were asked about time, test patterns, font, languages, number of items and contents.

The student spent 50-60 minutes completing. The average was 55 minutes. All of the students were satisfied with the patterns and formats of the test. The font was appropriate to read. One student commented that the reasons in some items were too long. She suggested that the test should state briefer sentences. The students thought that the concept test cover more than content being taught in grade 10. Five students thought that 24 items were appropriate and one students wanted more items and expanding time to do the test. The entire student considered that the test was difficult in a whole picture. The most difficult problems were items number 22 and 23. The difficulty in the test was caused by the term Pauli Exclusion Principal and Hund’s rule. Despite clear statement in IPST textbook, those terms were not familiar to the students. They thought that those two concepts were taught in higher grades.

Summary of the Chapter

Interpretive research was used as a methodological framework of this study. Its paradigm viewed the world with the meaning that people consciously or unconsciously constructed into concepts, language, knowledge, and so on. To understand those constructions, researchers must interpret the meanings of them. The best and the most common methods to collect those data qualitatively were observation and interview in the real settings. Other methods were also used to ensure the trustworthiness of the research. Secondary data sources portrayed the context surrounding the participants. Both primary and secondary data sources were discussed throughout the process. One reason was to explain the research method while the other was to keep thick description and ensure the quality of the research.

CHAPTER IV

THE DEVELOPMENT AND IMPLEMENTATION OF ATOMIC STRUCTURE INSTRUCTIONAL UNIT

The Atomic Structure Instructional Unit (ASIU) was developed in order to give students an opportunity to engage in the model and modeling activities, with the integration of the nature of science in learning atomic structure concepts. The ASIU was designed under the guiding of important curriculum document together with the international accepted curriculum from review literature that aimed to promote the sufficient and efficient science literacy. It enabled people to live in the present and future society which much rely on science, technology, information and competition. Every classroom has its own context and culture so the design and development of the ASIU was regarded according to the unique characteristics of each school. The study in phase I and II were conducted to take into account of the school context including current situation, teachers' perception of the problems in teaching and learning atomic structure and the nature of science. This chapter also explains how the ASIU was modified according to the teachers' response as well as describes the characteristics of the ASIU itself, both in the developing and in the final versions.

The Design of ASIU

To design the ASIU, the essential features of curriculum design were considered. The first key element to be regarded was the curriculum starting from the National Education Act, followed by the National Science Curriculum Standard that meets the content area of this study. The general accepted chemistry textbooks and teachers' handbooks from the Institute for the Promotion of Teaching Science and Technology (IPST) which were used across the country were discussed as the guidance. The result from phase I was presented here to explain why the ASIU was constructed as it was.

1. Curriculum Document

1.1 The Thai National Education Act

This instructional unit was conducted with an aim to promote student's understanding of the atomic structure and the nature of science in the theoretical framework of constructivism. In section 22 of The Thai National Education Act B.E. 2542, it is stated that education shall be based on the principle that all learners are capable of learning and self-development, and they are regarded as the most important. The teaching-learning process shall aim at enabling the learners to develop themselves at their own pace and to the best of their potential. Even it isn't stated directly that two of the main features of the constructivist theory of learning are very similar to what is stated in the previous statement (Bright, 2006). It is essential that learning should be student-centered and that "students learn best the concepts that are in their zone of proximal development" (Slavin, 2006) therefore students must be allowed to proceed at their own pace to reach their full potential. The zone of proximal development refers to the notion that students are able to accomplish certain tasks with the aid of a guiding instructor or their higher achiever friends if they could not normally do on their own.

Constructivist theory is a view of learning based on the belief that knowledge is not a thing that can be simply given by the teacher lecturing at the front of the room to students in their desks. Rather, knowledge is constructed by learners through an active, mental process of development; learners are the builders and creators of meaning and knowledge. Constructivism draws on the developmental work of Piaget (1977) and Kelly (1991). Fosnot (1989) defines constructivism by reference to four principles: learning, in an important way, depends on what we already know; new ideas occur as we adapt and change our old ideas; learning involves inventing ideas rather than mechanically accumulating facts; meaningful learning occurs through rethinking old ideas and coming to new conclusions which conflict with the old one. A productive constructivist classroom consists of learner-centered and active instruction. In such a classroom, the teacher provides students with experiences that allow them to hypothesize, predict, manipulate objects, pose questions, do research, investigate, imagine, and invent. The teacher's role is to facilitate this process. The design and development of the ASIU were underpinned with constructivism in a holistic view. Every activity in the ASIU will establish the essential features of constructivist classroom which is shown in Table 4.1.

Table 4.1 The essential features of constructivist classroom

Essential Features of Constructivist Theory	**Into the Practicing**
Knowledge is actively constructed by learner.	Students are encouraged to do activities actively and physically in the classroom
Knowledge is best constructed through authentic learning.	Linking classroom learning experiences to the real world situations
Knowledge is best constructed when a new concept is linked to a number of different concepts learner learned, learning or will learn in the future.	Students are able to express their existing knowledge in the classroom before, during and after being engaged in the activity. The knowledge that will be taught is related both to subject matter and to interdisciplinary, even in real life knowledge.
There are multiple sources of knowledge.	Use multiple sources of knowledge besides textbooks such as articles, news or VDO.

Source: Office of Commercial Services Queensland University of Technology (2002)

1.2 National Science Curriculum Standard

When considering the 2002 National Science Curriculum Standard, developed by the IPST, in light of connecting with chemistry content areas, the learning standard of atomic structure content appears in strand 3: Matter and Properties of Matter. It is the strand 3.1 that involved with the atomic structure concept for teaching chemistry in Level 4 which includes Grade 10-12. In the first, sub-Strand 3.1, it is explained that student should: understanding matter, its quality and relationship with structure, skill in searching for knowledge procedure, and possess science consciousness, communicating acquired knowledge and application of knowledge.

Table 4.2 Learning outcomes and learning substances of atomic structure

Learning Outcome	Learning Substance
1. Investigate, discuss, and explain atomic structure, types, and number of constituents of an atom from its nuclear symbol.	1. An investigation and discussion about atomic structure, types and number of constituents of an atom using atomic model
2. Analyze and compare electron configuration in energy levels of an atom.	2. An analysis and comparison of electron configuration of an atom.
3. Explain the relation between outer electron energy level with properties of element and chemical reaction.	3. An investigation about the relation between electron and properties of elements and chemical reactions.
4. Verify and analyze properties of compound and atomic number of elements.	4. A verification of properties of compound
	5. An explanation about atomic number of elements, the rearrangement of elements in periodic table and predict the trend prediction of the properties of elements in periodic table.

Another standard that ASIU was based on was the Sub-Strand 8 which is determined thatstudents who completed the Level 4 (Grade 10-12) should learn. The standard about nature of science and technology was considered as the learning outcomes of the ASIU.

> **Sub-standard 8:** Nature of science and technology: The student should be able to use scientific process and scientific mind in investigation, to solve the problem. They should know that the most natural phenomena have definite patterns explainable and verifiable within the limitation of data and instrumentation during the period of investigation, and understand that science, technology and environment are interrelated.

Level Standards Grade 10-12

1. Pose questions based on knowledge and understanding of science or personal interest or issues arising which are subjectable to investigation or experimentation in a comprehensive way and with a great confidence.

2. Set up the hypothesis which is supported by theory or which predicts findings or set up model or schemes for investigation.

3. Carry out research and collect data which involve important variables and factors; that is factors that affect the other ones, factors that cannot be controlled and number of replicates, to achieve sufficient reliability and significance.

4. Choose materials, techniques, apparatuses for investigation, observation and measurement for the breadth and depth, both qualitatively and quantitatively.

5. Collect data and record results from investigation systematically, correctly and comprehensively both in qualitative and quantitative terms, while checking for probability, appropriateness or defects in data.

6. Treat data by considering numerical reports with high significance and present data in the proper way.

7. Analyze and interpret data and then evaluate correlation with conclusion or essential issues to check the proposed hypothesis.

8. Make models or pattern representations or mathematical models or point out trends of data gathered from investigation.

9. Scrutinize reliability of methods and result from investigation based on errors in principles, measurement and observation and propose improvements on method of investigation.

10. Bring methods and new knowledge from investigation to bear on new questions to solve new problems in new situations in real life.

11. Realize the importance of shared responsibility in explaining, expressing opinions and concluding for the scientifically correct presentation to the public.

12. Record and explain with reason the results from investigation using referenced and researched evidence to obtain reliable support and readily concede it. The knowledge is subjected to change when new data and additional evidence crop up to challenge or oppose old views giving rise to the need of careful checking and perhaps to accept new knowledge.

13. Prepare presentations, write reports and/or explain concepts, processes and results from the project or work to others.

1.3 IPST Chemistry Textbook and Teacher Handbook

According to IPST Chemistry Textbook (IPST, 2003a), its substances consist of 6 sub-topic namely, Dalton’s atomic model, Thomson’s atomic model, Rutherford’s atomic model, Bohr’s atomic model, electron cloud atomic model and electron configuration in atom. The statements identifying propositional knowledge for the students to know and understand are based on chemistry teacher handbook (IPST, 2003b). The knowledge required students to understand atomic structure is related as a continuous series. The knowledge required for students to learn are presented in statement as follows.

1. Atom is the smallest part of a substance which cannot be seen by eyes. Atoms can be studied by modeling or creating models.

2. Models are constructed from experiment data and can be changed according with new evidence from the latest experiments.

3. Dalton's Atomic Theory proposed that elements are made of tiny particles called atoms which cannot be created, divided into smaller particles, or destroyed in the chemical process.

4. The study of electricity conduction of gas in vacuum tube lead to the discovery of Cathode ray.

5. From cathode ray experiment, it is found that constituents of an atom have negative charge particle called electron and positive charge particle called proton.

6. Thomson’s atomic model suggested a model of the atom as a sphere of positive matter in which electrons are positioned by electrostatic forces. In the neutral state, atom has both positive and negative charge equally.

7. Rutherford’s atomic model described the atom as a tiny, dense, positively charged core called a nucleus, in which nearly all the mass is concentrated, around which the light, negative constituents, called electrons, circulate at some distance, much like planets revolving around the Sun.

8. Scientists later found the non-charge particle in the nucleus of an atom called neutron. They inferred that there are three important constituents of an atom: electron, proton and neutron.

9. The atomic number is the number of protons found in the nucleus of an atom.

10. The mass number, also called atomic mass number, is the number of protons plus the number of neutrons in an atomic nucleus.

11. Isotopes are forms of an element; therefore their nuclei have the same atomic number, the number of protons in the nucleus, but different mass numbers because they contain different numbers of neutrons.

12. The nuclear symbol consists of three parts: the symbol of the element, the atomic number of the element and the mass number of the specific isotope.

13. The studies of spectrum of elements lead to the understanding of energy level of electron in an atom.

14. In the Bohr Model, from the experiment of element spectrum, the neutrons and protons occupy a dense central region called the nucleus, and the electrons orbit the nucleus much like planets orbiting the Sun (but the orbits are not confined to a plane as is approximately true in the Solar System).

15. In an acceptable concept of the atom now, there is an appeared electron cloud model - an electron "cloud" which surrounds a nucleus. The cloud consists of a probability distribution map which determines the most probable location of an electron. The cloud is more dense where the probability of finding electron is high. The cloud is less dense where the probability is low.

16. One step further of atomic model study is to use the new quantum theory to write and solve a mathematical equation describing the location and energy of an electron in an atom. The proton and neutron are in the nucleus of an atom while the electrons are traveling around the nucleus that may differ in size, shape, or orientation in space.

17. Within each principal energy level, the electrons occupy energy sublevel: s, p, d and f.

18. The principal energy levels may be divided into different number of sublevels.

19. Sublevels in the same principle energy level have different energy level

20. Each sublevel has a different number of orbital which is a space that can be occupied by up to two electrons. (s sublevels have one orbital, which can hold up to two electrons. p sublevels have three orbitals, each of which can hold 2 electrons, for a total of 6. d sublevels have 5 orbitals, for a possible total of 10 electrons. f sublevels, with 7 orbitals, can hold up to 14 electrons).

21. The electron configuration of an atom describes the orbitals occupied by electrons on the atom. The basis of this prediction is a rule known as the Aufbau principle, which assumes that electrons are added to an atom, one at a time, starting with the lowest energy orbital.

22. The next principle of electron configuration is Pauli Exclusion Principle which stated that to occupy that same orbital, two electrons must have opposite spins.

23. According to Hund's rule, when electrons occupy orbitals of equal energy, one electron enter each orbital until all of the orbitals contain one electron with parallel spins. The full arrangement of electrons in orbitals is more stable than half-filled. Both of full filled and half filled are more stable than the other electron arrangements in orbitals.

24. Electrons in the outermost energy level of an atom related to the element's chemical reactivity, is called valence electron.

2. Results from Phase I

As mention at introductory of this chapter that every single classroom has its own culture of learning. The communities of students who share their experiences together are affected by the context of their classroom provided by the teachers and the ongoing situations. The study of classroom context is necessary for designing and developing the instructional unit. This topic is about to present the summary of the analysis of teaching and learning atomic structure in the real context from the first phase of this study which was used to develop ASIU. The study focused on teachers' understanding and teaching of nature of science in atomic structure concepts as well as how they perceived of the problem of teaching and learning such concept. The data obtained from interviews and classroom observation. After that the discussion of students' understanding of atomic structure and nature of science is presented.

2.1 Teachers' Understandings and practices of the Nature of Science

The results from phase I showed that the teacher had an informed understanding of nature of science in several tenets. Aspects of the nature of science that the teachers understood most were the scientific world view (Table 4.3). All teachers' understanding of what science is, were categorized into informed understanding. Teachers were able to explain that science is the study of natural phenomena. They also pointed that science heavily relies on evidences. For the next aspects, the teachers understood that scientific knowledge is subject to change when scientists get new evidences or new experiments. The aspect that teachers had misconception was the scientific law and theory. The teachers thought law is more certain than theory and higher in order than theory. Considering teachers' practices, none of teachers' teaching was categorized into explicit and reflective. For the nature of science in the aspect about how to acquire the knowledge, the teachers had a variety of understanding category. All teachers had an alternative understanding of method to do science. In teachers' views, there was the only one method to inquire scientific knowledge called 'scientific method'. There is no other method as Chonlada (a pseudonym) said "If it isn't scientific method, what else? I can't see any other method".

Table 4.3 Categories of teachers' understanding and practices of nature of science in the aspect of scientific worldview.

Nature of Science Aspects		**Teacher's Understanding Category (Teacher's Practices Category)**		
		Arunee	**Banburi**	**Chonlada**
Scientific worldview	What science is	Informed (Deficient)		
	Science relies on evidences	Informed		
		(Deficient)	(Didactic)	(Implicit)
	Science is tentative	Informed (Didactic)		
	Theory & law	Alternative (Deficient)		

It is not surprising when look at teaching category, all teachers' teaching about method to do science fell into deficient category. This means that all teachers taught science strictly. The laboratory was conventional and relied on experiment guiding step by step. About the observation and inference in scientific inquiry (Table 4.4), teachers' understandings were various. There were informed, ambiguous and alternative understanding. The teaching of observation and inference also varied. Two teachers taught this aspect as implicit by letting the students do the experiment with both observation and inference, but the teachers didn't point out these characteristics of scientific inquiry. The students missed an opportunity to discuss about the usefulness of observation and inference, as well as the differences between them. Even the lesson was so much available to do so. The aspect that teachers understood most was the imagination and creativity in scientific inquiry. The teachers could show that scientists used both imagination and creativity in their work. The teachers talked about this aspect in the classroom when the contents related to scientists' work. Their teaching was categorized into didactic teaching.

Table 4.4 Category of teachers' understanding and practices of nature of science in the aspect of scientific inquiry

Nature of Science Aspects		**Teacher's Understanding Category (Teacher's Practices Category)**		
		Arunee	**Banburi**	**Chonlada**
Scientific inquiry	Universal scientific method	Alternative (Deficient)		
	Inference & observation	Informed (Implicit)	Ambiguous (Deficient)	Alternative (Implicit)
	Imagination & creativity	Informed (Didactic)		

The nature of science that teachers predominately neglected in the classroom was the scientific enterprise including science interacting with culture and society (Table 4.5). To consider science as a human activity that has the facets of sociology and psychology was not concerned by teachers. They had an informed understanding in the topic of 'subjectivity in science'. But there was a variation in understanding of the aspects of the interrelation of science, society, and culture. The teachers didn't teach science as the human enterprise. The notion that science is universal and independent from social and cultural influences was also held by the teachers.

Table 4.5 Category of teachers' understanding and practices of nature of science in the aspect of scientific enterprise

Nature of Science Aspects		Teacher's Understanding Category (Teacher's Practices Category)		
		Arunee	**Banburi**	**Chonlada**
Scientific enterprise	subjectivity in science		Informed (Deficient)	
	science, society and culture	Alternative	Informed (Deficient)	Ambiguous

From the research finding of teachers' understanding and practicing of the nature of science, the teachers need to develop their understanding of nature of science as well as valuing their teaching nature of science. To observe the classroom, it was found that teachers rarely reflected the nature of science in their classrooms, even in the areas they understood well.

The result of teachers' understanding and practicing the nature of science shaped the ASIU and workshops. Every lesson had to integrate nature of science explicitly. Students must have opportunities to discuss about scientific experiences they are engaged in terms of content and the target aspect of the nature of science. For the teachers, the workshops would address the important aspect of nature of science, especially scientific inquiry and scientific enterprise.

2.2 The Teachers' Perception of the Problems of Teaching Atomic Structure with the Integration of the Nature of Science

In this section, teachers were interviewed how they taught nature of science in atomic structure lesson. The questions were about what teaching method they used and how they reflected nature of science in their teaching. The teachers were also asked to give examples of activity that they used including the evaluation to show how those activities were effective.

In overview, the problems about teaching and learning atomic structure from teachers' perceptions were because of the abstract concepts, students' memorization without understanding. There was a lack of experimental equipments, materials and understandable models. Students' skill to draw upon imagination was limited. Students studied science concepts, without understanding fundamental ideas.
The teachers pointed out that the most difficult topics were Thomson's cathode ray tube experiment and his atomic model, Rutherford experiment, the calculation about light and energy related to atomic spectrum, electron cloud model and orbital, .

Arunee (a pseudonym) explained her teaching and let students conclude the lessons logically. She said that when her students made a conclusion, she would ask them how that knowledge came. In her perception, rational study makes students understand more science. Banburi (a pseudonym) and Chonlada both addressed experiment as the basis of teaching nature of science. Chonlada usually taught science by explanation and examples. She also preferred experiment as teaching method. In her perception, this way of teaching was acceptable to science because science is a fact, she said.

The next question was about the reflection of nature of science in a classroom. Arunee said that scientific knowledge was obtained from study and inquiry in very specific details, collecting the data and making a rational conclusion without subjectivity, environmental effect or thought and belief of others. While Banburi pointed that studying atomic structure uses imagination and reason. Chonlada selected history of science to reflect nature of science. Furthermore, the change of theory over the time also reflected nature of science in her view. About activity they used in a lesson, Arunee used experiment as an activity for the student to experience. She gave an example as experiment of a spectrum, flame test experiment, which student could learn about a line spectrum of various atoms from different compound. Banburi assigned her students to search the information from Internet and discussed together in a classroom. Similar to Chonlada, she used questioning and discussion as the main activity in an atomic structure classroom. The assessment teachers used to evaluate a lesson were different. Arunee used observation questioning and test. Banburi used students' experiment meanwhile Chonlada used questioning, students' work and test.

For the problems in teaching and learning atomic structure and the nature of science as presented in Table 4.6, all teachers commented that the nature of atomic structure content is abstract. Arunee suggested that it is better to use materials such as video or the real equipment. In her classroom, the real cathode ray tube made easier for students to understand Thomson's experiment. Whereas Banburi assigned her students to search for information or knowledge before they went to class. Chonlada was different. She said she didn't have special techniques or methods. She gave lectures about atomic theory and discussed with her students. She said she didn't have equipment to do experiment. The teachers also talked about the topic that was difficult to learn. The teacher from school 1 thought that the calculation about light and energy was difficult. It involved the calculation interchange from wavelength and energy. The students had to have mathematics skills such as unit conversion. Besides these, the electron cloud model and atomic orbital were difficult as well. Banburi said that the experiment of Thomson and Rutherford were difficult for students to learn. The students couldn't link the experiment to atomic model. Both perceptions of Arunee and Banburi about the difficult topics were similar to those of Chonlada. She thought the experiment of Thomson, the atomic spectrum and electron cloud model were problematic topics for students to learn and understand.

When asked about the causes of students' misconceptions, Arunee drew many causes. Firstly, she suggested that students' skill to draw upon imagination to study atomic structure was limited. The consequence of that limiting forced students to memorize without understanding, and later, it changed to the misconception. Particularly, the study of electron could be modelled. Students learned this model but didn't understand the theory and its origin. It easily led to misconception. Additionally, the lack of teaching materials or understandable models was the cause of misconception because students study the unseen. Banburi and Chonlada had the same view. Banburi thought that only memorizing without experiment made students have misconceptions. Chonlada thought that students studied the unseen that she and students didn't know whether it was true or false. It was the cause the misconception. In her idea, studying with justification made more understanding.

Table 4.6 Teachers' perception of problems of teaching and learning atomic structure and nature of science

Problems in Teaching the Nature of Science and Atomic Structure	**Arunee**	**Banburi**	**Chonlada**
Techniques to teach abstract	Materials such as VDO, the real cathode ray tube	Searching for the knowledge before going to class.	- No special methods - Let the student search for the theory - Discussion - No experimental equipment
Difficult topics to learn	- The calculation about light and energy - Electron cloud model - Atomic orbital	- Thomson's atomic model - Rutherford's experiment	- Cathode ray tube - Atomic spectrum - Electron cloud model

Table 4.6 (Continued)

Problems in Teaching the Nature of Science and Atomic Structure	**Arunee**	**Banburi**	**Chonlada**
Causes of misconception	- Studying atomic structure need imagination but students' skill to draw upon imagination is limited. - Memorizing without understanding, and later, it may change to the misconception. - Studying science concept without understanding the basis such as study electron cloud model which students didn't know its origin of theory. - Lack of materials or understandable model.	Only memorizing without experiment.	Studying the unseen that we don't know whether it is true or false

Table 4.7 Teachers' expectations to solve the difficulty and problem in teaching and learning atomic structure

Teachers' Expectations	Arunee	Banburi	Chonlada
Other things to teach	How to inquire scientific knowledge and use science to solve everyday life problems.	Skill of mental modelling	Just only concept and nothing beyond.
Leaning Supplements	The curriculum materials that help students see the unseen. Some materials, like model that can reflect the theory. Some materials that students can study by themselves, IT, games or programmed instructions.	Making everything easy for the students to learn.	Animation because it represents theory and makes more understanding.

The next question is about teachers' expectation of their teaching. In atomic structure concepts, Arunee would like to teach students not only scientific content but how to inquire knowledge and use science to solve everyday life problems. In the same question, Banburi said that she wanted students to develop skill of mental modelling. Contrast to Chonlada, she thought teaching just only science content was enough. She didn't want to teach more than the concepts. Atomic structure was the fundamental concept for further study, as she said:

> ..Frankly, in this concept, I teach for basis. I don't want to teach in-depth. I don't know…I just teach what it is. Some teachers let students construct atom..into sublevel. I see but I don't do like that. I don't like it. Making into a level. Is it right? Did you see? They let students make models of an atom. ….I think this concept should be taught as the fundamental concepts for further study. I will not teach more than this.
>
> (Phase I Interview, Chonlada)

In the last conclusion of interviewing, three teachers were asked what teaching and learning supplements or materials they needed to enhance their practices or students' learning. Arunee said that she wanted the curriculum materials that help student see the unseen. She gave an example as model that can reflect the theory or materials that students could study by themselves. There are information technologies, games or programmed instructions. Banburi gave a broad answer. In her view, she preferred everything that was easy for her students to learn. "Make it easy" she said. Chonlada had a specific answer. She recommended using animations as a teaching material. She once had the experience from workshop about animation. She was very impressed. "It will work in atomic structure lesson" she said as last.

Research findings from teachers' interviews gave information to design and develop the ASIU. Problems of teaching and learning, including teachers' expectation were addressed for designing activity. The specific contents that teachers' pointed needed to change from memorizing theory into activity-based knowledge generating. Model-based approach was the proper framework in this case. Teaching method using model-based approach provided teachers and students with hands-on activities, VDO, animation and understandable models. The problems of studying the unseen were also based on model. The designing of the ASIU started with modelling activity to solve the problems. Questioning and discussion were used because teachers were familiar with this method but the questions were designed to promote rational thinking and understanding rather than memorizing. Discussion would draw from activity to meet nature of science embedded in lesson.

2.3 Students' Understanding of Atomic Structure

From the Atomic Structure Concept Test (ASCT) data analysis, percentages of students who correctly answered the first and both tiers of the ASCT were presented in Table 4.8.

Table 4.8 Percentage of grade 10 students who correctly answered only the first tier compared with those who correctly answered both tiers.

Item	Percentage of Students Correctly Answering		Item	Percentage of Students Correctly Answering	
	First Tier	Both Tiers		First Tier	Both Tiers
1	8.03	5.11	13	69.34	46.72
2	78.10	48.18	14	51.09	45.99
3	60.58	32.12	15	38.69	25.55
4	84.67	66.42	16	70.07	37.23
5	62.77	22.63	17	63.50	52.55
6	80.29	74.45	18	5.84	0.00
7	48.91	44.53	19	37.96	29.93
8	83.21	67.88	20	83.21	79.56
9	56.93	2.19	21	82.48	21.17
10	92.70	85.40	22	75.91	14.60
11	64.96	45.26	23	64.23	53.28
12	27.01	4.38	24	51.09	40.15

The difference of percentage of students who could answer correctly in the first tier with those who correctly answered both tier, indicated that students were likely to memorize the concepts with understanding. For example, item 9, which was to explore students' understanding of atomic number, was explored. There were 56.93 percent of the students who understood what is atomic number. When considering the students who gave the right reason to explain why they chose that correct answer, the percentage dramatically reduced to 2.19. This result showed that students know what atomic number is, but they failed to explain how to use atomic number to identify an element. The low percentage of students who could answer correctly in the first tier and both tier indicated that students didn't understand those concepts at all, even with memorizing.

This method of analysis was useful for instructional unit designing and developing. When plotting the scatter graph from the data in Table 4.8, students' understandings of atomic structure would be divided into three groups, Conceptual-Rational Understanding (CRU), Rote memory (RM) and Alternative Conception (AC). The graph showed in Figure 4.1, was available to diagnostic for the problematic concepts.

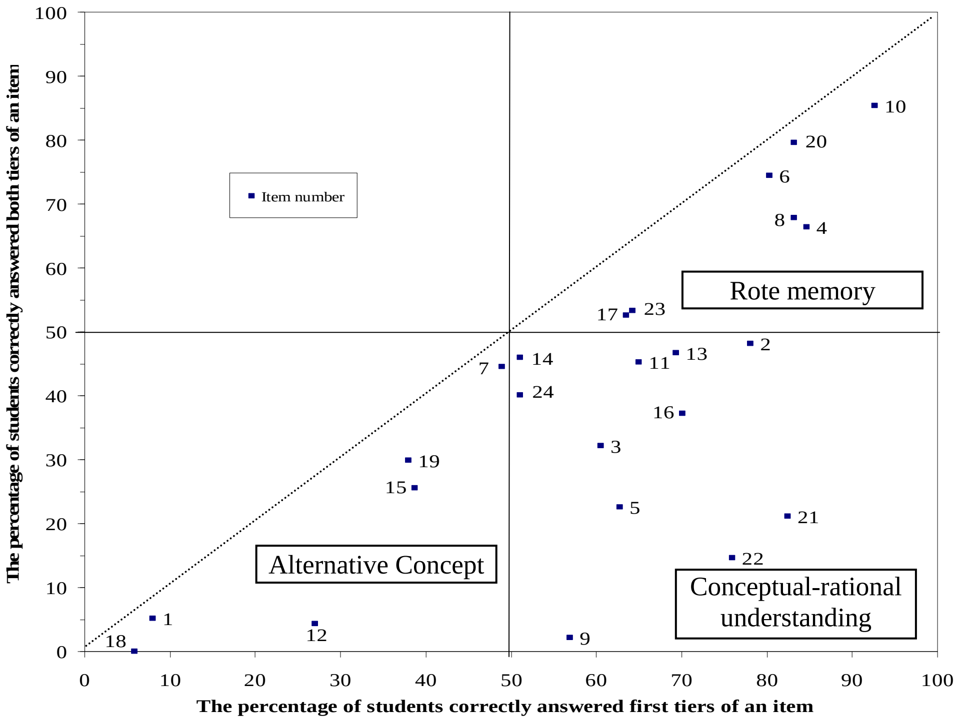


Figure 4.1 Scatter graph shows the percentage of students correctly answered only the first tier plotted against with those who correctly answered both tiers of each item

The concepts that students have a difficulty to learn were the concepts in alternative conception category. Even students experienced atomic structure lesson, they still had a difficulty to answer the concept test. These concepts could confuse them, such as sublevels in energy level from item 19. Or the concept they didn't have an opportunity to learn in traditional lesson even it was implied in the first page of IPST chemistry textbook (IPST, 2003a), such as the role of model in atomic theory. The concepts that teacher avoided to teach, such as the probability of electrons in an atom (item 15). Table 4.9 showed concepts by the categories. Concepts in alternative conception need to be addressed explicitly. When designing and developing the ASIU, It was needed to make sure that these concepts were not missing or neglecting.

The concepts in rote memory category needed to be changed in teaching method or learning activity. Research data indicated that students usually memorized these concepts without the rational understanding. In long term, these memories without understanding would lead to misconception as Arunee commented in the last topics. These topics were going to take into account when designed instructional units. The meaningful learning was integrated to the lesson. The scientific knowledge or content needed to be humanized. The origin of questions, scientist's experiment and atomic model would be linked together. Each topic had to be connected, not separately taught. Questioning and discussion had to be designed to let students develop their knowledge upon activity they are engaged, not from the textbooks they read or the lecture they listened to.

The last category of topics that students had a rational and conceptual understanding, consisted of 6 concepts. Even though most of the students understood these topics, there were some of students that had a difficulty to learn and understand. Under the assumption that the students' conception reflects what they experienced in classroom, the past lesson they were engaged didn't develop their understanding. Teaching and learning activity had to be various to meet learning styles of individual differences. If teaching methods are the same throughout the unit, the students who had different learning styles would not have an opportunity to develop their knowledge in the way they preferred. In units, it was necessary to ensure that the teaching methods were diverse.

The findings from the ASCT shown in Table 4.9 guided instructional unit designing and developing. The concepts that students understood were categorized into alternative concepts needed to be more considered than past teaching. In rote memory category, those concepts should be taught in meaningful ways. The students were engaged in activity and learned concepts by means of model and modeling which allowed them to participate in real experiences about science.

Table 4.9 Concepts of items and students' understanding categories

Item	Concepts	Students' Understanding
1	The role of model in atomic theory	AC
2	Characteristics of model	RM
3	Dalton's atomic theory	RM
4	The nature of cathode ray tube	CRU
5	Observation and inference of cathode ray experiments	RM
6	Thomson's atomic model	CRU
7	Gold foil experiment	AC
8	Constituents of an atom	CRU
9	Atomic number	RM
10	The relevance of atomic number and mass number	CRU
11	Isotopes of an element	RM
12	Nuclear symbol	AC
13	Atomic spectrum	RM
14	Bohr's atomic model	AC
15	The probability of electrons in an atom	AC
16	Quantum mechanics model	RM
17	Atomic orbitals	RM
18	Energy level of an atom	AC
19	Sublevels in energy level	AC
20	The nature of atomic orbital	CRU
21	Aufbau principle	RM
22	Pauli exclusion principle	RM
23	Hund's rule	CRU
24	Valence electron	AC

Note**:** CRU = Conceptual-Rational Understanding, RM = Rote memory, AC = Alternative Conception

2.4 Students' Understanding of the Nature of Science

Eight open-ended questions asked students to explain their understanding on core aspects of nature of science focused in this study. Students' answers were read and reread, coded, grouped into categorizes and then made themes to be interpreted aspect by aspect according to the nature of science review in chapter 2.

2.4.1 Science Relies on Science

Although the first questions tended to ask about the importance of evidence in science, the question was very open to them to express their views of characteristics of science. Students' answers were coded into 22 initial codes which were the highest number for all aspects. Five categorizes emerged after codes which were:

1. Credibility is the landmark of science: Most of students viewed science as the credible characteristics. Groups of answers that view science as the knowledge that could be relied on, was the majority answer (137 of 509 codes). Students viewed science as the fact or truth. Science was concrete and can be proved.

2. Rational thinking is the process of science: "Reason" became the word that was most frequently used to explain some characteristics of science. Those students viewed science as a process of thinking with reasoning, analyzing, creating and using theory or principle (102 of 509).

3. Science is the study of natural phenomena: The common definition of science from the students could be explained by this category. In their view, science means the study of natural phenomena. It is also the study of environment and surroundings. From this meaning, students viewed science as everything that happens in everyday life.

4. Think about science is to think about how to acquire knowledge: Many students explained science as a way to inquire knowledge. In their views, science could be explained as a process of seeking for answers, such as, observation (21), inquiry (14), systematic method of study (27). Sometimes creativity and imagination were used in those processes. The discovery was still the way to gain knowledge as well.

5. Values of science: When talking about science, students usually pointed out the advantages and disadvantages of science. Science was valued as its potential of explanation to the nature and to make an understanding of our world surrounding us. Science is responsible for the development and at the same time, the decay of environment from the use and destructions of nature. Science was also viewed as a profession or work.

6. Other views about science: Few students had different views of science. Two students thought that science was complicated, while four stated that it was enthusiasm or curiosity that played an important role in science.

2.4.2 Methods to Do Science

The majority of students thought that science has a universal method to obtain knowledge (166 of 312) which is called scientific method. Students were also confused about the steps of the scientific method. The number ranged from 5, 6 or 7 steps. Those steps usually comprised of observation, questioning, setting hypothesis, conducting experiment, collecting data, making a conclusion, and making a report. There were students who thought that scientists used only experiments in their work. These students applied this notion to the other fields as this statement, “not only science uses those steps, but everything uses this process too.” (Student’s answer STD323Q1).

Even thought the majority of students held a strong notion of universal scientific method, but some of them understood nature of multiple methods to do science. Out of 312 students' codes, 44 of them stated explicitly that there were more than 1 method to do science. According to the students, methods to inquire knowledge numbering in range were: different experiments in the same topic, field studies, observations and explorations, imaginations, direct experiences, serendipities, constructing models, inquiry and analyzing existing knowledge. It was indicated that some students had a conceptual understanding of nature of scientific inquiry. One student wrote, "Nothing absolutely, scientific study may have a pattern but it doesn't mean all of everything. My answer is that there are many methods to inquire scientific knowledge" (Student's answer STD220Q1) and the other said "Now, we usually think that to inquire scientific knowledge, we have to use both step and non-step. If we make an understanding, with reasonable thinking, modern scientific knowledge will occur" (Student's answer STD129Q1).

2.4.3 Science is Subject to Change

Most students understood that science is subject to change (275 of 282). There were only 7 students who answered that scientific knowledge will not change. The reasons they gave were: scientists get the additional data or information; scientists performed new experiments; new knowledge has inferences that are more credible and the old theories broke down.

2.4.4 Scientific Theory and Law

This aspect of nature of science became the most misunderstanding students held. There were only 3 students who viewed that both law and theory could change. Comparing to theory, law has a higher rank of hierarchy for example: law can't change but theory can. Law can't be disputed because it is a truth which was proved many times. Theory is a guiding but law is a rule for scientists. Theory comes from several hypothesis or experiments. Theory is estimated statement or educated guests. Hypothesis becomes theory which later becomes law.

2.4.5 Observation and Inference in Science

When asked how scientists were certain about their theory, most of the students answered that it was because of evidence or experiment result which scientists could rely on. It was only 25 from 293 that were able to link between the inference scientists made and the experimental observation. Some students thought that scientists used imagination with their findings to make a certainly conclusion. The potential to explain the phenomena of scientific theory, from the students opinion, also indicated of the certainty that scientists are looking for.

2.4.6 The Human Subjectivity in Science

The question from the NOSQ asked the students if it was possible for scientists in different groups to derive their conclusions in different ways despite the fact that they had access to, and the use of, the same sets of data**.** Students' answers from the NOSQ were coded and categorized. In the 13 categories, both revealed alternative conception and conceptual understanding. The students' answers were placed into categories which included repeated questions, the rhetoric of scientific theories, ambiguous explanations, and incomplete evidence. All were considered to show an alternative conception of the nature of science and its effect on scientists' work. The other categories which were considered to be examples of a conceptual understanding of this aspect of the nature of science were: thoughts, views, beliefs, biases, experiences, imagination and creativity, methods of observation and analysis, theory and conceptual framework, and interpretation. One student was able to state precisely what the subjectivity of science is, which some researchers call the theory-laden aspect of the nature of science (McComas, 1998). The student said "scientists who view that the meteorite impact may get it from astronomer's point of views. While scientists who think about the volcano eruption may get it from geologist's views" (Student's answer STD315Q1).

2.4.7 Science, Culture, and Society Interaction

"Is science universal?" A question was asked to the students. If it is not, how it interacts with social and cultural milieu that science was presented. Students reacted with this question differently. There were two main categories of students' answer codes. Firstly, science is universal. It is independent from social and cultural values. Students gave a reason as, "Although norm was changed but science is not changed." (Student's answer STD133Q1). Scientists are seen as a very private person, who usually worked in laboratory as the student portrayed "scientists mostly work alone. There are no other people to help them study." (Student's answer STD131Q1). This notion was much closed to the way students' view on scientists work. Students who view science as a flat dimension like, a strict experiment following five steps of scientific methods, usually think it is separately done from the context.

For the students who think science depended on and affected by social and culture milieu usually view science as a human activity happening in everyday life. Those students viewed scientists as people who are a member of society. The students revealed, "I think that society, social norms, and cultures influence on thinking. Science is a process of thinking so it (science) is a blend of social and cultural norms held by individual." (Student's answer STD211Q1). There was student who understood that local wisdom from each community shape the way science was developed. The student said, "Science depends on society and culture as well as local wisdom" (Student's answer STD317Q1). The student viewed that sometimes, science impeded with the beliefs or religions of people. Many scientists would choose areas to study according to social acceptance for example, "Galileo invented telescope but his ideas conflicted with religion so he was imprisoned" (Student's answer STD223Q1).

2.4.8 Creativity and Imagination

Most of the students (131 of 137) understood that creativity and imagination were crucial in science. From students' views, scientists must inevitably have creativity and imagination. When asked in what part of their work scientists used creativity and imagination, students (57 from 131) understood that creativity and imagination were used in designing and planning steps. While other students thought that was the conclusion or after data collection. Some students believed that scientists used creativity and imagination to plan how to inquire the knowledge. While only a few students (9 of 131) viewed that scientists used creativity and imagination in every part of their work.

3. Model-based Approach and Teaching Strategies

Teaching approach to be used in the ASIU was model-based approach which was discussed in chapter 3. Activities were designed according to the nature of each topic in atomic structure. For example, the first activity introduced the students about the role and the importance of model and modeling in scientific inquiry. To study the unseen entity such as atom, scientists need to construct the representatives that they can work with. In every lesson, the two main themes that appear as the approach or teaching and learning were model and modeling and the target aspects of nature of science to be explicitly emphasized. Furthermore, other principles were also considered as follows:

3.1 Model and Modeling

Creating models both physical and mental, working with models and using models as conceptual frameworks for generating and answering questions are important scientific skills. Models and modeling encourage students to observation, questioning, dialogues, critiquing and prediction. Understanding of models and their functions promote students to learn science.

3.1.1 Explicit and Reflective Nature of Science

The lessons in this curriculum encourage teaching and learning regarding the nature of science. So, students are not only engaged in the process of scientific inquiry, but they also “reflect on what they have done” in the activities. Students participate in the scientific process by making observations and inferences, collecting and analyzing the data, creating and revising models to critique, presenting the findings to peers. Students also explicitly discuss and reflect on the nature of science, how and why scientific knowledge is established, including the interaction among science, culture and society.

3.1.2 Atomic Theory

Atomic theory is the scientific knowledge that has long been developed. It is the fundamental concept for the advanced chemistry and other science disciplines. Atomic theory consists of important and necessary concepts, fascinating story, interesting history and remarkable people. In line with this assertion, the activities emphasize the teaching and learning of atomic theory to help students build the necessary frameworks for learning additional scientific concepts and the nature of science.

3.1.3 History of Science

The context of history of science in classroom provides the meaningful teaching and learning. It portrays the origin of question to be inquired, how and why scientific concepts have been developed and changed over time. Tracking of history of science experiences students with the real scientific enterprise.

3.1.4 Scaffolded Technology Enhancement

Technology plays an important role to support science and learning science, regardless it is simply or complex. Good technology makes the lesson safe, simple and accessible for both teachers and students.

The Development of the ASIU

From concept mapping that portrayed the concepts and their relation, the topics were selected and arranged. The objectives of the lessons were set as a goal of learning outcome that meet the philosophy of education stated in the National Education Act 1999. The units also reach the National Science Curriculum Standard (IPST, 2002). After that, the activity was designed.

1. Topic Arrangement and Activity Design

The concepts of atomic structure are typically taught by the chronological ground which models and theories have been developed. For example, IPST textbook starts with the introduction about ancient Greek model and then Dalton's atomic theory and so on, until the electron could model which is the recent acceptable model. Considering the concepts to be taught in 4.1.1, from both concept mapping and propositional knowledge statements, it can be categorized into 6 main topics: early atomic theory, Dalton atomic theory, Thomson's atomic model, Rutherford's gold foil experiment, Bohr's atomic model, electron cloud atomic model and electron configuration. From the results in phase I, the teacher didn't integrate nature of science in classroom so the lesson was needed to address the target aspects of the nature of science which was capable by the nature of content and the knowledge have been developed. The activities were designed in a variety of teaching strategies to serve the diversity of individual differences. Besides these, the materials will be developed to enhance teaching and learning process as the teachers' comments. Teachers' interviews as well as the review literature from chapter II were the useful data sources to design the activity in each topics.

Considering students' understanding of atomic structure explored by the ASCT, the result indicated that the students tended to remember atomic structure composition rather than to understand the source and origin of structure, and secondly the students could not bind the processes scientists' experiment and theory found, especially, (1) the construction and role of model in the study of atomic theory (2) the connection of scientists' experiment and the formation of atomic model and (3) the electron arrangement in an atom. The research result was emphasized to improve the teaching method concerning atomic structure, underlined of the development for meaningful and conceptual instruction and learning.

The lesson started with introducing the role and function of model in science with the activity which was about how constructing scientific models from data obtained. The second lesson introduced the history of science to the students by letting them investigate the evolution of atomic theory over time, from the ancient Greek model to the electron cloud, which is based on quantum mechanics theory. The works of Thomson, Rutherford and the other scientists were grouped into the topic 'the discovery of subatomic particles' which discussed about the discovery of electron, nucleus of an atom and their properties which shaped the model of an atom at that time. After that the work of Bohr was discussed, followed by the lesson of quantum mechanics model. The difference from IPST textbook was the two individual lessons dedicated to the activity that introduced the students with the modern atomic model. According to the teachers, the quantum mechanics model was very sophisticated for them and they were not confident to teach this topic. The activity needed to be simple, understandable, and appropriated for the students and teachers. Electron configuration was much related with the electron cloud model, which needed to be taught as hands-on activity rather than memorizing the Aufbau diagram. The topics, problem addressing from phase I and review literature and the activity design were summarized in Table 4.10.

Table 4.10 Topics of atomic structure, problems/misconception addressing and the activity to be designed

Main Topics	Subtopics	Problems/Misconceptions (Data Sources in Parenthesis)	Target Activity (from Researcher's Planning Journal Notes)
1. Model and modeling of an atom	- Nature and properties of model	Most of the students didn't understand how model was constructed and what model to be used in science (the ASCT).	Students should work with model such as constructing, comparing, revising, and critiquing models.
	- Role and function of model in science	Lack of materials or understandable model (Phase I Interview , Arunee).	The discussion has to address why model is important for scientists' work.
			Model can be used to study the unseen entity such as atoms.
2. Evolution of atomic theory	- Ancient Greek model - Dalton's atomic theory	Confusion as to, when and how atomic model have been developed, or caused hybrid models (Justi and Gilbert, 2000).	The use of historical approach to enhance students' understanding of science content and nature of science.
	- Overview of atomic theory development	Studying the origin of the theory makes students understand more (Phase I Interview , Arunee).	In Dalton's atomic theory appeared the term both theory and law, so these terms could be added in this lesson.

Table 4.10 (Continued)

Main Topics	Subtopics	Problems/Misconceptions (Data Sources in Parenthesis)	Target Activity (from Researcher's Planning Journal Notes)
3. The discovery of subatomic particles	- Thomson's cathode ray tube experiment and his atomic model	The teachers' teaching of observation and inference aspect of the nature of science were categorized into implicit and deficient category (RVNOS).	The real cathode ray experiment could be presented to students for observation, at least from the VDO observation
	- The Rutherford's gold foil experiment and his atomic model	Thomson atomic model and Rutherford's experiment were the difficult topics for the students (Phase I Interview, Banburi and Chonlada)	The experiment of Thomson and Rutherford both relied on observation and inference nature of science which was appropriated to be addressed.
	- Constituents of an atom and their properties		The gold foil experiment could be reproduced as the scattering experiment. The cultural, social, and scientific interaction could be addressed in this lesson.
4. Atomic spectra and the Bohr atom	- Atomic spectrum - Bohr's atomic theory	The calculation about light and energy were difficult topics to learn (Phase I Interview , Arunee)	The link between energy, wavelength and frequency calculation must be drawn from real observation. Students have to see line spectrum in various situations. Distinguish line spectrum from continuous spectrum.

Table 4.10 (Continued)

Main Topics	Subtopics	Problems/Misconceptions (Data Sources in Parenthesis)	Target Activity (from Researcher's Planning Journal Notes)
		Students usually stuck with this model; even they have learned the quantum mechanics model. (Harrison and Treagust, 2000)	Imagination and creativity nature of science could be emphasized in the work of Niels Bohr when he used solar system to analogy atomic model explanation.
5. The quantum mechanics model	- The introduction of quantum mechanics - Atomic orbitals	Study science concept without understanding the basis; for example, to study electron cloud model, the students don't understand the origin of theory (Phase I Interview, Arunee).	The activity should start with the introduction of probability of electron in an atom.
		Electron cloud model is a very difficult topic to learn (Phase I Interview , Arunee, Banburi and Chonlada).	Science professors suggested using mathematics and probability in the same manner that scientists construct the orbital of themselves.
		Students were confused and had misconception in atomic orbital (the ASCT, interview, Nicoll, 2001; Tsaparlis and Papaphotis, 2002 ; Nakiboglu, 2003).	Works of Erwin Schrödinger was interesting. They can be used to portray nature of science in the aspect of multiple methods to do science, such as thought experiment.

Table 4.10 (Continued)

Main Topics	Subtopics	Problems/Misconceptions (Data Sources in Parenthesis)	Target Activity (from Researcher's Planning Journal Notes)
6. Electron configuration	- Aufbau principle - Pauli exclusion principle	Teacher's expect the materials that students can study by themselves (Phase I Interview , Arunee).	Students can manipulate by hands-on activity rather than memorize and write down the diagram of electron configuration.
	- Hund's rules - Valence electron	Students were able to arrange electrons into atomic orbital but they couldn't explain why and how according to Aufbau principle and Pauli exclusion principle (the ASCT).	Students should have an opportunity to work in group and communicate during learning communication in classroom. VAST model (Chamrat, 2006) could be used in this lesson.

After the concepts were determined and arranged, the details of teaching and learning procedure was developed in form of lesson plan. The lesson objectives were based on curriculum document and the activity itself. Teaching periods of the ASIU comparing to the IPST curriculum were presented in Table 4.11.

Table 4.11 Periods of time teaching in each main topic of the ASIU comparing to the IPST textbook

Main Topic	ASIU Teaching Periods	IPST Teaching Periods*
Model and modeling of an atom	2	0
Dalton’s atomic model	1	1
Thomson’s atomic model	2	1
Rutherford’s atomic model	2	2
Bohr’s atomic model	2	3
Electron cloud atomic model	1	1
Electron configuration in atom	2	2
Total	13	10

Note: *According to the IPST Teacher Handbook (IPST, 2003b)

The lesson plan, the student handbook and textbook were developed after they were completed. The experts who were two science educators and one scientist reviewed them. According to these experts, some parts of the lessons and textbook had to be revised. For example, the format of lesson plans and some terms were corrected. The student handbook was also revised according to lesson plans. The exercises were added as well as withdrawn for the appropriate of time, student’s knowledge level and lesson objectives. Then the lessons and textbook were sent to experts for reviewing again. When the experts agreed that lessons, the student handbook and textbook were suitable to implement, the hard copy in final form was printed out. All of ASIU was sent to the teacher to review and correct. By their expertise in a classroom, the lesson plan, the student handbook, and textbook were modified to take into account of teachers' responses.

2. Responses from the Teachers

The teachers review the documents used in the study before the workshop and the semester started. The objective of teacher's reviewing was to revise the ASIU before it was implemented by the teacher themselves. In the conversation of the focus group, the themes that teachers commented on lesson plans, the student handbook and textbooks emerged, which were presented here:

2.1 Time

In the first semester, atomic structure topic was not the only content to be taught. The students had to study two more topics which were the periodic table of elements and chemical bond. The traditional teaching of atomic structure was very much based on lecture and students' self-study, for example, the teacher assigned them to search for the information from the internet and discuss in the classroom. The teachers might assign them to write the report about atomic theories that had been developed over time. For the ASIU, the students had opportunities to do model and modeling activity in every lesson. Furthermore, the lessons also had section of expressing ideas, such as classroom discussion or student presentation. The teacher from school B was very much concerned about the time setting. She wanted to complete atomic structure concept as her normal teaching which is about 10-12 periods. Because ASIU was set to finish in 13 periods, teacher B felt worried that the ASIU implementation might affect the other lessons, while other teachers were not strict about the time. In conclusion, the teachers agreed to set 13 periods of 9 lessons for implementation. However, the time could be adjusted according to the real situation or the unexpected events which normally occurred in the real experiences.

2.2 Content

The selected contents were 6 main topics starting from the role of model and modeling of an atom in the early atomic theory until the recent accepted one which is quantum mechanics model. All teachers agreed with the content to be taught in ASIU. But in the details of subtopics, teacher C would like to add more details about the calculation of line spectrum energy. According to Plank's constant, Teacher C wanted the student to solve the problem by the equation, $E = \frac{hc}{\lambda}$. However, in real situation, there was an activity for students to observe continuous spectrum and line spectrum of which they had to calculate interchange between wavelength, frequency and energy. This activity appeared in lesson 6 'Can You See the Light as Bohr Did?' For the overview of the ASIU, all teachers agreed that the content was appropriate for the 10^{th} graders. They thought the contents covered science standard of the IPST and met the learning outcomes and learning substances.

2.3 Direction of the Activity

Activity direction was the point that the teachers most commented. One teacher strongly reflected her opinion on the way direction was written. In her suggestion, the direction had to be clear and could guide students in every step. The most confusing problem direction appeared on lesson 1: Seeing the Unseen through Models. She pointed out that the direction of coloring 2D model according to the height of mystery landscape in the black box should have at least one decimal point. She reasoned that the students might be confused what color they should paint if the height data was 2.4. In the case of lesson 2: journeys to atomic history, the direction of activity assigned students to collect the historical data to identify and compare important aspects of each atomic model developed in particular time by the following questions:

- Who: the scientists who developed the atomic theory

- What: the experiments, observations and evidences scientist used to support their ides.

- Why : the reasons why scientist was interested in exploring or conducting the experiments/observations.

- When: the time when model was developed including the technology which was available at that time.

- Where: the places and communities of scientists' work and its effects on their work.

- How: how the atomic model can and cannot explain and predict the phenomena.

The teacher thought the word 'what' 'why' and 'how' should be change ed into the terms that more represent the key words as the activity wanted student to understand. For example, 'what' should be changed to 'evidence' or 'experiment' The word 'why' should be changed to 'question' or 'origin' which asked the students to identify why scientist did or felt interested in such experiment or observation. The word 'how' should be changed to 'explanation' which was the content of theory that can explain or predict the phenomena involving atom. For the rest of the lessons, the teachers thought that the direction was clear. The students could understand by themselves without teachers' further clarification.

2.4 Exercise and Key Answer

One thing that the teachers actively suggested was the key answer of the exercises. This included all activities appeared in the student handbook. Even though there were answer keys for the exercise, the teachers wanted the lessons to have all answers of every question not only in exercise but also in the discussion. Because most of the questions in discussion activity were open questions, the teachers suggested adding examples or direction of conversations of the discussion, for example, how to comment, or response to the students' answer which was not judged to be right or wrong. Data collection was the same case. The teachers recommended to add guiding or example of data to be collected. For example, in the first activity, students have to measure the depth of black box and wrote the data into data sheet in their handbook. In teacher version of the student handbook, it should have the data in the data sheet or table as an example. The lesson plans were revised as the teachers' comment.

Characteristics of the ASIU

The final version of the ASIU consisted of 3 documents and several particular materials which were developed according to the designed activities. The details of documents and example materials had been developed and used in this study were described as follows.

1. Lesson Plans

The main document of the ASIU was lesson plans which consisted of 9 activities. Being validated by experts and teachers ensured the quality of the lessons in terms of learning outcomes, concepts, learning activities, and assessment. The overview of lesson plans is presented in Table 4.12. The topics highlighted in the overview are the names of each lesson, teaching time, concept to be taught, the target aspect of the nature of science, a particular model and modeling instructional strategies used in lesson, and the chapter of textbook related with the lesson.

The title of the lesson was carefully constructed. It represented the activity as well as implied lesson concepts. At first, many lesson titles were constructed by brainstorming (from the researcher) and written on researcher's planning journal notes. The least relating name or non-appropriate name was eliminated. The name that didn't represent the substance of the lesson was also withdrawn. Lastly, the name that sounds familiar, remarkable or modern, for example the phrase 'seeing the unseen' or 'a journey to..' were habitual for using. The slogan such as 'mix and match' was used in lesson seven because it was popular among teenagers while representing the analogy and metaphor as the instructional strategies. In lesson 4 Trace Rutherford's

Lines not only meant that the student did the experiment which was reproduced from Rutherford's, but also implied that students used the line of scattering object to figure out the hidden shape under the cover. One teacher commented about the lesson title during the first focus group that it did not only make the students interested in the lessons, but also kept the teachers' attention.

> Teacher: I wonder how you got lesson titles.
> Researcher: Do you like them? I constructed them to represent the activity and content.
> Teacher: I think they are nice names. Yes I think they hook students by the cool name as teenagers usually use.
>
> (Focus Group, Workshop I)

Time for teaching in each lesson was agreed from teachers. The time was flexible because of school situation and special events. Even though the time was set for advance, teachers could adjust it to be used in each activity, for example, the discussion of students might be longer than the time setting. The teacher could allow them to do so, because students' ideas about nature of science might immerge at that time.

Each lesson had a particular aspect of nature of science embedded in it. The nature of science sometimes emerged from learning activities as in lesson 1 Seeing the Unseen through Models which relied heavily on observation and inference. Many aspects of nature of science appeared in scientific content, such as imagination and creativity in scientists' works. The obvious nature of science became visible in the lesson because it was dominant in content, activity, or scientists' ideas. In the same lesson, nature of science was not necessary embedded just in one aspect. To prevent missing or confusing students, one aspect of nature of science was addressed explicitly as a lesson objective. For other aspects, teachers could comment on them when they had an opportunity to do so.

Instructional strategies used in lesson plans were also important. As a learning and teaching theoretical framework, model- based approach guided and shaped teaching methods employed in this research. Experienced the whole unit, Students were engaged in scientific activities starting from concrete model and modeling to the abstract model such as explanatory and mental modeling. In lesson 7, students were engaged in the analogy and metaphor activity using the understandable entity to represent the concepts of Bohr's atomic theory. After that, they mapped the similarities and differences of metaphor of analogy which was one type of model to theoretical target. Students identified the crucial relationship that makes the analogy useful and pointed out the phenomena where analogy breaks down. In lesson 8, students were introduced to the concept of quantum mechanics model of an atom. They could use mathematics and probability in the same manner that scientists construct the orbitals; students learned that there were multiple methods to do science. In the same lesson, the discussions also focused on thought experiment which Schrödinger used to develop his atomic theory. The last column presented a chapter in the textbook that related to lesson plan. Concepts in lesson 1 were associated with chapter 1 model and modeling of an atom.

Lesson 2 was related to chapter 2 evolution of atomic theory that was the summary of essential atomic theory and models developed over time. Chapter 2 presented each atomic theory and model starting from the ancient Greek to the current acceptable model as the holistic view. Lesson 3, 4 and 5 were associated with chapter 3 the discovery of subatomic particles which discussed the discovery of electron, proton and neutron in details. Lesson 6 and 7 were related to chapter 4 atomic spectra and the Bohr atom which focused on the work of Niels Bohr and his atomic theory. Lesson 8 and 9 were associated with chapter 5 the quantum mechanics model and chapter 6 Electron Configuration respectively. The discussion of textbook developed for the ASIU was presented in the next topic.

Table 4.12 Summary of the ASIU

Lesson No.	Title	Time (Min)	Concepts	The Nature of Science	Teaching Strategies	Textbooks
1	Seeing the Unseen through Models	110	The work of scientists that use model and modeling to explore the unseen entity	Observation and inference	Constructing and comparing multiple models	Chapter 1: Model and Modeling of an Atom
2	A Journey to Atomic History	110	The history of atomic theory development.	Evidence based on characteristics of science/theory and law/science is tentative	Historical approach and comparing model in the historical context	Chapter 2 : Evolution of Atomic Theory
3	All About Electrons	55	The discovery of electrons and their properties lead to the plum pudding atomic model	Creativity and imagination	Model reasoning	Chapter 3 :The discovery of Subatomic Particles
4	Trace Rutherford's Lines	55	The Rutherford's scattering experiment and his atomic model	Observation and inference/ science, culture and society interactions	Modeling skill, Reproduction of historical experiment	Chapter 3 :The discovery of Subatomic Particles
5	Antarctica Adventure	110	Atomic number, mass number, atomic mass and isotopes	Subjectivity in science	Mathematical modeling for problem solving and data representation	Chapter 3 :The discovery of Subatomic Particles

Table 4.12 (Continued)

Lesson No.	Title	Time (Min)	Concepts	The Nature of Science	Teaching Strategies	Textbooks
6	Can You See the Light as Bohr Did?	55	Atomic spectrum and Bohr's atomic theory	Observation and inference	Constructing explanatory model	Chapter 4 : Atomic Spectra and the Bohr Atom
7	Mix and Match for an Atom	55	Bohr's planetary model	Creativity and imagination	Creating analogy and metaphor	Chapter 4 : Atomic Spectra and the Bohr Atom
8	My Probability, My Orbitals	55	Quantum mechanics model (electron cloud model)	Methods to do science	Constructing conceptual model	Chapter 5 : The Quantum Mechanic Model
9	Modeling the Atoms, (Everyone Can Do It!)	110	Electron configuration	Subjectivity in science	3D hands on model/ model as a representative	Chapter 6 : Electron Configuration
Summary	Nature of science as a modeling activity	13 periods	Atomic structure concepts	8 aspects of NOS	Model-based approach	6 chapters

2. Textbooks

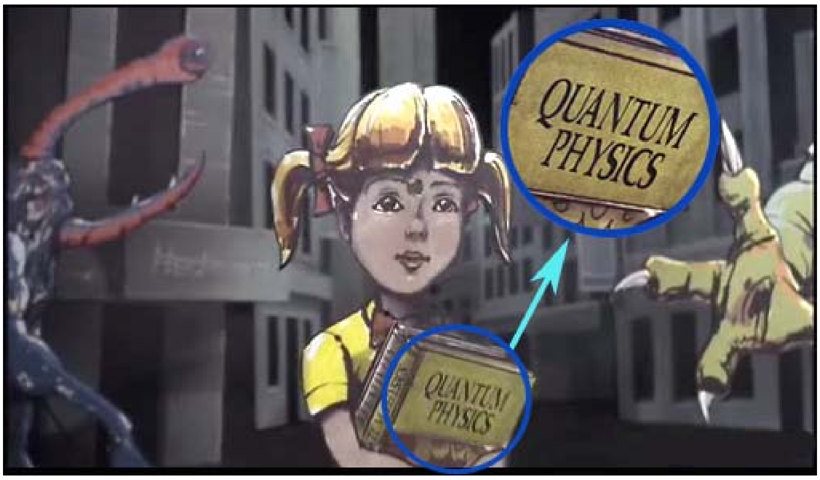
The information of textbook development was based on several arguments taken from researcher's field notes that were related to lesson plans. First of all, textbook was the important learning material which provided ready-made teaching texts and learning tasks. In the eyes of learners, no textbook means they have no purpose. Without a textbook, students think their learning was not taken seriously and they were likely to be out of focus and teacher-dependent. In this study, the period for accessing classroom was limited. A textbook was a framework which regulated and timed the ASIU and perhaps mostly important, for teachers who were first hands for this instructional unit, the textbook meant security, guidance, and support. The title of textbook was 'Chemistry Textbook for Nature of science as a Modeling Activity: Atomic Structure'. It consisted of 6 chapters as in Table 4.12. The books quoted Richard Feynman's statement (Feynman, Leighton and Sands, 1963) that portrayed the importance of studying atomic structure.

> …If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed onto the next generations of creatures, what statement would contain the most important information in the fewest words? I believe it is the atomic hypothesis (or the atomic fact, or whatever you wish to call it) that all things are made of atoms-little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence, you will see, there is an enormous amount of information about the world, if just a little imagination and thinking are applied.

The textbook consisted of 6 chapters with 85 pages totally. In each chapter, the special textboxes were attached near the focus concepts. For example, 'Did you know' box which introduced students with interesting story of science, tips or knowledge that humanized science and relate science to students' everyday life. The questions asked students with the quiz question that provided the answer below in the same box. 'Did you know' box showed as Figure 4.2 taken from Chapter 5 quantum mechanics model asked students to realize the word 'quantum'.

Did you know: What is quantum?

In the scene of the movie “Men in Black” (1997), among a variety of harmful-looking aliens, Agent J suspects on the eight year old girl who held the textbook “Quantum physics”.



Is quantum difficult? Is it hard to understand? And what is actually “quantum”?

Let’s check it!!!!

The word comes from the Latin "quantus," for "how much." A quantum (plural: quanta) refers to an indivisible entity of energy. For instance, a photon, being a unit of light, is a "light quantum." It means that light does not come in continuous energy. Rather, it’s discrete of package of energy. Quantum theory is a big concept of modern science. It does explain many natural phenomena especially the very small and very fast moving such as electrons. Sometimes it is hard to think about this strange concept. That light and electrons behave like wave and particles. Electrons can be determined by probability.

Figure 4.2 ‘Did you know’ box asked students to think about ‘quantum’, its meaning and concepts

Sometimes ‘Did you know’ asked students to imagine or think about philosophy of science with easy questions. For example, ‘Did you know’ box from chapter 2 evolution of atomic theory, asked students what characteristics a philosopher had and how it was different from scientists, presented by Figure 4.3.

Did you know?

- **Who is philosopher**?

Philosopher means "lover of wisdom."
Philosopher is a person devoted to studying and producing results in philosophy.

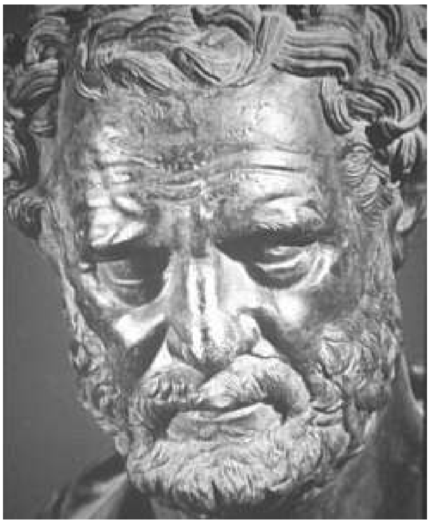
- **What are the differences between philosopher and scientist**?

Scientists study and try to explain natural phenomena. They rely on evidence and logics.
While philosopher sometime study of beliefs, ethics, aesthetics, and rely on the reasons only.

Figure 2.1 The Thinker – the famous sculpture of Auguste Rodin (French artist) can represent some characteristics of philosopher.

Figure 4.3 'Did you know' box asked students to define philosopher and identify the differences between scientist and philosopher

There was another text box named 'Brain exercise'. This box motivated students to generate ideas without specific answer. An example 'brain exercise' was taken from chapter 2 which asked students to interpret Democritus atomic theory (Figure 4.4).



In His Own Words:
Democritus proposed that everything is made of atom and between atoms there is space.

By his famous quote
"By convention, sweet; by convention, bitter; by convention, hot; by convention, cold; by convention, color; but in reality, atoms and void"

Brain exercise
Can you interpret about Democritus's quote?

Figure 2.3 Sculpture of Democritus - Greek philosopher who believed that everything is made of atoms.

Figure 4.4 'Did you know' box asked students to interpret Democritus atomic theory

One of the most interesting characteristics of this textbook is printing picture in color. Because several pictures in this textbook represent the color of phenomena such as continuous spectrum and atomic spectrum, some pages were printed in color. The other pages that had only texts were printed in black and white.
All students in this study had textbook of their own. The textbook had 85 pages totally.

3. The Student Handbook

The student handbook resembled teacher's lesson plans in the part of activity's overview, objectives, student handout, data recording and exercise. In each activity, it started with the title of activity followed by the picture represented activity substance. The activity objective was also addressed to acknowledge students with the purpose of the activity. It also directed the lesson assessment. Students in this study used two documents for their learning, textbook and handbook.

4. Teaching Materials

Because of the nature of teaching and learning with models, many materials were developed as tools for teaching and learning. Even though other models such as explanatory and mathematical model used in this study were also important, physical model had been constructed and employed by the teachers. Students were considered as a central equipment of activity. It’s worth to discuss some teaching materials involved in the study.

4.1 Seeing the Unseen through Models

The activity in lesson 1 engaged students to the discovery of scientific knowledge from the hidden entity- the invisible things. Students understood how scientists construct scientific models from data they obtain. By this experience, students used the technique to figure out the mystery landscape of objects similar to "Scanning Probe Microscopy" or SPM (that scientists use modeling atoms) to construct 2D, 3D physical model and 3D visual model constructed by computer. Constructing and comparing multiple models will help students to achieve modeling skill which is defined as one of the scientific literacy. This activity also leads to the discussion of nature of science. The landscapes or model they construct are the inference that they draw from observation using probe. The accuracy of data also relies on how the students measure and carefully conduct the data collection. The same set of data which may give the different result depends on the method of interpretation. The teaching material for this activity was ‘Black Box’ as presented in Figure 4.5

Figure 4.5 Black boxes with different objects inside for the activity 'Seeing the Unseen through Models'

The box was prepared by gathering one shoebox for each small group of 2–3 students. Each box should have a mystery landscape glued to the bottom. This landscape can be made with household objects like rolls of tape, plastic party cups, containers in various sizes, and molded figures of clay or plaster. The important thing is for the landscape to have a highly varied topography. Also, students seem to be more engaged if the contents of each box are different. Small, excited crowds often gather for the revelation of what is really in each box. Be sure to tape the boxes shut so that students cannot see what is inside. Punch holes in the lid of each box in a grid pattern, spaced approximately 2 cm apart. The boxes should be reusable year after year if they are handled properly.

4.2 All About Electrons

In this activity, the students observed the videos and animations of the two experiments, cathode ray tube experiments and oil drop experiment. Using the observation, students constructed the hypothesis consistent with the phenomena they observed and connected them to the atomic theory and atomic model. Videos of cathode ray tube experiment were taken from internet, especially, www.youtube.com. Videos were selected to match five important phenomena of cathode ray tube.

1. Cathode rays' properties are independent of the cathode material, gas or types of electrode.

2. If an object is placed in the path of the cathode ray, a sharp shadow of the object is cast on the glowing tube wall at the end behind anode.

3. The cathode ray can push small paddle wheel and move them.

4. Cathode ray is deflected from a straight line path by an electric field and bends towards a positively charged plate.

5. The cathode ray is deflected from a straight line path by a magnetic field.

The selected videos were edited into 1-2 minutes long video clip. Without narration, students had to create hypothesis by themselves from their observation. All videos were managed by Microsoft Movie Maker which is available in every Personnel Computer operated by Windows. The animation which represented oil drop experiment of A.R. Milliken was modified by replacing English soundtrack with Thai language. Thai script was translated from the original narration which was modified to fit within 3 minutes length of the animation. The original soundtrack was removed and the new Thai narration was replaced by the use of Movie Maker. The narration of oil drop experiment was:

> Thomson's work in identifying the electron as a constituent part of atoms was of incredible importance. Nevertheless, it fell short of a complete triumph because Thomson's experiments could not determine the charge and mass of the electron independent of each other. The charge of the electron was determined by R.A. Milliken after an exhausting research effort measuring the charge on oil droplets. What Milliken did was to put a charge on a tiny drop of oil, and measure how strong an applied electric field had to be in order to stop the oil drop from falling. Since he was able to work out the mass of the oil drop, he could calculate the force of gravity on one drop, and then he could then determine the electric charge that the drop must have. By varying the charge on different drops, he noticed that the charge was always a multiple of

- 1.6 $\times 10^{-19}$ C, the charge on a single electron. This meant that it was electrons carrying this unit charge.

4.3 Trace Rutherford’s Lines

This activity will engage students to the experiment of subatomic particles with indirect determinations. This technique is important for studying the subatomic particle that is impossible to be seen directly and can provide a platform for the introduction of the Rutherford’s model of an atom. In Rutherford's famous experiment, alpha particles were directed at a thin sheet of gold foil with the idea of measuring the deflection of the alpha particles. From the data gathered, Rutherford was able to draw conclusions about the size of the nucleus. We can learn about the concepts of Rutherford’s experiment through this experiment. Students will indirectly identify the shape of an unseen object as Figure 4.6 (left). The material for the activity called ‘scattering plate’ with its preparing is described as follow.

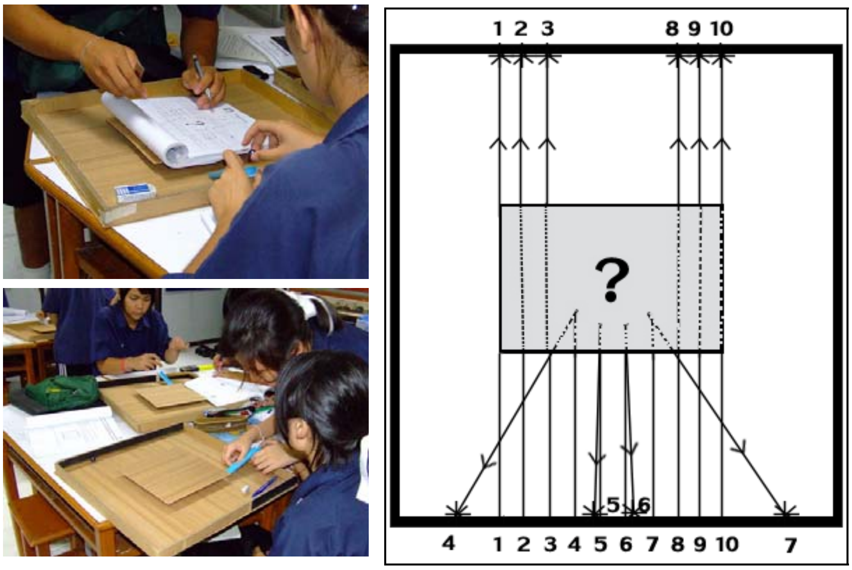


Figure 4.6 Students worked with scattering plate to find the shape of hidden object that resembled Rutherford’s scattering experiment

Cut 2 inch-thick wood into a shape as Figure 4.7. Then, attach each shape with the tray (made from the cardboard box cover, size 50×50 cm) and cover the shape with plywood or cardboard which is much larger than the shape and can be placed over the block so that the shape cannot be seen. Check to make certain that there is enough room for the marble to roll underneath the cover. The containment fence was made by cutting plywood or cardboard which is in length, 50 cm. attaching with the end of every side. To make the Ramp, cut a 15 centimeter piece (~6 inch) of PVC pipe in half lengthwise. After that, use sandpaper to flatten one end of the ramp to help stabilize it.

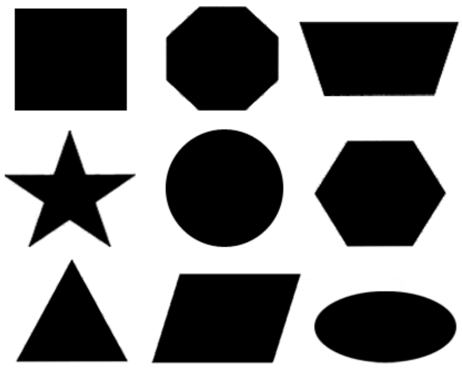


Figure 4.7 Shapes of wood used as the hidden shapes under the cover

4.4 Antarctica Adventure

In lesson 5, the activity emphasized the understanding of human factors that influence scientists' work. Students investigated the UCLA professor, Dr. Davis McClaren who is the focused character in the movie (DVD) "Eight Below" (Barber *et al.*, 2006). The movie "Eight Below" was edited using Microsoft Movie Maker to a length of 25 minutes. The movie is the story of scientists who went to Antarctica to collect a rock sample suspected to be a meteorite. The mission was completed and Dr. Davis McClaren received an outstanding honor for his work, but his sled dogs were left in Antarctica. Because the edited movie was limited by time and shaped by the focus aspect of nature of science, all scenes presented to students were selected to focus on scientists' work. The edited movie was stopped at the scene in which he had to decide whether to spend his remaining grant money to launch a new mission back to Antarctica or not. He wanted to go back to rescue the sled dogs that had saved his life during the first journey which would mean that he would not be able to complete his intended research. In addition, it might have affected his eligibility for future grants. At this point, students were asked to help the scientist make a decision using their knowledge of isotopes. Students determined whether the rocky looking chunk's origin is Earth or extraterrestrial. To do this, student research teams compared the atomic mass by calculating and comparing the percent abundance of isotopes of selected elements in the mystery Antarctic sample with Earth samples.

4.5 Can You See the Light as Bohr Did?

Figure 4.8 Yellow color flame showed light emitted from burning sodium chloride which was one of the element tested in 'Can You See the Light as Bohr Did?' activity

In this activity, students participated in the activity showing how different elements emitted different specific wavelengths of light energy when burned. It can be identified when the light is separated with a spectroscope. For the universal experiment, Flame tests were performed with a Nichrome wire which are notoriously difficult to see and to interpret. This is probably because the brief color of the flame appears in an area surrounded by the blue color of the Bunsen flame, and necessarily appears in the same place as the blackbody radiation given off by the hot wire. As a result, students often doubt of what they see or what they ought to see and are generally disappointed with the flame test experience.

Solid alcohol is a little cup usually used in any Thai restaurant is used for the flame test activity. It could be bought from any general store with a reasonable price. One cup could be used for 20-30 minutes. The advantage of solid alcohol is the time spent in burning metal salt that emits color flame. The time is long enough to use spectroscope to observe line spectrum in darkish room. Even though the light from alcohol fuel gives a slight color, the amount of metal salt could be adjusted to make vivid color as teacher needs. The more metal salt is added, the more color is clear. Make sure that metal salt is not too much added; it will extinguish the fire. However, working with flammable materials, teacher needs to concern about safety as priority.

4.6 VAST Model

Figure 4.9 VAST-Models (**V**isualizing **A**tomic **S**tructure **T**hrough-**M**odels)

In lesson 9, the activity had the students engaged in the hands-on activity. Working with 3D hands-on VAST-Models (Visualizing Atomic Structure Through-Models), students can develop the understanding of electron configuration and link between microscopic chemistry to macroscopic level using symbolic entities for atomic structure.

VAST-Models is 3D hands-on model for learning atomic structure. VAST-Models consist of teacher's demonstration (Figure 4.10 right) and student (left) analogical hands-on models reflecting the historical development of models used in representing atomic structure. The models above represent the quantum mechanical model. The demonstration version was invented by Research Services Instrument Shop, the University of Georgia. After designing, the technician used the transparent plastic processed by the heat and vacuum to shape the orbital model. The student hands-on version is made from cutting fleece that is easy to stick by Velcro into orbital shape. Buttons in different colors represented proton, neutron and electron (Picture 4.11, left). They are attached with Velcro in the back that is easy to affix with the nucleus (Picture 4.11, right). The nucleus made from Styrofoam ball is wrapped up by fleece.

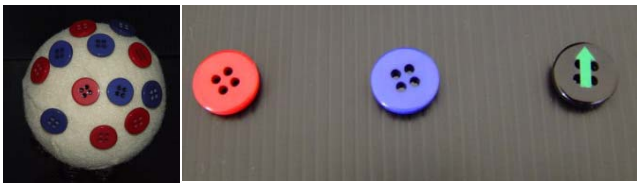


Figure 4.10 Buttons in different color represented proton, neutron and electron affix with the nucleus made from Styrofoam ball wrapped up by fleece

The Implementation of the ASIU

1. ASIU Workshop and Teacher Meeting

Three workshops were set to introduce the activities and make an agreement among the teacher about the lesson plan to be taught. The first workshop was done in the early May 2007 before the starting of the first semester. The first five lessons were demonstrated to the teachers. Three teachers and science educators discussed about the content, activity and the materials for implementing in classroom. The Atomic structure model textbook, the student handbook and the lesson plan were reviewed page by page on that full day workshop. The workshop was started by introducing the teachers to the significance of the study and the lesson plan. Teachers also participated in discussing about the theoretical framework that the ASIU especially underlie- the model-based approach. Lesson plans were adjusted to fit with the real classroom with teachers' suggestion because of their experiences of teaching. Even though the lesson plan was revised, the activities and the main purposes of the ASIU still remained. There was another workshop when the teachers taught about a half of the ASIU. The main purpose of this workshop was to monitor about ASIU implementation. The last four lessons were also discussed in this workshop. However, during the implementation of ASIU, the researcher had an informal meeting with each teacher before and after classes. The meeting was about the lesson to be taught, the main ideas of content and the focus nature of science aspects. After class, the teachers were usually interviewed about the events in the classroom. The conversations were heavily addressed on how and what student could understand science concepts and the nature of science.

The last workshop was set for member checking. Over all data were presented to the teachers, such as, total number of ASIU class, some findings from the ASCT and the NOSQ. The teachers were asked to express their opinions. The evaluation was made by the teachers. All workshop and informal meeting were recorded. The data was used to analyze as a supplement for the main data acquired from six instruments.

2. Timeline of the Implementation

The implementation of ASIU in each school was different. It depended on school events and the teachers' characteristics. Degree of reflexive in time of each teacher was different. Arunee followed lessons plans while trying to maintain the time. She made an effort to cover all activity so the real periods she spent on ASIU were 15 totally. It was the same as Chonlada who was stricter in schedule. She was very concerned about time to implement ASIU but still kept all activity. Banburi spent 12 periods for all ASIU lessons. Banburi's timetable of ASIU was implemented on Monday and Thursday. During that time, Monday was frequently holiday so the lessons were postponed. Sometimes she could find special periods for making them up. However, she could implement all activities as Arunee and Chonlada did, but she punctually implemented the lessons. The details of teachers' teaching and students' learning were discussed in the next chapter. Timeline of implementation is presented here to portray the whole view of research in the fields. In Table 4.13, ASIU was implemented in the first semester of academic year 2007, Starting from May to July. Before and after the implementation of ASIU, the secondary research data were collected by The ASCT and the NOSQ. According to 6 topics, primary data sources comprised of 6 classroom observation videotape recording, 6 classroom observation field notes, 6 Teacher pre-instructional conversational interviews and 6 teacher post-instructional conversational interviews from each school. Three students from one classroom were informally interviewed during and after the implementation of the lessons. It was totally 54 interviews from 9 students of 3 schools.

Summary of the Chapter

This chapter presented the design and development of the ASIU regarding the National Education Act, the Thai National Science Curriculum Standard focused in the content area of this study, the general accepted IPST chemistry textbook and teacher handbook. Those four documents were the framework for designing the ASIU. In details, the research findings from phase I and literature review lead to developing of activities based on a model-based approach. Data sources from teachers and students used as main factors to design the ASIU as well as implications of the existing research are related to this study. The final version of the ASIU consisted of the lesson plan, the atomic structure textbook, the activity handbook, and the teaching materials. The lesson plan had 9 activities using 13 periods to implement. Before the implementation of the ASIU, the most important things taken into account of instructional unit development were the teachers who were directly stakeholder of this study. Along with the implementation of the ASIU, the workshops were set as a meeting of the interchange ideas for making an agreement.

Table 4.13 The timeline of ASIU implementation in school A, B and C

	Topics	Activity of the Lesson	School A	School B	School C
1	Model and Modeling of an Atom	Seeing the Unseen through Models	1. May 23, 2007 2. May 28, 2007 3. May 30, 2007	1. May 22, 2007 2. May 29, 2007	1. May 23, 2007 2. May 25, 2007 3. May 28, 2007 4. May 30, 2007
2	Evolution of Atomic Theory	A Journey to Atomic History	4. June 4, 2007 5. June 6, 2007	3. June 5, 2007	5. June 4, 2007 6. June 6, 2007
3	The discovery of Subatomic Particles	All About Electrons	6. June 11, 2007	4. June 7, 2007	7. June 11, 2007
4	The discovery of Subatomic Particles	Trace Rutherford's Lines	7. June 13, 2007 8. June 18, 2007	5. June 12, 2007	8. June 18, 2007
5	The discovery of Subatomic Particles	Antarctica Adventure	9. June 20, 2007 10. June 25, 2007	6. June 14, 2007 7. June 19, 2007	9. June 20, 2007
6	Atomic Spectra and the Bohr Atom	Can You See the Light as Bohr Did?	11. June 27, 2007 12. July 2, 2007	8. June 21, 2007	10. June 25, 2007 11. July 2, 2007
7	Atomic Spectra and the Bohr Atom	Mix and Match for an Atom	13. July 4, 2007	9. June 26, 2007	12. July 4, 2007 13. July 9, 2007
8	The Quantum Mechanic Model	My Probability, My Orbitals	14. July 9, 2007	10. June 28, 2007	14. July 11, 2007 15. July 12, 2007
9	Electron Configuration	Modeling the Atoms, (Everyone Can Do It!)	15. July 11, 2007	11. July 3, 2007 12. July 5, 2007	16. July 23, 2007

CHAPTER V

RESEARCH FINDINGS

This chapter provides the answers to the research questions from phase III. The first question searched for an understanding of how teachers implement the ASIU. The second question explored how the teacher unit instructions practice influenced students' understandings of atomic structure concept and the nature of science. The findings portrayed by themes emerged from multiple data sources using thematic data analysis. The school context and teacher's characteristics were discussed before the theme was reported because each school was different and unique. In the details, students in each school also had different learning styles which reflected on their understanding of atomic structure and the nature of science. The last topic of this chapter portrayed the common finding drawn from three schools.

School A: Arunee and Her Students (Apinya, Akara and Aubonpan)

1. Introduction

1.1 School Context

During World War II, many schools in Bangkok and the sub area of Bangkok were closed as a subsequence of the war. To solve the problem, The Royal Thai Army Chemical Department founded the school in 1944 for serving children of government servants and workers in the Royal Thai Army Chemical Department. At first, the school began teaching at the primary level until 1955 when it also started the secondary level. Now the acceptance was not limited to service only Royal Thai Army families. Since the school was transferred in 1976 to under the administration of Ministry of Education, the school became public and served for all children as a public school. The school has been categorized as an "extra large" school. In the academic year 2007, there were 3,638 students and 147 teachers. Each grade 7-9 consists of 12 classes with 50-60 students in each class. The amount of students was reduced to 45-50 students in each of 12 classes at grades 10-l2. Classes in Grade 10-12 are separated into three programs with four classes in the science program, four in mathematics and English, and four in social and languages. In the three classes in the science program for each of Grades 10-12, the students were put in a class using GPA from Grades 7-9.There were 16 science teachers of which three were chemistry teachers. Each chemistry teacher taught in all of Grades 10-12.

1.2 Teacher (Arunee)

Arunee (a pseudonym) graduated with a bachelor's degree in education (chemistry major) and a master's degree in education. She has taught chemistry and general science for about 26 years. She has also taught the concept of atomic structure for 21 years. Arunee attended conferences and seminars on science education at least twice a year to improve her teaching and her content. At the time of the study, Arunee taught about 17 periods a week. She had responsibilities as the vice head of the science department and administrator of the science library. In addition, Arunee was involved in classroom research with university lecturers concerning science teaching. The research was concerned with writing lesson plans using constructivist-based teaching. In her professional development, she was perusing rising up her professional ranking by submitting research reports to the Teacher's Council of Thailand.

1.3 Students

The students were from one Grade 10 class in the science-program. There were 43 students in the class with 17 boys and 26 girls. The students were aged 14-16 years. Most of these students were relatively high in academic ability from grade 7-9. Arunee agreed that the achievement of the students in this class was in fact quite high compared to other classes. However, she wasn't able to predict that they would be good learners because high school teaching styles were different from those of middle school. She recommended six students to be studied in-depth. The researcher selected three of them who had high, middle and low academic achievements. They were Apinya, Akara and Aubonpan.

Apinya who was 15 years old, was the highest achieving student of this class according to the teacher's comments. Even though she got the highest GPA from middle school, Apinya preferred to sit at the back of classroom. In her group, there were 5 other girls who were her close friends. Her friends had mixed academic achievements. Apinya came from good family background. Her father was a doctor who worked for a public health organization. It influenced her expectations; she would like to study medicine after she graduated from high school.

Akara was a 14 year old boy. Even though Arunee classified him as a middle achievement student, Akara was a member of high achieving students which were all boys sitting in group at the center of the classroom. He usually participates in classroom activities for example, helped the teacher to carry teaching equipments during her demonstrations. Akara appeared to be interested in science, especially physics since he became a 10^{th} grade student. He came from middle level family. Even though his father was a scientist, Akara didn't want to be a scientist. He still had not made a decision what faculty he would like to study in after his graduation from high school.

Aubonpan was a 15 year old girl who sat at the back of the classroom next to Apinya's group. She came from middle level family. She usually participated in school activities such as staff in sport day management. At first, she decided to study in the science program because of her friends. Not long into the semester, she thought that science was too difficult and not appropriate to her. She hardly understood not only chemistry but also biology and physics. However, she did enjoy participating in classroom activities.

1.4 Classroom Setting

There were two rooms used for this class, one was a science laboratory and the other was a multimedia science classroom with computer and LCD projector. The science laboratory consisted of eight tables set in two columns and four rows (Figure 5.1A). The multimedia classroom consisted of nine tables set in three columns and three rows (Figure 5.1B). There were 15 groups of students seated at eight tables with 3 to 4 students in each group. The laboratory was used on Wednesdays while another room was used on Mondays.

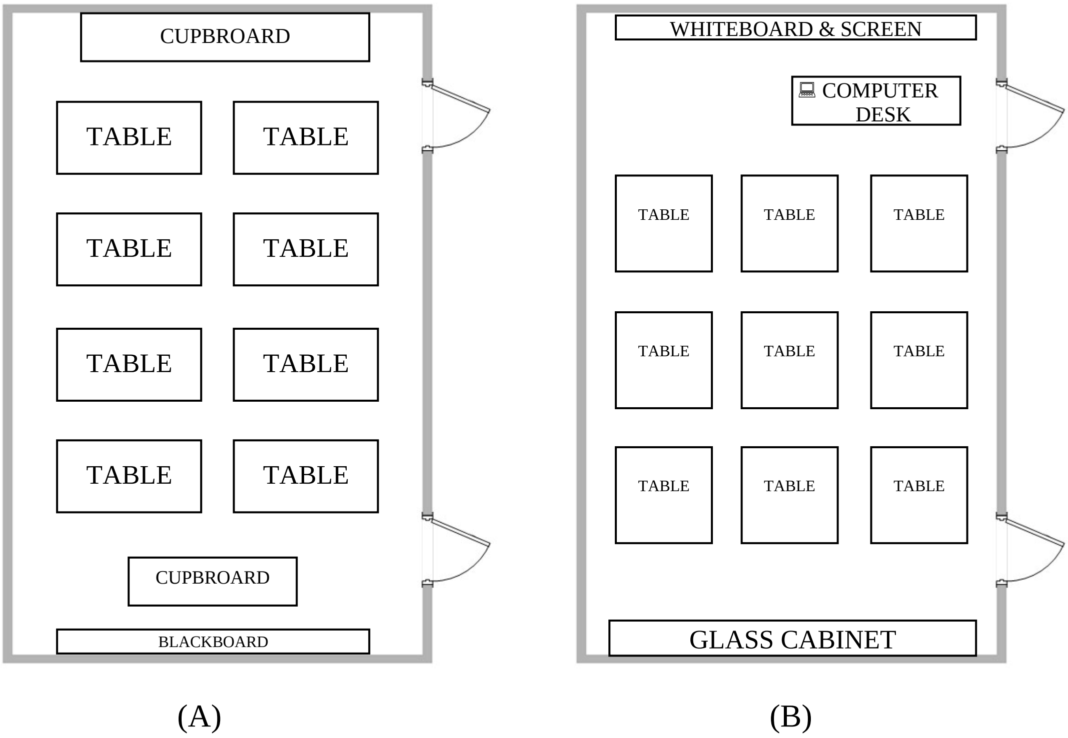


Figure 5.1 School A classroom used in the ASIU implementation (A) science laboratory (B) multimedia science classroom

2. Themes of Research Findings from School A

In this topic, the researcher drew together the main themes that represent a consensual picture of the consequences of atomic structure instructional units in 3 schools. These themes are derived from classroom observations, field notes, informal interview, NOSQ, ASCT and lesson documents.

2.1 Arunee's Implementation of the ASIU

Arunee's implementation of the ASIU emerged theme to be discussed here includes 4 topics. Firstly, she implemented the ASIU building after her experiences on professional developments. She knew that the nature of science was essential and a benefit to students. Implementation of the ASIU gave her opportunities to understand and practice the integration of the nature of science into her class. Second, she viewed the ASIU as a lesson that could help students change from passive to active learners. She thought characteristics of model-based approach were prominent in hands-on activity. An attempt to change students to active learners appeared in her practicing throughout the ASIU implementation. Third, Arunee's practices of atomic structure lesson were changed to reflective and explicit teaching according to the implementation of the ASIU. She implemented the ASIU with conceptual understanding compared to prior the ASIU. Lastly, she addressed the nature of science explicitly and held the conceptual understanding of the nature of science, Arunee tended to use lecture to emphasize some important concepts. Another reason for using lecture was because she didn't have time to review the sequences of lesson plans. She canceled classroom discussion that lead to the conclusion. Instead, she directly talked about the concept for the students.

2.1.1 The ASIU as Building on the Experiences and Professional Development

Even though teacher Arunee agreed that nature of science should be integrated into science teaching before implementing the ASIU. In her teaching experiences, she had never integrated the nature of science explicitly before but she expressed that she would like to teach more than scientific content. If it was possible, she will integrate the nature of science into her lessons. The problem was she didn't know what the nature of science actually was. She also had no ideas how to integrate them into her lesson. When she became the research participants, the ASIU met her expectations. She could relate the ASIU to her experiences from professional development. Before the implementation of the ASIU, Arunee talked about the value of changing her teaching methods. She critiqued on the traditional teaching method that students acted as passive learners. Even she had talked or commented on nature of science sometime in her class but previous lessons didn't give an opportunity for students to participate in the nature of science experience. From Arunee's view, teaching the nature of science was essential and came up with a new teaching method that she thought benefited the students more than the old style. Arunee had an internal drive for change. This prompted her to adapt her teaching.

The next step of her readiness to teach the nature of science came from three research workshops in present research. Three workshops could link back to her participation in professional development. Arunee collaborated with university researchers who helped her to do action research. In that professional development program, she developed her values of the nature of science. Previous professional development gave her the initial ideas to teach the nature of science. In this research, she said that ASIU gave her the opportunities to teach the nature of science. She made the conceptual understanding. She had a chance to implement the lesson that integrated the nature of science by herself. She gave comments on implementing the ASIU related back to her experiences as "the standard requires students to understand the nature of science. The professional development pointed to the values of teaching the nature of science. When I implemented it by myself, I have learned what it is and how to teach it" (Arunee informal interview pre lesson 4).

2.1.2 An Attempt to Changed Student's Learning Style from Passive to Active Learner

Arunee believed that implementing the ASIU could change students from passive learners to active learners. She also viewed that students' learning styles determined students' success on science in education. She pointed out that a model-based approach would help students to comprehend scientific concepts and the nature of science. From her view, traditional teaching, such as giving a lecture, still worked to convey only scientific concept. However, giving a lecture made students become knowledge acceptors which didn't enhance students' thinking skill. "They're used to be passive learners" teacher Arunee said during the first informal interview. She suggested that students who had experienced the lecture method made them become knowledge-acceptors which was not an effective teaching method for the students to conceptualize scientific concepts and aspects of the nature of science. This learning style didn’t support students to develop their higher order thinking. She commented on the ASIU after implementing lesson 1 as “It is good for the students to do the activity more than only sit and listen”. Her implementations of the ASIU reflected her intention to change students from passive learners to active learners. Arunee encouraged the students to actively participate in hands-on activities from the first lesson until the last lesson. It appeared that Arunee gave the time for the students to do the activity a large portion compared to other parts of the lesson.

2.1.3 The Influences of ASIU on Teacher’s Understanding and Practicing of the Nature of Science

Implementing of the ASIU changed Arunee’s understanding of the nature of science and also altered her teaching of atomic structure. After participating in this research, Arunee developed her understanding of the nature of science for all 8 aspects focused in this study. Before the lesson, Arunee spent 5-10 minutes talking to the researcher about the ASIU practice. In this conversation, Arunee reflected her understanding of the nature of science in respect to what a particular lesson addressed. For example, lesson 4 : Trace Rutherford’s Lines, Arunee asked if her understanding was correct. “This lesson emphasizes on observation and inference, doesn’t it? The students observed the video clips and made inferences in the next column”. She asked like this almost every time she was available. The conversation before the implementation of ASIU confirmed her conceptual understanding from the workshop earlier. Arunee had reflected her understandings of the nature of science in each aspect up to three times, in the workshops, before the lesson and during her teaching respectively.

The implementation of the ASIU influenced on her practices because every lesson intended to integrate the nature of science reflectively and explicitly. Arunee’s implementation of the ASIU made her teaching of atomic structure change from deficient, implicit and didactic category in the phase I result into explicit and reflective category in most of her implementation. When asked if she will extend the integration of the nature of science to other lessons in her regular practices, she said that she would teach the nature of science integrated into her lesson in the next semester. However, there were aspects of the nature of science that Arunee implicitly showed her reluctance to integrate into her teaching. They were theory and law, effects of social and cultural milieu on science and methods to do science. She didn't let the students discuss and she gave a short talk about these aspects in class. It was too brief to be grasped by the students. Her implementation of the ASIU emphasized on three aspects of the nature of science; theory and law, effects of social and cultural milieu on science and methods to do science, were in between of didactic to explicit and reflective.

2.1.4 The Inclination of Teacher-centered Teaching

Even though highly concerned about how to implement the ASIU to make a change for students, Arunee frequently switched to use her old teaching style. This happened at the beginning of the unit implementation. At the first class, inter-observer agreed that the teacher-centered approach was very obvious. This teaching style, lecture, appeared again many times despite that she tried to follow the lesson plan strictly. Her old teaching style had existing patterns which she had comment on during the last workshop

> ...I know that whenever I didn't read the lesson plan carefully I couldn't remember what questions to ask and how to make them [students] think. Sometimes I have other responsibilities such as a meeting with the school board. The class after that would not satisfy me. I know myself
>
> (Teacher focus group, the 3rd workshop)

Even though she had read the lesson plans to be taught she still needed time to review the details of the lessons again. The lesson that Arunee discussed with the researcher, she said that she could follow the lesson plan and she gave comments for her teaching at the class as 'successful'. When she was asked about her criteria, she said that 'successful' meant whenever the students had discussed about the issues raised in classroom and they could make a conclusion about scientific concepts and nature of science focused in the classroom. This was one method of her evaluation of her lessons. Time for preparing herself for the lesson was not so long. The researcher discussed with the teacher using 5-10 minutes to talk about the lesson. The conversation usually started with the lesson objective. The main aspect of the nature of science focused in that lesson. She also reflected her understanding of the relation between science concept and the nature of science. She reviewed the order of classroom activity. She called this process teaching preparation. She said the ASIU was new for her. Sometimes she had learned at the same time as her students did. It is to be noted that 5-10 minutes was not quite long enough but it positively influenced Arunee's confidence about her teaching. In the model-based approach class, Arunee had to work with multiple models e.g. physical model, computer model, conceptual model. She thought those teaching materials were not her obstacles to teaching the lesson. Even she had never worked with them before because this was the first time she used models to teach in her class. She could deal with those models such as black box from lesson 1: Seeing the Unseen through Models or VAST model from lesson 9: Modeling the Atoms, (Everyone Can Do It!). The absence of teaching preparation for her was questions to ask. Arunee felt difficult if she couldn't use the proper question for students to reflect their understanding of activities they engaged. To persuade student to the conclusion of the lesson, in her opinion, it would work if she could make up her understanding of the lesson. Otherwise she might turn to use teacher-centered teaching consciously and unconsciously.

2.2 Arunee's Implementation of the ASIU Influenced on Students' Understanding of the Nature of Science

2.2.1 Science is the Study of Natural Phenomena

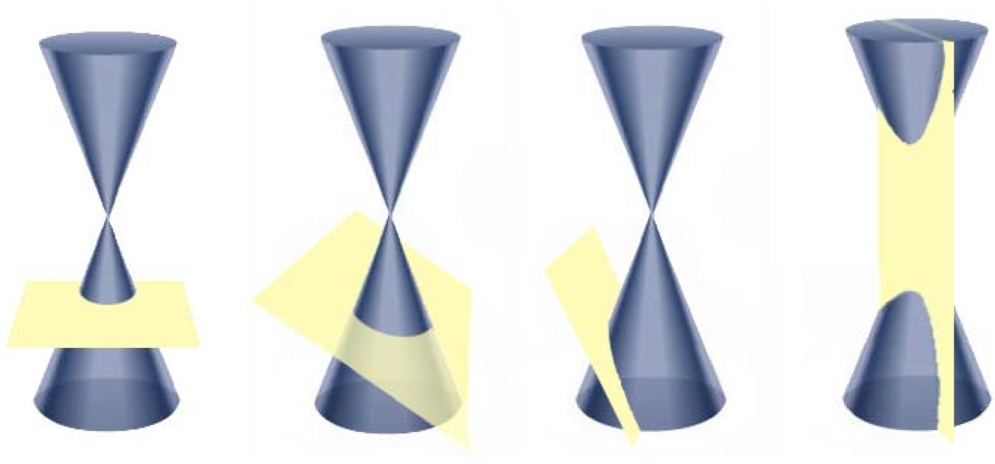
All three students from school A were able to explain about science before they engaged the ASIU. Comparing their answers on NOSQ before and after engaged the ASIU, meaning of science in students' view wasn't quite change. Apinya gave her answer that science was fact and the study of nature. After experiencing the ASIU, her view about what was science was still the same. Science in her view was the study of natural phenomena. For Akara, his views of science were broad and diverse more than the other two students. He explained science in several facets. Beside viewing science as a study of nature, Akara viewed science as credibility, methods of thinking and value of science. Science, according to Akara was the method of thinking that used cause and effect. Science could be trusted because it was provable. Science had values as it could give an explanation using principle and truth. In the case of Aubonpan before engaging the ASIU, science was the study of nature both living things and non-living things. Science sought for the truth from natural surroundings. Later, Aubonpan's understanding about science slightly changed to the study of natural phenomena, changing and truth.

2.2.2 Experiment Result, the Champion of Scientific Evidence, only Obtained by 'Scientific Method'.

Students after experiencing the ASIU, expressed their understanding that science relies on evidence. Evidence in the meaning of students obtained from experiment which followed only one method called 'scientific method'. When asked to talk about the role of evidence to the credibility of science, all students understood that evidence was needed to confirm scientific knowledge. Apinya stated that evidence was important for science. In her view, evidence came from the explanation of natural phenomena. If scientific knowledge could successively explain the phenomena, this could be the evidence for such knowledge claim. Apinya changed her view about the role of evidence in science after experiencing the ASIU. She added the word 'experiment' in her answer. Apinya stated that scientific conclusion was certain because scientists had new experiments and the knowledge claim was not in conflict with the experiment result or natural phenomena. Her answer was similar to Aubonpan's answer. For Aubonpan, evidence was needed by science but she emphasized that evidence that scientist relied on, must come from experiment.

Different from other two students, Akara didn't specify the type and source of evidence. Instead, he addressed the role and importance of evidence for scientific knowledge. It was to be noted that the view of sources of evidences related to the notion of method to do science. Students who think that evidence obtained from experiment also held the alternative conception that there was only one method to do science called 'scientific knowledge'. While students who didn't specify the source of evidence, Akara, also held the concept of there are multiple methods to obtaining scientific knowledge. Apinya had a strong alternative conception on the aspect of methods to do with science. She understood that scientists have only one method to study natural phenomena called 'scientific method'. At the end of lesson 3 on the topic of electrons, Apinya commented on the activity during the informal interview post lesson 3 as "many activities passed by but I didn't see the experiment as I had done. When would we do the experiment? I expected chemistry was about chemicals and working in a laboratory." Apinya already had a method to do 'science' in her mind. It was only one kind of research which occurred only in the laboratory, besides this, she didn't think it was a scientific study. The alternative conception about methods to do science were alike for Apinya and Aubonpan. Aubonpan understood that there was only one method that scientists used to search for scientific knowledge which was a scientific method. It's to be noted that Aubonpan used to have the conceptual understanding before she engaged the ASIU. From pre-NOSQ administered to the students before they engaged the ASIU, Aubonpan stated that there were 2 methods to do science. The first was scientific method. The second was the modeling with rational. After experiencing the ASIU, Aubonpan changed her answer to consider 'scientific method' as the only one method to do science. All scientists universally use this method.

Focused on what related to the understanding of nature of science in this aspect, tracking back to lesson 8: My Probability, My Orbitals, the lesson that addressed different methods scientists used to study atoms. This activity introduced the concepts of quantum mechanics model of an atom to the students. Students used the probability to be found themselves in school by mathematics at the same manner of scientists construct the orbitals of an atom. Students were asked to draw the region that they could be found on the school map every 30 minute starting from 7.30 to 16.00 from a regular school day. From spots, students were asked “What do the spots look like?”. After that students delineated the volume that gave orbital an apparent border in the inside which students was located. Students were asked again “What does the volume look like?”. The questions led the students to the comparison of their orbital and atomic orbital. In this part, the lesson aim was for the students to discuss about the concept of orbital constructions. However, the students didn’t have a chance to discuss. From the observation and field note (A8), the teachers took a role in this part. She read the questions and answered them. While the teacher talked in front of the class, Students checked their answers in the worksheet. For Apinya, she didn’t talk to her friends. Aubonpan and Akara were the same. The teacher finished this part of lesson without letting the students made any conclusion. The next activity in the same lesson, students tried to use their modeling skill to imagine the shape of conic sections. Students were asked to predict the shape of 4 different cross sections by the planar (Figure 5.2). This activity challenged students to use thought experiments to find out the answers. However, Arunee decided to reveal the answer by herself instead of letting the students find out. She talked to the class instantly after she assigned the task:



(1) (2) (3) (4)

Figure 5.2 Four different cross sections of conic geometry which students were asked to predicted the result by ‘thought experiment’

Arunee: Can you draw? This cut strength forward. This cut is slide. Make a little bit slide and drawing like this. When you go home, draw it from imagination...Let see how you can draw the shape….Let see how you use your thought experiment. [Prepare to let the students go]...Teacher Thunwa still doesn't come. So we have a time to draw. It doesn't need to have homework. I saw some students can draw the right answer conic section. [Teacher takes a break by 2 minutes and walk around computer table] Arunee starts to talk
Arunee: students, the conic has a shape like this [Arunee starts drawing the cone on visualize and explain how the conic sections look like]

(Field note A8)

This lesson finished by the teacher revealed the shapes of cross section of cone without any moment that students could express their understanding on modeling their orbital comparing to atomic orbital. Furthermore, students didn't have a chance to discuss about methods to do the science. Even though the experiment that Schrödinger use to develop his theory of quantum mechanics model of an atom. This class was omitted from those discussions that left nothing for the students except the very strong notion of universal scientific method. Akara was different from Apinya and Aubonpan. He held the conceptual understanding about methods to do science. The reason behind his proper understanding came from his background. In his personal interest, Akara was a scientist in nature. When asked if he thought himself as the same level of being a scientist? He said "I think I am. [a scientist because]. I'm curious. It's not only about nature but everything around us (Informal interview, post lesson 5)" In his answers on pre-ASIU NOSQ, Akara stated that there were two methods to do science. He thought scientists used both scientific methods and mental models to study and search for the answer. Later, he revealed that this notion came from a physics lesson. His physics teacher stated that there were 2 methods to inquire for knowledge, one was scientific methods and one was mental modeling. And then he changed his answer from "two methods" in pre-NOSQ to "several methods" in post-NOSQ which were observation, thinking methods, inquiry, experiment or mental modeling.

2.2.3 The Superiority of Law over Theory: Stereotype that Hardly to be Obliterated

The aspect of the nature of science that students were misunderstanding most was the aspect of theory and law. Similar to Apinya and Aubonpan, the conceptions on the meaning and function of theory and law of Akara were limited. This aspect was the only one aspect from eight that Akara held an alternative conception. Their ideas were widely similar or almost resemble those among teachers and students both in Thailand and internationally. They congruently thought theory could change but law couldn't change. This could be considered as a stereotype view of theory and law. When talked about 'law' people usually think about truth, fact which was extremely certain and unchangeable. Otherwise, theory was view as an educated guess, comment or even hypothesis.

The reason that made theory changeable for Akara was "theory comes from experiments of individual scientists" which wasn't the conclusion like law. For Apinya, in pre-ASIU NOSQ, theory was able to change because "Theory is comment based on knowledge, analysis, and evaluation and to be proved several times, then becomes law". It was clear that theory was developing law. In case of Aubonpan, her ideas of hierarchy of theory and law, was similar to Apinya. She stated "Theory is the result from several experiments but can be changed. Law is the developed theory which is developed in progress. It is fact and undisputable".

The lesson that emphasized theory and law aspect of nature of science was lesson 2: A Journey to Atomic History. Theory and law were discussed in the part of Dalton atomic model. After 3-4 students in each group had finished studying 6 stations which were the stories that how, what, when, where, why atomic theories were developed. The first station was about atomic theory in Greek era and the station 2-6 were Dalton, Thomson, Rutherford, Niles Bohr and Erwin Schrödinger atomic theory respectively. The students had to answer the questions that addressed the nature of science in two aspects. First, science heavily relies on evidence. And second, theory and law are both scientific knowledge. While laws are generalizations or universal relationships related to the way that some aspect of the natural world behaves under certain conditions, theory is inferred explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws. However, not all scientific laws have accompanying explanatory theories. In the part of Dalton atomic theory from station 2, the students were asked these questions:

> Why Dalton's atomic theory did become accepted?
> What is the evidence Dalton used to confirm his ideas?
> What is the Law of Constant Composition?
> What is the law of conservation of mass?
> What are the differences between theory (e.g. atomic theory) and law (e.g. the Law of Constant Composition)

The questions tended to motivate students to think about the differences between theory and law. Because in this part, both theory and law were related, students were introduced about theory and law ideas. Dalton used the experiment result from the other scientists such as Law of Definite Proportions, announced by Joseph Louis Proust, Anton Lavoisier and Robert Boyle. From the implementation of the lesson, theory and law were omitted for classroom discussion even they were addressed in this lesson 2. The critics came later on the 3rd focus group. All teachers participating in this study commented that if the lesson aimed to address the issues of law and theory, the unit should have the explicit activity related directly to law and theory. This lesson was too implicit and at least 'didactic' which research showed teaching teachers about the nature of science by didactic or implicit means had limited success (Abd-El-Khalick and Akerson, 2004). Besides these, nature of science in the aspect of theory and law was the biggest misconception held by both teachers and students (McComas, 1998b, Yutakom and Chaiso, 2007).

2.2.4 Developing an Understanding of Observation and Inference from Atomic Modeling Activities

Observation and inference, as the methods to study the unseen entities, was the aspect of the nature of science that students frequently experienced in the ASIU. This aspect was emphasized in lesson 1: Seeing the Unseen through Models, lesson 3: All About Electrons, lesson 4: Trace Rutherford's Lines and lesson 6: Can You See the Light as Bohr Did?. However, almost all scientists' experiment on atomic structure relied on observation and inference. Students' understanding of observation and inference at the earlier of the ASIU experiences wasn't clear. Later, appeared their conceptual understanding after experiencing lesson 4: Trace Rutherford's Lines, for example, when Apinya worked in group with 2 other students. She launched the marble and recorded its scatter line. She also predicted the shape of uncover object.

> Apinya: It wasn't flat like planar, from it reflecting line. I guess it must be a circle.
>
> Friend: How are you certain?
>
> Apinya: Look at this [scattering line]. It reflects depending how the edges of object look like. Every line is not the same.
>
> (Field note No.A4)

From her prediction, Apinya later realized that this was one of the nature of science's aspect. After class she said in the informal interview post lesson 4 as "Many of experiments or scientific inquiry we do like this. We don't know what the truth is, but we make a conclusion from the experiment result or what we have observed". After finishing lesson 6, all students could explain the difference between observation and inference. When asked why historical model was accepted at that time, Akara answered "because they inferred from the data available at that time. They constructed model according the phenomena they had observed".

2.2.5 Science is Social and Cultural Free: Little or no Growth in Understanding of the Social-cultural Dependent Nature of Science when Classroom Discussion was Omitted

Apinya and Aubonpan held the alternative conceptions of the influence of society and culture on the development of science. In their view, science is universal. It is independent from the value and norm of people in society. Science is free from social and cultural impacts. An absence of classroom discussion of lesson 4: Trace Rutherford's Lines left nothing to Apinya except her previous understanding that science was isolated from social and cultural norm and value. Unfortunately, the absent reflection and classroom discussion changed Aubonpan's conceptual understanding to alternative conception. The connection of society, culture and science was omitted again by Arunee's implementation of the ASIU. From classroom observation in lesson 4: Trace Rutherford's Lines, the aspect of nature of science related to society and culture were not emphasized. This activity engaged students to the experiment of subatomic particles with indirect determinations. Technique used by Rutherford was important to study the subatomic particles that were impossible to be seen directly. His experiments led to the development of his atomic model. In Rutherford's scattering experiment, alpha particles were directed at a thin sheet of gold foil with the idea of measuring the deflection of the alpha particles. From the data gathered, Rutherford was able to draw conclusions about the size of the nucleus. Students could learn about the concepts of Rutherford's experiment through this experiment. Students indirectly identified the shape of an unseen object. After that students read the handout "Particle Accelerator" and made a comparison between their experiment and the scientist's experiment with the particle accelerator. When the students finished the experiment, they were supposed to have classroom discussion which aimed to give an opportunity to students to reflect their understanding about the influence of society on scientific mega-project research such as particle accelerator at CERN (European Organization for Nuclear Research) and Jefferson Lab. It appeared that**:**

> Teacher Arunee sat on the seat in the front of the class, talking about the comparisons between Trace Rutherford's Lines materials of the activity and the real particle accelerator at Jefferson Lab. It was not quite classroom discussion. It looked like the teacher revealed the answers of the worksheet to the students. The classroom is usually not quiet. Students talk, but most are not related to the lesson. Apinya is writing something in her book. It's not chemistry book or worksheet. Apinya is probably doing her mathematics homework
>
> (Field note A4)

The big gap with this class was students didn't have a chance to express their understanding. The activity in the classroom was very important as well as the opportunities to reflect their ideas. Even though the class had an explicit activity integrating the nature of science, it changed nothing if the process of reflection was omitted.

2.2.6 The Use of Movie to Enhance Students' Understanding of Subjectivity Impacts on Scientific Enterprise

Lesson 5: Antarctica Adventure was one of the most explicit and reflective lessons for the nature of science. All students had the conceptual understanding that individual views, thoughts, values, agendas, and experiences determine what and how scientists conduct their work. In this activity students viewed the edited movie about the scientist who came to Antarctica to collect meteorites. The scientist conducted his work with appreciation to his sled dog which saved his life during the journey. After watching the movie, the students talked about the factors that impact scientists' work, for example, views, experiences, bias, feeling and so on. Students after experiencing the discussion on scientists work could point out effects that influenced individual scientists. They also extended this situation of characters in the movie to the real scientific work. As Apinya wrote on post- NOSQ:

> Two groups of scientists may think differently. For example, scientists who believed that dinosaurs became extinct because of meteorite impacts may see the evidence as the huge meteor impact craters. For another group, they may see the evidence as tremendous volcanic craters so they hypothesized that dinosaurs became extinct because of massive and violent volcanic eruptions
>
> (Apinya's answer on the NOSQ post the ASIU)

Akara and Aubonpan had the same ideas as Apinya. They could pointed that scientists were ordinary people who could be good and bad people. Students talked about how to validate the scientific knowledge claim as Aubonpan said:

> Research: What can we do to accept scientific claims from scientists who have emotions or feelings?
>
> Aubonpan: Do like [we did in] this activity. Check the evidence, work in groups, or let other scientists check their work.
>
> (Aubonpan informal interview post lesson 5)

Experiencing the ASIU not only enhanced their understanding of subjectivity in science, but also extended to peers review as the necessary process of the scientific community.

2.2.7 Understand Creativity and Imagination by Thomson's Experiment and Bohr's analogy of Atomic Theory

Students understood the role of creativity and imagination in science before they engaged the ASIU. They viewed that scientists used creativity and imagination for designing and planning the experiment. Their views reflected the nature of science in some parts because creativity and imagination plays an important role in every part of scientific inquiry not only just designing and planning. Students experienced two lessons that addressed this aspect of the nature of science. First, lesson 3: All About Electrons emphasized creativity and imagination as Thomson could design and adapt a cathode ray tube to several types. Students appeared to understand that creativity and imagination weren't used for design only, Thomson also interpreted the experiment data to constructed an atomic model. Akara pointed that creativity and imagination was needed because "the difficulty is how to make an inference from what you see". Apinya and Aubonpan congruently thought that without creativity and imagination, drawing an atomic model from experiment data might hardly occur. A later lesson of ASIU addressed creativity and imagination again but from a different point of view. In this class, students were introduced to how creativity and imagination was used to develop a conceptual model- Bohr's atomic theory. Lesson 7: Mix and Match for an Atom, introduced students to the analogy and metaphor in science, for example, Bohr used the solar system to create an analogy of his atomic model. In this activity students interpreted the similarity and difference between the solar system and Bohr's planetary model. Students expressed their understanding of creativity and imagination again by creating their analogy or metaphor to five statements of Bohr atomic theory. As well as presenting their ideas, students also created the analogies from the keys concept of Bohr atomic model. After that students identified the important parallel relationships linking the two systems. From the activity, the students critiqued the role of creativity and imagination as they were important in both the activity they experienced and the scientific enterprise. As Apinya said "Creativity and imagination are necessary for science but they must be based on fact and reason".

2.3 Arunee's Implementation of the ASIU Influence on the Students' Understanding of Atomic Structure

The research explored students understanding of atomic structure using ASCT one month after they finished experiencing the ASIU. Students' understanding of atomic structure concepts, according to ASCT analysis, were divided into three categories, conceptual-rational understanding (CRU), rote memory (RM) and alternative conception (AC). At first, students' prior knowledge was studied using ASCT before the implementation of the ASIU to study the influences of the ASIU implementation on students' conceptions on atomic structure. After students experienced the ASIU, it was found that students held conceptual-rational understanding more than rote memory and alternative conception category. Akara held CRU more than the other two students. He held 18 CRU, 3 RM and 1 AC. Apinya held 14 CRU, 6 RM and 2 AC. For Aubonpan she held 13 CRU, 4 RM and 5 AC. Akara held more conceptual-rational understanding in concepts than Apinya. Apinya held the number of the conceptual-rational understanding as same as those of Aubonpan. Three students' understanding of concepts in atomic structure were presented in table 5.1. Their understandings were categorized as CRU in Dalton's atomic theory, the nature of cathode ray tube, Thomson's atomic model, gold foil experiment, constituents of an atom, the relevance of atomic number and mass number, Bohr's atomic model, the nature of atomic orbital and valence electron. There was only the energy level of an atom that the three students' understandings were categorized as AC. Students' understandings of the other concepts were mixed. Each student had different academic achievement. The way each student participated in the ASIU was unique. These findings showed some interesting issues to be discussed, especially when related back to the ASIU implementation shown in the next topics.

Table 5.1 Concepts of atomic structure and school A students' understanding categories

Concepts	Apinya		Akara		Aubonpan	
	Pre-ASIU	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**
Dalton's atomic theory	AC	CRU	AC	CRU	AC	CRU
The nature of cathode ray tube	CRU	CRU	CRU	CRU	CRU	CRU
Observation and inference of cathode ray experiments	CRU	RM	CRU	CRU	RM	RM
Thomson's atomic model	AC	CRU	CRU	CRU	CRU	CRU
Gold foil experiment	AC	CRU	AC	CRU	AC	CRU
Constituents of an atom	AC	CRU	AC	CRU	RM	CRU
Atomic number	CRU	RM	AC	RM	AC	RM
The relevance of atomic number and mass number	CRU	CRU	CRU	CRU	CRU	CRU

Table 5.1 (continued)

Concepts	Apinya		Akara		Aubonpan	
	Pre-ASIU	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**
Isotopes of an element	AC	AC	AC	CRU	AC	CRU
Nuclear symbol	CRU	CRU	AC	RM	CRU	AC
Atomic spectrum	AC	RM	AC	CRU	AC	CRU
Bohr’s atomic model	AC	CRU	RM	CRU	AC	CRU
The probability of electrons in an atom	AC	RM	CRU	CRU	AC	CRU
Quantum mechanics model	AC	RM	AC	RM	CRU	CRU
Atomic orbitals	RM	CRU	RM	CRU	AC	RM
Energy level of an atom	AC	AC	AC	AC	AC	AC
Sublevels in energy level	AC	AC	AC	CRU	AC	AC
The nature of atomic orbital	AC	CRU	AC	CRU	AC	CRU
Aufbau principle	AC	RM	AC	CRU	CRU	CRU
Pauli exclusion principle	RM	CRU	CRU	CRU	CRU	AC
Hund’s rule	AC	CRU	RM	CRU	AC	AC
Valence electron	AC	CRU	AC	CRU	AC	CRU

Note: CRU = Conceptual-Rational Understanding, RM = Rote memory, AC = Alternative Conception

2.3.1 Students’ Identifying Atomic Model Physical Characteristics, Figures and Constituents

Students expressed their understandings of various atomic models by explaining their physical characteristics such as shapes, figures and constituents. These understandings were developed in the beginning of the ASIU implementation, lesson 1 Seeing the Unseen through Models and lesson 2 A Journey to Atomic History. At first, students viewed the atomic model as the physical version of the scientists’ theories. This understanding was the basis for further understanding in later lessons of the model, for example, functions of the model and concepts of such a model. Akara expressed his views on the atomic model as:

> The atomic model was a physical model of the atomic theory. Scientists used models to explain their ideas. In other words, models made their atomic theory simple to understand for other scientists and people.
>
> (Akara informal interview post lesson 1)

His understanding of model was the physical version of the scientists' ideas. It was similar to Aubonpan.

> ...I think scientists use models to explain theory. Like Dalton, he used billiard balls as a model for his atomic theory. He used billiard balls to teach the students in his class. This might let students understood better.
>
> (Aubonpan informal interview post lesson 1)

As they had seen the atomic model as the physical version of the atomic theory, students explained atomic the model by its shape and constituents. For example, all three students described Dalton atomic model during the informal interview post lesson 2. They explained Dalton's model as a round shape and spherical ball. Apinya compared Dalton's model with "a smooth boule". For Akara, it looked like "a snooker ball" and "It is round like a ball. It looks like the Styrofoam ball used in the activity." Aubonpan said. All three students could explain briefly Dalton's atomic theory but they weren't able to explain how Dalton used law of conservation of mass and law of definite proportion derived from his atomic theory. However, the lesson 2: A Journey to Atomic History didn't have the aim of students knowing the detail of each atomic structure. Students were able to explain the shapes of Thomson's atomic model**,** Rutherford's model, Bohr's atomic model, Quantum mechanics model and various atomic orbital. Their understandings of the physical characteristics of the atomic model reflected on their answers of the ASCT. All students held CRU on the concepts related to atomic model, for example, Thomson's atomic model, constituents of an atom, Bohr's atomic model and the nature of atomic orbital.

2.3.2 The Connections of Scientists' Experiment to the Inference of Atomic Models

Previous topics, student could correctly depicted Thomson atomic model. Furthermore, they were able to connect model to the cathode ray tube experiment. All students could explain that the modification of Dalton's model was the exist of electrons. From this, students were asked to indicate why Thomson inferred that an electron was the fundamental particle of every atom. It was found that all three students could explain why Thomson believed that the electron was the constituent of every atom as Apinya said in the informal interview post lesson 3: "Even though he changed kinds of gas or electrode, the cathode ray still existed. So he concluded that the cathode ray must come from any atom". Akara and Aubonpan gave the answer in the way as Apinya did. The reason they gave for Thomson's conclusion was the existence of the cathode ray and whether electrodes and gases were replaced. They were not only connecting the cathode ray experiment to the plum pudding model. The students could point out the most remarkable of Thomson's work related to the atomic model. As Aubonpan commented "The most important part of Thomson's work was the discovery of an atom. From Dalton atomic model, it didn't have the details. Thomson was the first person who proposed the discovered constituent" (Aubonpan informal interview post lesson 3). Akara had the different perspective from Aubonpan. From his view, the most remarkable part of Thomson's work was the way he conducted the experiments that led to the inference of new atomic model at that time. He said "I think the difficulty is how to make an inference from what you see. This is the real key to success" (Akara informal interview post lesson 3). From Akara's view, the connection of the experimental result to the conclusion that became scientific knowledge was very important as same as the scientific knowledge. For Apinya, she said that Thomson's modification of the cathode ray tube was the real creative work. In her understanding, different experimental designs of the cathode ray tube were the most important part of his work.

> ...When Thomson changed several designs of the cathode ray tube, for example putting a magnetic field or wheel into the tube. Those designs lead to the discovery of an electron and helped him to propose the new atomic model. If he didn't do this, he might never have discoverd the new atomic model
>
> (Apinya informal interview post lesson 3)

As the students could give comments based on their understanding of Thomson's work, it was to be noted that they had an understanding in concept of Thomson's experiment connecting the new model as the plum pudding model. The findings from the ASCT confirmed that the students had conceptualized the cathode ray tube experiment, the plum pudding model and the connection between them. Another connection of the scientists' experiment to atomic model that the students could understand as influenced by the ASIU was Rutherford's gold foil experiment. Arunee commented at the last focus group from the 3rd workshop that the lesson 4: Trace Rutherford's Lines was one of the most successful lessons that she implemented. However, this was the teacher's point of view. To explore the students' understanding of Rutherford's atomic model, classroom observation and informal interviews were needed to find the answer. All three students could explain what Rutherford's model looked like. However, they seemed to already know the structure of Rutherford's model before they engaged the ASIU. What they had learned from this lesson was the principle of the scattering experiment and how Rutherford's inference of the atomic model had come from what he had observed. Half of the time in lesson 4 was used for the scattering activity to construct the shape of the hidden object. Students constructed the model of the hidden object by rolling the crystal to hit an object and observed the reflecting line. After that students discussed their own experiences to the gold foil experiment of Rutherford and made a comparison. From this lesson the students came to understand the concept of Rutherford's experiment, for example, "…cannot observe an atom directly, Rutherford used an indirect way to study an atom. In his experiment, there were 3 main objects; shooting a particle, the target to be shot and the result to be observed" (Apinya informal interview post lesson 4). The students also explained more defiles as Akara gave more detail when asked to connect the experiment result to Rutherford's atomic model "It couldn't be

Thomson's model. There was something very hard and positive inside an atom. Rutherford called it a nucleus. Thomson discovered the electron first, then Rutherford discovered nucleus" (Akara informal interview post lesson 4). Responded to the lesson 4, Aubonpan expressed her understanding in both Rutherford's work and his model. She could connect them by indicating why Rutherford inferred that it must have been the nucleus in an atom.

> Research: Could you tell me why Rutherford believed that an atom does not look like Thomson's model?
>
> Aubonpan: the result from his experiments. The reflection of the alpha particle indicated the nucleus was inside an atom. It has a high density and high positive charge. It was also very small because most of the alpha particle could pass while it rarely reflected.
>
> (Aubonpan informal interview post lesson 4)

In this topic, all students had gained an understanding as a consequence of the ASIU implementation. From the post-ASIU result of the ASCT, the findings show that students held CRU on the concepts of the nature of the cathode ray tube, observation and inference of the cathode ray experiments and gold foil experiment.

2.3.3 Students' Understanding of Concepts within the Atomic Model

The students' understanding of the physical characteristics of the atomic model such as shape and figure later developed into a higher level of understanding of the atomic model. Since lesson 3: All About Electrons, the ASIU encouraged students to think about the concepts within model such as functions, explanations and conceptions of the atomic models to explain the target system. Atomic models constructed by scientists had the conceptual explanation within the physical characteristics. Scientists used concepts within models explained and predicted the atomic phenomena. The electron cloud model was the best example of this theme. From its figure, it was not difficult for the students to describe the electron cloud model. However, the concepts held by the electron cloud model were a key to this atomic model. The informal interview revealed that students could describe the electron cloud model as the representative of the probability to meet the electron in the region. Students explained the methods to construct the electron cloud model relating back to the activity from lesson 8: My Probability, My Orbitals. “The electron cloud atomic model is different from the previous model. It came from a high level of calculation” Aubonpan explained the methods to construct the model. However, the concept of quantum theory was too abstract and difficult for students. For the less complicated conceptual model like Dalton’s atomic theory, students could explain using the Billiard ball model. They were able to point to the theory behind the spherical ball as an atomic model. Apinya raised her example “even though his model didn’t have the information inside. He used his theory to explain this model. He could use his models to give an example of the chemical reaction”. The next example of the understanding of the conceptual model was the interpretation of the nuclear symbol. The question asked students to identify what information the nuclear symbol $^{39}_{19}K$ didn’t imply. To answer this question, students had to understand the concept within this mathematical model. The result was diverse. Akara had the CRU on this concept, while Apinya used her rote memory and Aubonpan held alternative conceptions. For the concept related to the electron cloud model. Aubonpan held CRU in both the probability of electrons in an atom, Quantum mechanics model while Akara and Apinya held RM. From classroom observation, the three students participated in the same experience in different groups. Aubonpan was the only one who had an opportunity to reflect her understanding in the class. She was selected by other members in her group as the representative to give the presentation of student’s orbital. Before she went out, Aubonpan prepared her presentation seriously for 2-3 minutes. For Akara and Apinya’s group, there were other students who were voted to present. Akara talked to his friends and Apinya worked on her student handbook while other students gave presentations. The situation was reversed when Arunee began to make a conclusion. Apinya stopped her work and Akara paused his conversation to listen to Arunee’s explanation about the concept of the atomic orbital. At the same time, Aubonpan started her work on her student hand book until the end of the class. These events during the ASIU implementation occurred in the classroom reflected on the students understandings' of conceptual model. Akara and Apinya held CRU on atomic orbital while Aubonpan held RM.

2.3.4 Student's Using Information of Atomic Model for Problem Solving

Since the atomic model of Rutherford had the details of its constituents, the students were introduced to the use of model information to solve the problem. Concepts related to problem solving were atomic number, the relevance of atomic number and mass number and isotopes of an element. From the ASIU implementation, atomic number and mass number were presented to the students as the extended concepts from Rutherford's model. It was found that the students rarely explained atomic number and mass number related to the atomic model. This detached them from the study of the model. From lesson 5: Antarctica Adventure, students could calculate the number of neutrons by subtracting mass number with the atomic number. They also pointed that "the number of protons equaled the number of electrons" in a neutral atom as Apinya explained. The next lesson, students learned to find the atomic mass by making a calculation to determine the average atomic mass of elements. However, students became confused between 'mass number' and 'atomic mass' after class. The problems occurred because Arunee didn't emphasize that mass number was the count of protons in an atom while atomic mass was the average of mass or weight of an atom. In summary, students could identify the number of protons, neutrons and electrons from the atomic number and mass number. They could identify atomic mass from calculating an average from the mass of isotope and their percentage of abundance. For problem solving, students rarely related back to the atomic model as the calculation related to constituents of an atom. The results from the ASCT showed that all students pointed that the atomic number could distinguish among the atoms of different elements. Nevertheless, they failed to give the reason why. Their understandings' were categorized as RM. For, the relevance of the atomic number and mass number, all students held CRU as they could explain the relevance among the atomic number and mass number to calculate the number of protons , electrons and neutrons in an iron atom. In the concept of isotope, Akara was the only one who held AC. He was confused about the difference between C-14 and C-12 isotope. Apinya and Aubonpan were successful in identifying that the neutron was the deferent between two isotopes. They also pointed out that C-14 had the same number of protons and two more neutrons than C-12.

2.3.5 Students' Understandings of Atomic Model as the Explanatory Model

Students viewed the atomic model as the explanatory model was not clear until lesson 6: Can You See the Light as Bohr Did? Apinya raised the issue of this function of a model at the first lesson. She explained the model and its functions. In her view, the role of model was its utility to explain atomic properties. When asked to clarify the role of the model in science, Apinya said "When scientists constructed at the model, such as the atomic model, they used them to explain the properties of an atom. The model was the representative of an atom. To understand the model meant understanding atomic structure." (Apinya informal interview post lesson 1). Her comment was a good clue to start exploring how the ASIU had an influence on the students' understanding of explanatory model. There were two lessons related to the topic of Bohr's atomic model. Lesson 6: Can You See the Light as Bohr Did?, aimed to promote the student's understanding of the atomic spectrum that lead to the propose of Bohr's planetary model. The next lesson, Mix and Match for an Atom, intended to promote the students' understanding of the key concept of Bohr's theory of an atom. During the activity, the students' conversation expressed the use of Bohr's atomic model to explain the phenomena. As Apinya spoke to her friends:

> Apinya: Different compounds have a different flame color.
> Student A: Yes, because it is a different element in those compound.
> Apinya: It means that different atoms in each compound have different energy.
> Student: Energy from burning?

Apinya: Electrons get energy from burning. It emits excessive energy in the form of the spectrum. That's why we call it the atomic spectrum.

(Classroom observation lesson 6)

The students viewed the succession of the planetary model as its effectiveness to explain the atomic spectrums. The need of the explanatory model was the reason for change from Rutherford's model to Bohr's model. Aubonpan commented on Bohr planetary model "Bohr's model could explain what happens inside an atom like the change of energy level, while Rutherford's model couldn't". When the ASIU moved from lesson 5 to 6, the students changed their views of the model from the representative of an atom to a tool for understanding and explaining of the phenomena.

2.3.6 Students' Using Symbolic Features Represented Microscopic Entity

In lesson 9: Modeling the Atoms, (Everyone Can Do It!), students learned to use VAST model to represent the electron arrangement in an atom. The representativeness of these models that linked the macroscopic level to microscopic level was another function of the models. The study of atomic structure always employs symbolic features as the bridge between the macroscopic and microscopic world. Students worked with VAST and used them as a symbolic entity to study the electron arrangement in an atom which focused on the Aufbau principle, Pauli Exclusion Principle, Hund's rule and the valence electron. The introduction of the lesson started when Arunee asked the students to consider seat diagram and concert tickets. She challenged how students explained the same function of seat number and electron configuration such as ${}_1s^1$ and ${}_2p^1$. Arunee later implied that the electron configuration compared to the seat number. She asked, "When you know the seat number, what do you do when you go to the hall to see a concert?". The students answered, "we know where to sit". Arunee asked the next question "When you know the electron configuration of an electron, what do you know about this electron?". Many students answered that they knew where the electron positioned. Arunee began the activity by saying, “Today we will learn to determine the region to meet electrons by using the VAST model and some principles from scientist”. Learning to use models as a symbolic feature consisted of two parts. Students participated in two versions of the VATS model, the demonstration version and hands-on version. In the first part, Akara participated in this activity as the volunteer. He held the plastic plate for the model to build on. Several pieces of transparent plastic were placed on the table. The other volunteers could select what represented the right orbital. Akara sometime told his friends to choose. “The smallest one must be the inner orbital…yes that is it”, he said to the first volunteer. The students in class helped each other to build up to the fifth element, Boron. For the sixth to twentieth elements carbon to calcium, students from 15 groups (3-4 students per group) randomly picked from the stick of elements. After that, each group constructed the model of an atom to represent the electron arrangement in an atom.

In this time the development of using symbolic features emerged as well as applying the Aufbau principle, Pauli Exclusion Principle and Hund’s rule. Students built up the model which they found it had violated the Pauli Exclusion Principle and Hund’s rule. From the beginning of the activity, the students called the equipment by its real name. For example, Aubonpan asked her friend, “How many black buttons do you want?”. Later, the students coined the representative name as Apinya said “this electron” for a black button or Aubonpan pointed Styrofoam ball “the nucleus”. Furthermore, Apinya’s friend used the VAST model and taught her friends about the Aufbau principle. The use of VAST as a teaching model was discovered by many students eventually. Almost at the end of the lesson, the students after finishing exploring and examining the 14 models from the other groups, took their model to present to Arunee. This was another time the students had an opportunity to reflect on their understanding. However, the presentation was limited to only Arunee and some students. It was not a class presentation. The atmosphere for critique and evaluating in the classroom was absent. However, in lesson 9, the activity was effective in terms of the students understanding the symbolic, microscopic and macroscopic entity and were able to use them to conceptualize the concept of the

Aufbau principle, Pauli Exclusion Principle, Hund's rule and the valence electron at the same time.

2.3.7 The Latent Concept and the Students' Alternative Conceptions of Sublevels and Energy Level of an Atom

From the observation, problems appeared during the implementations of the ASIU that impacted on the students' understanding of atomic structure concepts. It was found that the students hardly understood the latent concepts in the activity. Latent concepts meant concepts in subtopic that could be extended from the main concepts. Every activity had the main concept which needed the students to understand. This main concept consisted of a number of subtopics which related to the main concept. For example, in Chapter 6, there were two main topics to learn; the quantum mechanics model and the electron arrangement in an atom. The first topic presented to the students using lesson 8: My Probability, My Orbitals. This activity related directly to the concept of the probability of electrons in atoms. From this activity, the students engaged in the activity that used the same principle as the quantum mechanics model which related to a chance of electron moving around the nucleus. To elaborate this concept to the next concept, the questions were used to lead the students to apply their knowledge to the new subtopics. The new subtopics were atomic orbital and the energy level of an atom according to the quantum mechanics model and not Bohr's model. There were gaps between the activity, main concept and subtopics in the implementation of lesson 8. After the students presented their orbital, the teacher spoke about the atomic orbital and compared it to the students orbital but the elaboration of the concept was absent. The teacher didn't talk about the energy level of the orbital. The concept of the energy level was absent despite being stated in the lesson plan and there were pictures and explanations clearly in student textbook (figure 5.3)

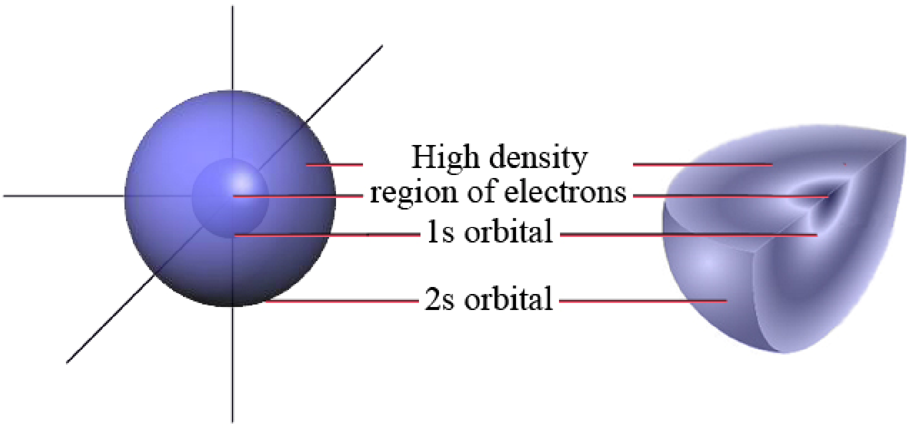


Figure 5.3 The overlay of 1s and 2s orbital, which were in the different energy levels

It appeared that all three students had the alternative conception in the topic: energy level of an atom. When asked to explain about the energy level of an atom according to the quantum mechanics model, all the students used the Bohr planetary model to explain. It seemed that all three students abandoned their understanding of the quantum mechanics model. Instead while explaining the atom which had a multilayer of orbital as a sublevel in the energy level, the students switched to use the less complicated model like Bohr's atom to explain energy level of an atom. Akara expressed his confusing notion after experiencing lesson 8: My Probability, My Orbitals as "I know an atom has an energy level, but I have no idea how orbitals arrange in an atom. I'm confused" (Akara informal interview post lesson 8). Akara thought he understood the atomic structure concept even though some topics was very hard to understand.

> ...I know that quantum is very difficult. This theory comes from a high level of mathematics. From the lesson, students didn't solve wave equation like Schrödinger did. We learn the principle. We learn about the probability of electron. What this electron cloud model does and I think I understand it.
>
> (Akara informal interview post lesson 8)

It was not only the subtopic energy level of an atom and sublevels in energy level that the student had difficulties to comprehend, but also the subtopics: atomic number and nuclear symbol, which was the extended concept of lesson 5: Antarctica Adventure. Arunee taught these subtopics not related to the activity directly. The extended topic was needed to talk carefully and explicitly about how it related back to the main concepts. Because the teacher left them behind by not connecting to the main concept, not surprisingly, confusion emerged on ASCT one month after the ASIU implementation (Table 5.1). The students' understanding on those latent were categorized as only alternative conception or rote memory.

3. Key Findings and Commentary on the Results Derived from School A

3.1 Related to the ASIU Implementation

In this research, Arunee implemented the ASIU with the existing value on the nature of science. The driving forces for her practice of the ASIU were her previous experience of professional development which addressed the value and benefit of the nature of science. It was incorporated with her expectations to change her students from passive to active learners. She implemented the ASIU as an opportunities for the students to experiences the hands-on activity which hardly occurred in the lecture class. Arunee changed from lecturing to student activity as a main teaching method. Considering the integration of the nature of science, Arunee changed from deficient, implicit and didactic to the implicit and reflective practicing of the nature of science in atomic structure lessons. During participating in this research, Arunee developed her understandings of the nature of science for all aspects. She had reflected her understanding several times, at least three times during workshops, pre lesson conversation and interview and lastly, during her implementation of the ASIU. However, Arunee couldn't abandon her old teaching style. As the ASIU implementation proceeded, whenever she had a chance, by consciousness, she would give a lecture. The times, that she usually gave the students a lecture, were during the introduction and discussion of the lessons. Another type of lecture teaching had given by unconsciousness. Whenever Arunee didn't have time for lessons preparation she tended to unconsciously give a lecture. She was familiar with lecture teaching for a long time so she could teach automatically without any script.

3.2 Related to the Students' Understanding of the Nature of Science and Atomic Structure

After engaged the ASIU, students had either changed or unchanged their understanding of the nature of science. They were able to explain what science was. Their common understanding was "Science is the study of natural phenomena". They could point that science relies on evidence. However, evidence came only from experiments. The students viewed science as the performing of the experiment. The only science activity for her was the experiment in the laboratory. Both Apinya and Aubonpan had an alternative conception in the aspect of the methods used to do science, theory and law and the interaction among society, culture and science. In contrast, Akara had a conceptual understanding in every aspect of science except theory and law. The findings showed that the students concept of the nature of science was the consequence reflection and discussion. If the students lacked of reflection and discussion, the lesson would not be effective. The implementations of the activities designed for addressing the nature of science should be aware that discussion or any opportunity given to the students to reflect their understanding had never been remised. Otherwise, this would inevitably result in the unsuccessful implementation of the lesson.The influences of the ASIU on the students' understanding of the nature of science emerged as themes discussed in the topic

The findings of the students' understanding of atomic structure were presented in seven themes. From seven themes became three key findings to discuss. First, the students' understanding was determined by the students purposefully and meaningfully participating in model-based activity. Comparing classroom observations to the results from the ASCT, it was found that the students had a tendency to hold CRU in concept that they understood well in activity. The next key findings, emerged when students participated in the ASIU in series, lesson 1-9. The data showed that the students developed their understandings of atomic models in progress. At the beginning of the ASIU experience, the students explained the atomic models as the physical models. They explained its physical characteristic, shape or constituents. Afterwards, students were able to connect the scientists' experiments to the inference in atomic models, for example, the cathode ray tube experiment and the development of the plum pudding model by Thomson. These understandings were developed when they experienced lesson 3 and 4. At the same time as developing the scientists' experiments to the inference atomic models, students appeared to understand the concepts within the atomic model. As this progressed, they began to view the atomic model as a conceptual model. For example, electron cloud model and atomic orbital. These models could not be seen as merely a physical model. Without the integration of understanding the conceptual model, the electron cloud model and atomic orbital were useless. Later on, students developed their understanding of utilities and applications of the atomic models. Students learned to use the atomic model for problem solving like atomic number and mass number and isotopes of an element. After that, students conceptualized another function of the atomic model to explain the phenomena. In other words, they learned how to use explanatory models such as Bohr's planetary model, in explaining the atomic spectrum. For the last lesson, the students expressed their understanding of another function of the model and modeling, the symbolic representativeness of the model. The students used the model as a symbolic feature to represent the microscopic properties of an atom. They comprehended this conceptual characteristic of the model by use of the VAST model to represent electron arrangement in an atom. In the last key findings, it was found that the misconceptions occurred with the latent concept. The students' misconceptions were discussed which related to the influences of the ASIU implication. When the teacher didn't explicitly extend the main concept to another concept related to hands-on activity, the left behind concept became the latent concept. The students' understandings of the latent concepts were also left behind too. The students' understandings of latent concepts were classified as AC, for example, energy level of an atom.

School B: Banburi and Her Students (Burin, Benjawan and Buttree)

1. Introduction

1.1 School Context

The founding of School B in 1992 related to the celebration of her majesty the Queen of Thailand's Birthday in the sub area of Bangkok. The school covers teaching from Grade 7 to Grade 12. The school is a special large size school with 3046 students and 132 teachers. There are 50-60 students in each class with 11-11-12 class system of grades 7-9 and 45-50 students in each class at each grade from 10-10-9 class system of grades 10-l2. For grade 10, the classes are separated into three programs with four classes in the science program, two classes in the social and mathematics program, and four classes in the social and language program. There are 16 (male 4 female 12) science teachers of which three are chemistry teachers. Each chemistry teacher teaches in each of Grades 10-12. The students in three classes in the science program in each of the grades 10-12 were put in their classes using GPA (Grade Point Average) from Grades 7-9.

1.2 Teacher (Banburi)

Banburi (a pseudonym) graduated with a bachelor's degree in education with a major in chemistry and minor in mathematics. After she graduated, she taught mathematics for four years. She started teaching chemistry in 1978 and so at the time of the study she had taught chemistry at the high school level for 27 years. Banburi preferred teaching organic and biochemistry. She did not like to teach quantitative chemistry (i.e., numerical calculations) because she thought it was hard to help students understand chemistry calculations. She liked to teach chemistry in Grade 10. She said: "Grade 10 is the first year for learning chemistry. If students have a good attitude towards chemistry, they will like it and not feel it is too difficult". She had to teach atomic structure because this was one of the topics for Grade 10. When teaching atomic structure, she begins with the memorizing of the first 20 elements in periodic table. In this semester, Banburi taught chemistry in Grade 10 for a total of nine periods for a week as well as also working in an administration office as a head of the school finance.

1.3 Students

One science program class at Grade 10 was selected by Banburi. There were 49 students in this class with 17 boys and 32 girls. The students were aged 14-15 years. Students in this classroom were heterogeneous of their academic achievements because school management randomly sorted students into classes.
Most of the students were from middle and lower socio-cultural status. Three students who were participants in this study were two boys and one girl, Burin, Benja and Buttree.

Burin was 14 years old at the time of the study. He was the student who sat in the group of all boys of the back of the classroom. He came from middle class family living near the school. His parent was office workers. At first glance, Burin didn't look active. His appearance were prudent, be immersed in thought and silent. Wearing eyeglasses, Burin looked scholarly. His academic achievement from middle school was good according to Banburi's comment. However, he had a sense of humor as well being as self-confident in expressing his ideas. In lesson 9 Modeling the Atoms, (Everyone Can Do It!), Burin came to present VAST model to the:

> This is the nucleus of an atom" Burin said. His hand holds the Styrofoam ball, the model of the nucleus, stuck with buttons in blue and red color which represented of the protons and neutrons. Students in the class are chuckling because he arranges the buttons to a smiling face. Later, he spreads the protons and neutrons all over the nucleus. "Even thought arranged by mistake, the number of protons and neutrons are right" his words make the class laugh again.
>
> (Field note B9)

Burin was a real fan of gaming. He loved to play both computer games and Play Station. Burin also loved to read comic books. His friends were interested in the same things as him. When they had free time, the boys usually talked about games, sports and other interesting issues. Science was one of the issues the boy often talked about.

Benja was an average achievement student from his background in middle school. He was a 14 years old. Benja's seat was in the first row. He sat next to Buttree. Benja always looked happy. He was a talkative person but quiet when the teacher asked or encouraged him to express his ideas. Benja had a good attitude toward science. He preferred to learn with hands-on activities rather than being taught by lecturing method.

> ...I like to work in a group. Doing things together with my friends is the way I like to work. If I don't' understand from the class I will get my friends to teach me whenever we have the free time. For group activity, it's like, we have been tutoring at the same time as learning.
>
> (Benja informal interview post lesson 3)

Buttree was a close friend of Benja. She was 15 years old at the time of the study. She came from a Chinese-traditional family with middle socio-cultural status. Her parents had their own small business. Buttree had been trying to enter a prestigious school, since graduating from middle school. The low percentage of acceptance made Buttree disappointed. Now, she felt happy in this school because the school was famous in this education district. She joined the group of her old friends which were good students. Buttree sat at the front of class and would concentrate fully. Her attentiveness also helped with her friends' study.

> ...Because I'm not a clever student, I have only 2.9-3.0 points of GPA from middle school. Before midterm or final examination, we have group tutoring. Sometimes this is would be at school, but mostly we went to someone's home.
>
> (Buttree informal interview post lesson 2)

Buttree was shy to express her ideas both in the classroom and the informal interview at the early states of the lesson. She had more confidence to communicate her ideas later. Almost every time Buttree was the first presenter of her group. This was especially so in lesson 7-9.

1.4 Classroom Setting

There were two classrooms used to implement the ASIU; the science laboratory and the normal classroom. The science laboratory consisted of eight tables set in two columns and four rows (Figure 5.4A). There were two groups of students at each table and about three or four students in each group. In the first few periods of implementing the ASIU, Banburi taught in the laboratory classroom because she thought it was more comfortable for students to sit in a group. However, the students complained that the laboratory was unsuitable to study because when the teacher talked from the front of the class the students at the back could not hear what she said. Furthermore, the building was blocked by two other buildings so the air didn't flow. For example, during the lesson 6, the students observed flame color and line spectrum. This made the laboratory very hot, to the point of sweltering. The odor of chemicals such as alcohol was strong in the air. Banburi couldn't stand it. She moved to the front door and then left the room for a while. The normal classroom was in the stand-alone building. The atmosphere of that room was airy. The table arrangement could be changed during the implementation of the ASIU. Students moved their table to join in groups. It seemed that both Banburi and her students preferred the normal room more than the science laboratory.

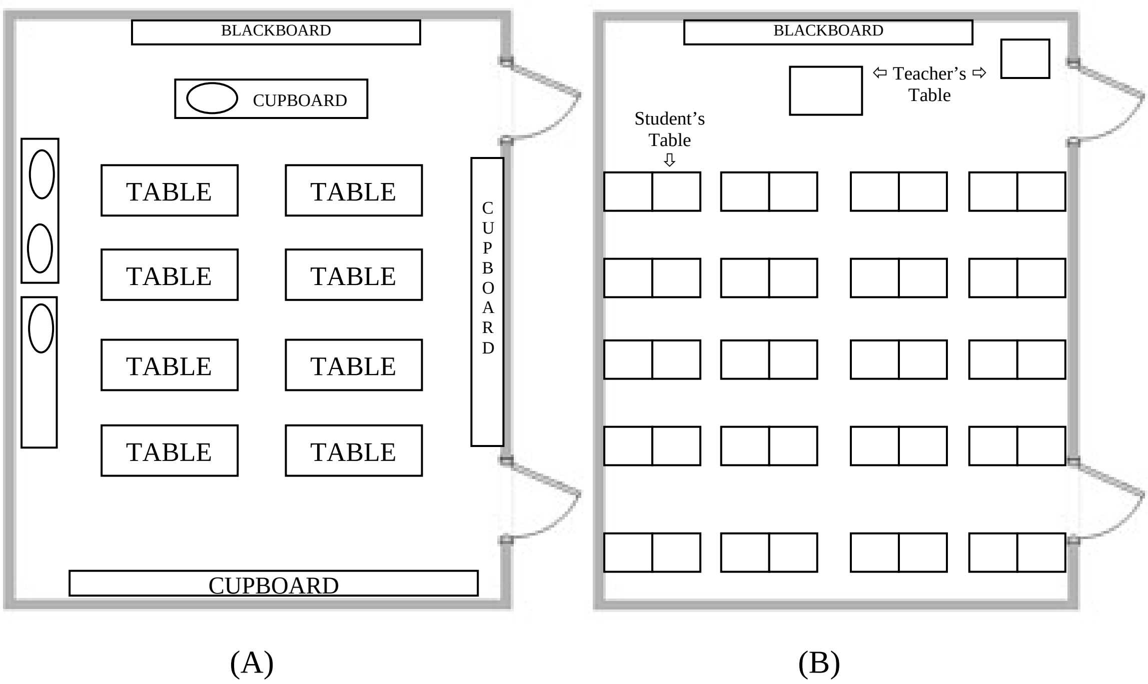


Figure 5.4 (A) Science laboratory and (B) Normal classroom

2. Themes of Research Findings from School B

2.1 Banburi's Implementation of the ASIU

There were many factors influenced by the ASIU implementation of Banburi. Some factors culminated in a positive way such as the open-minded and worry free way to teach using the new style. Some factors impacted on a negative way of teaching such as special duties for the teacher and the office atmosphere. Other influences would both support and impede Banburi's implementation of the ASIU. The impacts of those issues were discussed at the following.

2.1.1 Experience Teacher with Good Understanding of the ASIU Cloud Organize the Lesson Effectively.

Banburi had the responsibility to teach chemistry nine periods a week. It seemed very little teaching time compared to other teachers. However, Banburi had special duties as head of school finance. Her table was in the school office room. She sat next to the school vice principal's room. Working in the school office was different from work in science department. Almost all the time, the conversation in the school office related to school management, administration and finance. Even the teacher sitting next to Banburi was a science teacher, but they rarely talked about science and science teaching. Since she had the atmosphere of school management around her desk, preparation for teaching appeared short before going to class. Sometimes teaching preparation didn't occur. Many times during conversations, Banburi had to leave the interview to deal with people who visit the school in many purposes. The people came to meet Banburi such as electricity official, other teachers in the same school, parents and the school car driver etc. One day before the implementation of lesson 7, many people met Banburi as the field note describes.

> In the school finance office, June 2007.
>
> The conversation had stopped because a student's parent had come to talk with Banburi. Today is not different from other days; Banburi is busy with school payment such as water, electricity and various monthly payments. Many people call her on the phone, while many other people visited her in person. While she talked to the parent, there were 10 minutes left before she had to teach in the ASIU class. I'm afraid that she will forget the important target of the nature of science to be addressed. For the scientific content, Banburi could naturally teach them. I've planned to talk about the target of the nature of science when we walk to the classroom.
>
> (Field note B4)

What made the implementation work well in each class had not relied upon good preparation. Because Banburi had long experience in teaching chemistry, she could organize the objectives of the lesson she intended to do. Furthermore, the ASIU emphasized the students' role more than the teacher's role. Banburi's special duties of didn't have an affect on her teachings. It appeared to be noted that the ASIU needed less time to prepare if the teacher could understand the lesson objective and the nature of science to be addressed.

2.1.2 The Teacher's Expectation Reflected on the Teacher's Practices.

From the interview in phase I, Banburi expressed her expectation on teaching of atomic structure to make the students develop their skill of mental modeling. She also said "I prefer everything that is easy for the student to learn... Make it easy" (Banburi phase I interview). Her expectations reflected on her practice of the ASIU. She viewed the lesson as the easy thing to do. She had never complained about the obstacles in teaching and learning with the ASIU. When she implemented the ASIU, she expected to enhance the students' learning, for example, she moved students to the computer room and meeting room. She viewed that these rooms were appropriate as they had technical equipment. Banburi wasn't a strict teacher. She was kind to the students, so the students weren't afraid to talk to her about not only academic issues but also general conversation. Banburi expressed a positive view about her students at the early states of the ASIU implementation.

> ...What do you think about our students? They are lovely and gentle. I can say that school B students are good. They come from middle or lower class families. These students are polite and they also have a good relationship with each other. They have a high EQ.
>
> (Banburi informal interview pre lesson 2)

Banburi didn't have an expectation of salary promotion because she had almost retired. When talked about the future of her career, she commented on her retirement as "I will retire as soon. I have planned to build a computer room for the science department. It will not be too big. I think it will have about 10-15 PCs…not too many but enough..." (Banburi informal interview pre lesson 4).

This statement reflected Banburi's perspective of technology. Banburi expected the students to learn science with a technological enchantment. For her, good technology helped students to learn science. Whenever the lesson plan related to computers or videos, Banburi reserved those rooms by herself without any request from the researcher. They were two times that Banburi brought the students to computer room. The computer room was under Computer and Technology Department of the school. The room contained 60 PCs with Internet LAN and projector for displaying the monitor on a big screen. When the lesson needed Banburi to play a video for the students, she moved her class to the school meeting room. This room had a big screen of LCD projector. When she dimmed down the lights, the meeting room became a theater which made the students more interested. Classroom discussion took place in this room too. The atmosphere and table arrangement in the meeting room made the classroom discussion more serious. With or without expectation, Banburi gave the students a realistic experience of a scientific conference in this room.

Even when she spent most of the time with the modeling activity, Banburi also encouraged the students to reflect their ideas by reflecting and discussing. This opportunity to allow the students to talk, present, and discuss didn’t appear in lesson 1. At the end of lesson 1 Seeing the Unseen Through Models, she instead let the students talk as the lesson plan had determined. The students sent their models and student hand books to the teacher to check for accuracy. In this process, Banburi read, checked, and signed her signature as the symbol of homework submission. From this method of evaluation, students didn’t get to know why and why not their answer was correct or incorrect. Furthermore, students missed the opportunity to evaluate, analyze, compare, and change their misunderstanding into conceptual understanding by presentation and discussion in the classroom. Since lesson 2 A Journey to Atomic History, Banburi gave students opportunities to express their ideas. Banburi later showed that she expected to listen to the students’ ideas. In lesson 4 Trace Rutherford's Lines according to the lesson plan, there were only some groups that were randomly selected to present their ideas. When two groups had already presented their ideas, Banburi changed her mind to let all the groups presented. “I would like to hear what they think” she gave as the reason for her decision. When asked about the students’ achievement compared to the normal classroom, Banburi expressed that she didn’t want to compare the students’ achievement. As she said “you cannot compare with other classes because different experiences needed different methods of evaluation. It couldn't be compared [between students from the ASIU class with those from the normal class]." (Banburi informal interview post lesson 9). Banburi's statement indicated that she didn't expect this class to have better achievement than other rooms or vice versa. Rather, she preferred her students to experience hands-on activities that altered the students' experiences. In describing her ASIU class compared to her regular teaching on atomic structure, Banburi said that the experiences gained in the ASIU class gave the students more than just scientific knowledge:

> …When I teach the other class, I introduced the element periodic first, after that taught them to remember the first twenty elements. Afterwards, I taught atomic structure. Atomic structure takes not more than one month to tech. For the ASIU, I try to implement it for not so long compared to my normal class. However, during learning with models, the students get more than scientific content.
>
> (Banburi informal interview pre lesson 3)

Banburi didn't talk or showed her worries about implementing the ASIU. She felt confident to teach in the new style. It was to be noted that the students from school B also didn't request content-based learning. They didn't compare their lesson to the others as it was slower than other classes. It seemed the teachers' confidence reflected on the student's trust in the ASIU.

2.1.3 Teaching with Flexibility

Banburi had a portion of good organizer. In the first lesson, Seeing the Unseen through Models, she implemented the lesson within 3 periods according to time schedule in the lesson plan. Furthermore, her flexible personality had an influence on the ASIU implementation. It was her belief that the teacher could do thing wrong. In lesson 8 My Probability, My Orbitals, she had a misunderstanding with calculating the percentage. Banburi used her long experience of teaching chemistry to solve these problems. In the front of the class during giving an example to the method on how to calculate the percentage of probability found in students in a particular region, Banburi became confused about the time and number to be calculated, she stopped to read the lesson plan and changed the method of calculation immediately without any panics or worry. Banburi developed her flexibility in the ASIU implementation with the passing of time.

In the last lesson, Modeling the Atoms, (Everyone Can Do It!), she let all the groups present their constructed VAST models. The time for presentation of each group was approximately 2-3 minutes. The teacher decided to extend the lesson to another period to let the student of all groups have the same chance to reflect their ideas. Despite the limitation of time, Banburi lengthened her schedule because “it benefited the students” as Banburi gave her reason after finishing lesson 9. There were four classrooms used in the implementation of the ASIU by Banburi. At first, she used the regular class that arranged the table as line of troops. Students could change their position when they combined and worked in groups. When the lesson activity needed more space, Banburi moved the students to the laboratory room. The tables were round and the room had more space than the regular classroom. However, the room’s location was not appropriate to do the experiment. The wind did not flow out because it was blocked by the computer room and the next building which were both opposite. During the time of the ASIU implementation, the computer room opposite the laboratory was used twice in lesson 1 Seeing the Unseen through Models and lesson 5 Antarctica Adventure. Another room used during lesson 5 was the school meeting room. Banburi decided to show the students a video in this class because:

> ...I reserved the room for showing the movie because it had a big screen and LCD projector. The technician told me it was available today. We were lucky. This wasn’t a meeting at the same time as our lesson. The sound and light system was pretty good. The technician also adjusted the light level to make the room appropriate to show a movie.
>
> (Banburi informal interview post lesson 5)

Banburi knew how to use the school resources to the benefit to the students. She was ready to adjust or change her mind, schedules or classrooms, whenever they supported teaching and learning. This characteristic supported her implementation of the ASIU. Banburi was not only flexible in physical things, but also in her teaching. She continuously reduced her role in the class and encouraged the students to participate more in the lesson. For her, all the students must have an equal opportunity in the lesson, not only some groups or some students as representatives.

2.1.4 Teacher as an Activity Organizer

The role of Banburi during implementation of the ASIU was as an activity organizer. In the first lesson, Banburi was clear in her role after she had read the lesson plan.

> Researcher: What do you think about the ASIU in teaching for the student?
> Banburi: I don’t think it will have a problem. I have read the lesson. I found that the students will participate more in hands-on activities. The lesson required the students to learn and do things such as constructing a model and have a discussion.
>
> (Banburi informal interview pre lesson 1)

In almost every class, Banburi briefly talked about the lesson introduction and activity guidelines. She avoided using the lecture teaching method. The general atmosphere in every class was as the field note described:

> After Banburi briefly presented the modeling activity, she walked around the classroom while the students worked in groups. Banburi talked to the students group by group. The questions asked by the students were about the activity and the exercise in the student handbook. Like the past lesson, Banburi gave the students enough time to discuss in groups. It was about 15-20 minutes before she asked the students to present their ideas. During the presentation,

> there were discussions at the same time. Towards the end of implementing the ASIU, the distinctive point of Banburi's teachings were (1) she usually avoids giving a lecture (2) lessons were driven by the students such as doing hands-on activities, answer the questions and discussions (3) highlights of the lesson were student's lead role on activities and discussions.
>
> (Field note B7)

From the observation, Banburi often placed herself at a side of the blackboard listening to what students said. She let the student stand in the middle at the front of the class. And then she gave praise and asked the next group to come and present. Sometimes, she gave comments and asked questions to encourage students to think about the issues. She asked students to brainstorm and share their ideas. Besides the first lesson, Banburi was constant on her role as activity organizer for all the ASIU implementation. As the classroom field notes described:

> Banburi spokes with the students at the back of classroom. When the time for group discussion had finished, she walked to the front of her class, opened a student hand book and started talking:
>
> Banburi: Students, look at the first question. Who wants to answer this item? Explaining the concepts of the Bohr planetary model, who wants to answer?…..Quickly.
>
> [Break]
>
> Banburi: Answer.. What is it? Explain.
>
> There was a student standing from the right side at the back of the classroom. She prepares to answer the question.
>
> Students: The Bohr atomic theory explained the orbit of electron as the planets orbit around the sun. He compared electrons with planets and compares the sun to the nucleus. However, in his model, the electron in inner orbits has lower energy than the electron from outer orbit.
>
> Banburi: Good….Bohr compared his model to the planetary model as it is alike in terms of orbiting. You got 2 extra points. The next question asked you

to compare the same and the difference between the Bohr atomic model and the planetary model. For this question, I give 3 points.
[Many students raise their hand]

(Field note B7)

After that, the students presented their matching of familiar analogies with the five main Bohr atomic theories. During the presentations, the students took lead roles while Banburi acted as the commentator. From an informal interview post the implementation of lesson 5, Banburi expressed her views of the classroom discussions as “Students learned so much while they discussed. They learned from what they had done. They learned from the right or wrong answers of members in their groups. There are learning communities in groups and classroom discussion”. Even Banburi explicitly revealed her belief on classroom discussion as the effective way to make the students learn better and she had already been using a group and classroom discussions since lesson 2. She also kept this teaching method until the ASIU implementation had finished.

2.1.5 Teachers’ Understanding of the Nature of Science

Lederman (1999) found that a teacher’s conceptions of the nature of science do not necessarily influence his or her classroom practice but the teacher’s conceptual understanding of the nature of science appeared to have some degrees of impact when the teacher committed to integrate the nature of science in a classroom. The teacher, whether understanding the nature of science or not, didn’t have an impact on the students’ developing an understanding of the nature of science when they couldn’t go beyond the implicit teaching of the nature of science. In other words, the reflective and explicit integration of the nature of science relies on the teacher’s understanding. Banburi was an example. Her conceptual understanding of the nature of science in many aspects was worthless when she left behind the pro-content teaching as the result of the first phase of the research. During the ASIU implementation, the lesson plan emphasized the nature of science in each activity.

Banburi’s conceptual understanding of the nature of science appeared to be significant, especially the aspect of social-cultural and scientific interaction.

Banburi held that science both impacts and was impacted by social and cultural milieu that is embedded in science. This notion obviously emerged in lesson 4 Trace Rutherford's Lines. After doing the scattering experiment to infer the shape of a hidden object under the cover, students were introduced to the particle accelerator that was developed from Rutherford’s gold foil experiment. The students compared their scattering activity with the particle accelerator operated by Jefferson Lab. The students compared the same and difference in terms of energy source, accelerator, probe, unseen target, data collector, predictor, time taken for one experiment and cost. In the lesson plan, Banburi asked students to answer the questions: (1) Where is the money to invest for science research coming from? (2)What happens if society doesn’t have an interest or understanding of science? (3) Is public understanding of science influencing the development of science? (4) Why should everybody have to study science even though their carrier doesn’t relate to science? After that the students read the handout “Why Support Science?” and the students answered these questions in the classroom discussion again. The questions were (1) what are the effects of society toward science? And (2) what are the effects of science toward society? At this point, Banburi changed the procedures of teaching as noted in the lesson plan. She assigned those questions for the students to answer in groups. After that the students came to the front of the class and presented to their friends group by group. Students would like to diverse the task for all group members. In the group presentation, most of the students in the class had a chance to talk which they were reflecting upon their ideas on the nature of science. Banburi didn’t talk too much. She placed herself as the presentation organizer. When each group had finished, she made a summary. She selected only right answers to address again before she called the next group. Finally, she asked the students to make a conclusion as a holistic summary from the students’ presentation. The conclusion was “Science, culture and society: science as a human enterprise is practiced within, affects, and is affected by a social and cultural milieu”. This lesson finished to Banburi’s satisfaction as she gave praise to the students “The students had good ideas, didn't they? Their presentations were interesting. I think they did it well today" (Banburi informal interview post lesson 4).

If Banburi had an alternative understanding in this aspect, she would implement the lesson in different way. It might be that the classroom discussion would be remised. On the contrary, Banburi not only asked the students to explicitly talk about the interaction of society, culture, and science, she also gave this reflective opportunity to all of the students in the class.

2.2 Banburi's Implementation of the ASIU Influence on Students' Understanding of the Nature of Science

2.2.1 Science, Society and Culture Connecting: Bridging the Gap with "Classroom Reflection and Discussion"

Classroom discussion brought sociocultural issues to the lesson. Compared to the normal class of Banburi's, there was no room for other issues to discuss beyond the atomic structure. Despite many stories of scientists and scientific enterprise related and influenced by the society and culture in which the atomic study was practiced. The ASIU in lesson 4 was the only one lesson that explicitly addressed this aspect of the nature of science as the target. It was Banburi who was able to challenge students to think, talk and communicate to their peers. The lesson could fill the gab between school science and real science and society by raising sociocultural-based characteristics of science during the classroom discussion.

The strong point of Banburi's implementation of the ASIU was the opportunities for the students to reflect upon their ideas. According to lesson 4 Trace Rutherford's Lines, after completing their worksheet students were asked to answer the question "Why do we support science?" This question related to the student handout, "Why support science?" which was adapted from the overview of the article "Fermilab's Contributions to Science and Society" (Fermilab, 2006). Banburi gave students 3 minutes to talk to the classroom. During group discussion, Burin's group reflected their understanding in a group discussion before presenting. The conversation focused on the value of science on economics and politics.

> Burin: …Because science related to us, in every part of our lives.
>
> Friend 1: It is related to economics. That's why a big country develops science.
>
> Friends 2: Like Japan or America. Those countries are rich, as well as being advanced in science.
>
> Friend 1: They are rich because of science, or they developed science, so they became rich.
>
> Burin: It was not important. The point is they are both rich and advanced in science. Therefore, science and economics are related.
>
> Friends: Yes. Science is related to the military too. Don't forget the technology of nuclear weapons, missiles, and rockets.
>
> Burin: Therefore, it is related to politics, too.
>
> Friend 1: Sure, that's why we have to support science.
>
> (Classroom observation B4)

While Benja and Buttree's group talked about the effects of society on science, their ideas about scientific development was very much dependent on society.

> Benja: It wasn't that good if people in the country were only interested in physical things such as roads, buildings and bridges. Science needs to be supported by people, in other words, from people's tax.
>
> Buttree: Not only financial support, but what if people don't want to learn science? Who will be the scientists?
>
> Friend: Yes. It will have the lack of human resources if nobody wants to be scientists.
>
> (Classroom observation B4)

The classroom discussion came after a group discussion had taken place in each group of students. Burin was the first presenter of his group. He presented his understanding to the class as:

> …There are three main reasons why we have to support science because if people in a country don't participate or aren't interested in science, science won't progress. There is no new knowledge, new technology…

(Classroom observation B4)

Before engaging the ASIU, Burin already had the conceptual understanding of the nature of science in the aspect of science, society and culture. He viewed the values of science as people need science to make their life better. He described, "Science reflects social and cultural norms because people in the modern era need science for convenience and entertainment" (Burin pre the ASIU NOSQ). After participating in lesson 4 and having a classroom discussion, his answer was, "Science reflects society and culture, for example, once people wanted to fly, So scientists found the method to make them fly" (Burin post the ASIU NOSQ). Burin's view was still the same as his previous answer. He viewed how science's development was determined by social expectations.

The case of Benja and Buttree was different. Before engaging the ASIU, they had a universal science view. Both answers from them were similar. Burin's answer was science was "Universal and independent from society and culture" and for Buttree, science was "Independent from society and culture". After they had experienced the reflection and discussion, they changed their answers. For Benja, science "Reflects society and culture; the more people are interested in science, the more science is developed" (Benja post the ASIU NOSQ). Buttree answer's was similar to Benja. For her "Science reflects social and cultural norms" (Buttree post the ASIU NOSQ). The findings showed that Benja and Buttree could change their understanding of the influences of society and culture on science, while Burin could maintain his proper understanding. It was obvious that the ASIU in parts of lesson 4 influenced the students' development of the nature of science. Comparing the ASIU to the normal class, the teacher was able to add social and cultural issues by extending the question. Posting questions or challenging them to think outside of the class could fill the gap between classroom science and sociocultural-based science. This was a milestone in scientific enterprise that helped the students, as a member of society, become closer to the role of science.

2.2.2 The Interdependent Aspects of the Nature of Science: Understanding by Making Relations

Nine lessons in The ASIU had their aim the emphasis on the aspect of the nature of science. The students' understanding of the nature of science was explored mainly by compiling field notes during classroom observation followed by a short informal interview. From classroom observations and informal interviews, it was found that the students answered the questions by relating to the other aspects of the nature of science emphasized in the past and present lesson. They even related to the nature of science emphasized in the subsequent lessons. It was found that the aspects of the nature of science indeed were interdependent. Students could use one aspect to explain another. Students couldn't do this if they didn't understand the nature of science. When they made these relationships, students had conceptualized both an aspect and how it related to other aspects. The students' understanding of the nature of science and its interdependent characteristics appeared throughout the implementation of the ASIU. The presented subtopics are as follows:

A. Creativity and imagination

Creativity and imagination were the aspect of the nature of science that students mentioned more than only other aspects. Both creativity and imagination were an important role in science. This aspect of the nature of science was not only emphasized many times by the students, but also by Banburi. The reason creativity and imagination appeared several times in the students' conversations were because of media and advertisements. From radio and television "imagination is more important than knowledge" became a motto for thinking outside of the box. Furthermore, creativity and imagination were addressed in lesson 3 All About Electrons, which was an early lesson in the ASIU implementation. Imagination and creativity were the reasons students used to explain the characteristics of Thomson in his cathode ray experiments.

> ...Scientists use creativity and imagination in their work, to create atomic models from the data. Creativity was very important and imagination, too. Thomson performed experiments with the cathode ray tube using several designs. He used his creativity. He created an atomic model from what he observed. This used imagination. Comparing his atomic model to plum pudding needed imagination too.
>
> (Benja informal interview post lesson 3)

Buttree used the creativity and imagination to explain the characteristics of Rutherford that he could perform the gold thin foil experiment. She said "Rutherford must have been a creative person. He studied the unseen thing by indirect method" (Buttree informal interview post lesson 4). Again, Buttree commented on Bohr's work and his use of creativity and imagination. She spoke about Bohr's analogy of his atomic model in comparison to a planetary solar system model as "Scientists [Bohr] thought twice. First, he thought about his work and created the atomic spectrum. Second, he thought about how to communicate his theory to other people. To think in complex ways, scientists must be creative and imaginative" (Buttree informal interview post lesson 7). Students also related the creativity and imagination aspect to the past activity, such as Burin, who spoke talked about creativity and imagination playing an important role in observation and inference:

> ...Scientists used both creativity and imagination. For example, in the same data of the black box activity [lesson 1], we used several methods to create the things inside. The result of each method was different. It depended on how we created it.

(Burin informal interview post lesson 7)

Students realized that creativity and imagination were not new things. In ancient Greek era, philosophers used them to study nature. Students gave an example when talking about the role of creativity and imagination when referring back to lesson 2 A Journey to Atomic History as, “I think people in the ancient era used imagination much more than today because they didn’t have equipment which modern scientists have today. When Democritus realized the existence of an atom, it came from just his imagination” (Benja informal interview post lesson 7). Students not only explained why creativity and imagination were important in science, they also used creativity and imagination to explain other aspects of the nature of science such as observation and inference, subjectivity in science and the multiple methods that scientists deployed to search for the knowledge. The next topics discussed on interdependence of the nature of science aspects.

B. Observation and Inference

Another aspect, the observation and inference, were emphasized explicitly as the target of the nature of science in lessons 1, 3, 4 and 6. In this activity, the students observed the entity with their senses such as eyes and extended their sense. In lesson 1 they measured, the height of the black box and used three methods to construct the model, which was the inference of the unseen landscape in the black box. In lesson 3, student observed 5 video clips that contained different phenomena. Moreover, students inferred from what they had seen from the video clip that showed the cathode ray tube experiment. In lesson 4, students hit the hidden object by launching a marble from the ramp and observed the scattering line. From the scattering line, students made an inference from the hidden shape. Lastly, the students observed flame colors from their eyes. After that, they observed line spectrums from a spectroscope. Then, they developed conceptual models to explain atomic spectrums. Those four lessons put emphasis on the same aspect of the nature of science, because in the study of the unseen, like an atom, very much used both observation and inference. The students could explain this nature of science when they were asked to answer this question in their student handbook.

> Question: Can you determine the shape of the object under the cover board based on the different angles the marbles were deflected out? If so, how?
> Burin's answer: Yes, by observing the different angles and lines of the scattering marbles. The shape of an object was obtained by inferring from the data.
>
> (Burin's student handbook, page 29)

Furthermore, students perceived the influence of other aspects from their operation in the activity. For example, as Benja talked to Buttree to "…use our imagination draw the figure..." during which they made an inference from the hidden object. They talked about the influence of creativity and imagination again in an informal interview "to make the inference, scientists needed creativity and imagination" as Buttree said. Another example showed the subjectivity of an individual as Burin asked his friend to substitute for the task "…let's change the task. Give me the ramp [and a marble]. I think your eyes are better than mine. You have a sharp-sight…" Burin's nature of science connection was that subjectivity effects the observation. He understood that the differences in the individual would give the different observation.

C. Subjectivity in science

In lesson 3 and 4, students use creativity and imagination to explain the influences of the inference from the data they observed. The subjectivity of individual scientists was also used to explain how observation and inference were different. In lesson 3, the students compared what they had observed and inferred from the cathode ray tube experiments to those of Thomson. The student gave their reason of different to the question on page 30 of the student handbook as:

Question 4.2 what causes different or similar observations between you and scientists?
Benja's answer in his handbook was "Competence, experience, disciplinary and ability"

The subjectivity of individual scientists revealed the influence of subjectivity on scientists' work in lesson 1, 3 and 4. However, students didn't use the word "subjectivity" until they were introduced this word and the meaning in lesson 5, Antarctica Adventure which emphasized the impact of scientists' subjectivity on their work. The lesson also extended their discussion to other characteristic of subjectivity in science resulting from the inclusion of human factors. These effects sometimes provide opportunity for scientific development in regards to the ethics, creativity, imagination, different interpretation and new ideas learned. Sometimes it impedes the scientific progress, for example, scientists' personal bias and the human ability to distort and withhold information, or even to falsify their findings. However, in scientific enterprise, scientists have the methods to validate and evaluate scientific knowledge, for example, peers' reviews, conferences and journal publications.

After lesson 5, students often related the subjectivity in science to other aspects of the nature of science. In lesson 7 and 8, when asked to explain in any differences among scientists in relation to their methods to do science, hypotheses or conclusions, the students referred to this subjectivity characteristic of science with typical descriptions such as Burin's words – "factors from scientists themselves", and Benja's description that "different people think differently" or Buttree's own idea that it is "because of individual thought". Subjectivity, in relation to individual creativity and imagination also influenced how scientists designed methods to seek knowledge. Any possible effects on scientific work, sometimes, have a positive effect on scientific progress, but sometimes may also distort the conclusions, consciously or unconsciously. Students understood that working as a community openly and receiving peers reviews could reduce negative effect from subjectivity and sociocultural based science.

D. Multiple Methods to Do Science

Multiple methods to do science manifested as the target nature of science in lesson 8, My Probability, My Orbitals. Students participated in an activity leading to the understanding of a new atomic model. Students used probability to construct a region that could find themselves in school during school hours. After that, they delineated the region into an understandable figure. This activity was the initial idea for understanding the methods that Schrödinger used to construct electron cloud models. The lesson introduced students to Schrödinger's model based on probability and advanced mathematics. It was different from Thomson and Rutherford's. When asked to explain the difference, the students said that "the method to develop the atomic model" was different. Furthermore, students demonstrated the method as they the neared the end of the lesson. "Besides standard experiment, scientists used 'thought experiment' Burin said. Tracking back to his answer on the NOSQ prior to the ASIU, he thought that there was "Only one method to do science" which was "the scientific method". His understanding then completely changed when he participated in the ASIU, or specifically in lesson 8. Even one month after having experienced the ASIU, Burin's answer was constant. He still understood that there was "more than 1 method" to search for scientific knowledge, for example, "using scientific methods and constructing models".

Benja and Buttree shared a similar view to Burin. In addition, three students explained why scientists used multiple methods to do science. They gave many reasons to explain why scientists used multiple methods, such as methods to analyze data, interpretation, mathematical ability, and also the subjectivity of each scientist. Those reasons were categorized as the subjectivity in scientists' work. Creativity and imagination were another reason. Student thought that creativity and imagination could be subjective depending on individual scientists.

E. Evidences of Scientific Knowledge Claim

Even creativity and imagination were dominant in students' views of science. They didn't discard the importance of evidence for scientific knowledge claim. For example, the result from multiple methods to do science, must be based on evidence. Students respected evidence, especially experimental evidence. It was found that although science is affected by subjectivity, social and culture milieu, logic, rational thinking and evidence, is still important. Buttree shared similar views to Burin and Benja, specifying what made science to be credible.

> ...When scientists propose their conclusion or their discoveries, they came up with evidence. Scientists didn't present the conclusion alone. They also described how they had come to this conclusion."
>
> (Buttree informal interview post lesson 2)

Students agreed that other aspects of the nature of science had to be based on evidence. The effects from society, for example, determined what science should study, but the conclusion of all the studies still rely on evidence. The same could be said for creativity and imagination; regardless of their effects, the conclusion is still strongly founded on evidence.

F. Science is Subject to Change.

Students held that science is subject to change before the starting of the ASIU. From students' answers on the NOSQ prior to the ASIU, three students agreed that science could be changed if a new theory is shown to be more credible than an old theory, Burin and Buttree answered. Another reason was "[scientists] often obtain new information which is more accurate and complete" as Benja stated in his answer sheet. The ASIU emphasized subject to change the characteristics of science in lesson 2. Students investigated a timeline of atomic structure development and identified why historical models had changed. After this lesson, students indicated that historical models were changed because of input from new scientists, experiments, and evidence. Buttree's answer was an example of the students' understanding. She answered that science is subject to change "because there are newer scientists and the technology used in experiment has developed". Later, students commented on this aspect several times during the activities or informal interviews. They pointed out that different experiments resulted in changes of scientific knowledge because the new experiments often gave new results as new evidence. There were other aspects of the nature of science that could explain why science is subject to change, for example, creativity, imagination, and subjectivity in science. Creativity and imagination affected the results which changed Bohr's conclusion regarding his interpretation of the atomic spectrum. Flame color within the atomic spectrum was not a new thing. Rather, Bohr's interpretation of the atomic spectrum to create a new theory was the new thing. Burin also explained the effect social needs have on science with the example that "once people have a desire to fly, scientists then will find the method to make it possible" (Burin post the ASIU NOSQ). For Burin, The new methods scientists discovered later resulted from the change according to their social expectations.

In summary, the students learned and understood that science is subject to change. Moreover, the students related the changes in science, for example, knowledge, experiment methods, evidence, and goals to the following aspects; multiple methods to do science, science that relies on evidence, subjectivity in science and the use of creativity and imagination in science.

2.2.3 The Great Hiatus of Theory and Law in the Lesson

As the teacher finished lesson 2 A Journey to Atomic History, she left behind the topic of Theory and Law without any comment. The post lesson informal interview indicated that student's possessed of the alternative concept of theory and law without any change. Students' answers, both pre and post the ASIU, and taken from the NOSQ, were almost identical, as presented in table 5.2.

Table 5.2 Students' answer taken from NOSQ before and after the ASIU

NOS	Burin		Benja		Buttree	
	Pre-ASIU	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**
Theory and law	Theory can change, law cannot change.	Theory can change, law will not change.	Theory change, law can't change.	Theory can change but law cannot change.	Theory change, law can't change.	Theory can change but law cannot change.

Students compared law with theory by their credibility. In their understanding, law was the truth, fact or the observable phenomena. Theory was the comment, explanation and not necessary to be truth. The most remarkable characteristics of theory for the student were changeable. "Law is fact, it was proven to be true", Burin said during an informal interview. Furthermore, because law appeared in lesson 2 in the experiment, the Law of Constant Composition and the Law of Conservation of Mass, students thought that law came from experiment while theory was the comment on law. "Dalton didn't do the experiment, Anton Lavoisier did it, and so law came from experiment while theory was the comment of Dalton on it. It was true in some parts, but later it changed." Benja said. It was clear that students' understanding of law and theory was ambiguous. In the students' understanding, scientific knowledge could change if it was theory. Contrary, if that scientific knowledge was law, it would not change any more. Comparing the origins and functions of law and theory in the students' handbooks was not enough to change their ideas. Law and theory needed more special, explicit and reflective attention to address it in full.

2.3 Banburi's Implementation of the ASIU Influenced on Students' Understanding of Atomic Structure

Students' understanding of atomic structure was taken from classroom observation, writing field notes, informal interviews and the ASCT. There was a focus on students' understanding taken from the ASCT, to give on overview of students' conceptual understanding. It was found that Burin's understanding was categorized as 'conceptual rational understanding' (CRU) in 16 topics while Benja and Buttree had CRU in 14 and 11 topics respectively. For a 'rote memory' (RM) category, Burin and Benja had 2 concepts in this category, while Buttree held RM in 5 concepts. From 22 concepts of atomic structure, Burin held 'alternative conceptions' (AC) in 3 concepts, Benja 5 and Buttree 6 concepts. Table 5.3 shows the students' understanding of concepts in each category.

The concepts that all three students had conceptual-rational understanding of were: The nature of cathode ray tube, Thomson's atomic model , gold foil experiment, constituents of an atom, The relevance of atomic numbers and mass numbers, isotopes of an element, atomic orbitals, sublevels in energy levels, the nature of atomic orbital and Hund's rule. The concepts that Burin and Benja had CRU but Buttree held RM or AC were Dalton's atomic theory, Atomic spectrum, the probability of electrons in an atom and Valence electron. Considering the differences in academic background of the 3 students, Burin was better than Benja and Buttree in the understanding of every concept including the Quantum mechanics model that Burin had CRU but Benja and Buttree held only RM. Similarity to the former concept, Burin held CRU in Bohr's atomic model while Benja and Buttree held AC. Nevertheless, the concept of observation and inference of cathode ray experiments was the exception because Burin had RM and Benja had AC while Buttree appeared to hold CRU. However, all three students' understandings were categorized as rote memory in regards to the concepts of Atomic numbers and the Pauli Exclusion Principle. They also shared the same understanding in the alternative conception categories of nuclear symbols, energy level of an atom and the Aufbau principle.

Table 5.3 Concepts of atomic structure and school B students' understanding categories

Concepts	Burin		Benja		Buttree	
	Pre-ASIU	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**
Dalton's atomic theory	CRU	CRU	AC	CRU	AC	AC
The nature of cathode ray tube	AC	CRU	AC	CRU	AC	CRU
Observation and inference of cathode ray experiments	AC	RM	RM	AC	AC	CRU
Thomson's atomic model	RM	CRU	CRU	CRU	AC	CRU
Gold foil experiment	AC	CRU	AC	CRU	RM	CRU
Constituents of an atom	AC	CRU	CRU	CRU	CRU	CRU
Atomic number	RM	RM	RM	RM	AC	RM
The relevance of atomic number and mass number	CRU	CRU	CRU	CRU	RM	CRU
Isotopes of an element	AC	CRU	AC	CRU	AC	CRU
Nuclear symbol	AC	AC	AC	AC	AC	AC
Atomic spectrum	RM	CRU	CRU	CRU	AC	RM
Bohr's atomic model	AC	CRU	CRU	AC	AC	AC
The probability of electrons in an atom	AC	CRU	RM	CRU	AC	RM
Quantum mechanics model	RM	CRU	AC	RM	AC	RM
Atomic orbitals	RM	CRU	AC	CRU	AC	CRU
Energy level of an atom	AC	AC	RM	AC	RM	AC
Sublevels in energy level	RM	CRU	AC	CRU	AC	CRU
The nature of atomic orbital	RM	CRU	AC	CRU	AC	CRU
Aufbau principle	AC	AC	AC	AC	RM	AC
Pauli exclusion principle	AC	RM	AC	RM	CRU	RM
Hund's rule	AC	CRU	RM	CRU	AC	CRU
Valence electron	RM	CRU	AC	CRU	AC	AC

The result from the ASCT showed students' conceptions in holistic views in terms of change and no change from RM and AC into CRU or vice versa, before and after experiencing the ASIU. The details of students' understanding of atomic structure, present as follows:

2.3.1 Students' Understandings of Functions of Mathematical Models and Modeling in Science

After experiencing the ASIU students had a better understanding of model functions. They had changed their view of model from merely the representative of data into multiples functions. The model that students often mentioned in this study was a mathematical model. Before engaged in the ASIU, students thought that a mathematical model was a linear graph or a column graph which was used to present data. In their views, the mathematical model came from the conclusion of the data, as Benja said during an informal interview post lesson 5, "I used to think that graphs are used for presenting data. When we get data from experiments, we construct graphs, such as pie graphs. They are easier to understand". Some students knew that graphs were used to represent multiple functions; experiences didn't allow them to use mathematical models in several different ways except to present the collected data. As one student from school B commented:

> ...Scientists mostly used equations in their work.., they used mathematical models for prediction: predicting the trends of population growth, or the changing water levels when a flood occurs in the world. For me, I am familiar with basic graphs that are not so difficult, but I don't understand them too much. It is just for presenting data and making conclusions.
>
> (Benja Informal interview post lesson 5)

It is not surprising that students strongly perceived mathematical models as presentation tools. For 13 standards from the Thai National Science Curriculum Standard (IPST, 2002), involving the nature of science, in strand 8: the nature of science and technology in item 8 states that students should "Make models, pattern representations, mathematical models or point out trends from data gathered from investigations". It should be noted here that for the students, the functions of mathematical models were limited by their scientific experiences in the classroom. After watching the movie, the students engaged in modeling activities, constructing them from the data representing the percentage of the abundance of oxygen isotopes. At first, students were asked to write the nuclear symbol, identify the number of protons, neutrons and electrons, and to identify the atomic number and the mass number of oxygen-16, oxygen-17 and oxygen-18. After that, students calculated the atomic mass of oxygen from the percentage of terrestrial abundance compared with the atomic mass of rock sample. In the manner of scientists who study meteorites, students used Microsoft Excel to calculate the 17O /16O and 18O /16O ratio, comparing the data with the values from Earth, the moon, Mars, meteorite A, meteorite B and the mystery Antarctic sample. Students constructed a linear graph of the data for comparison, evaluation, prediction, and for making a decision via the peer review process.

Other students' views on mathematical models emerged when they worked with computers to construct linear graphs. Because of the limited number of computers, students had to work in groups of three per computer. Students who had both scientific and computer skills were chosen to work with and compile the data. For students with a higher ability, modeling the mathematical models were possible. Even though they could actively participate autonomously, some students preferred to act as assistants to their friends. The role of the mathematical model as a tool for problem solving and decision making was emphasized during classroom discussion. Not only did the students have to answer the activity questions using interpretations from the graph, they had to reflect on the importance of mathematical models in science. Students gave examples of how scientists use mathematical models in their work. Students saw that mathematical models provided strong evidence of knowledge claims. They also pointed out that mathematical models were used in multiple ways. Mathematical models could be used as a tool to solve problems in science. Benja then explained a model for problem solving. He said "Scientists use equations to solve problems. In physics, it is all about mathematics. It explains phenomena and solves problems in exercises. We use the formulas very often". Models can be explanatory tools. Some scientific theories or scientific laws are very abstract. Mathematical models make them more understandable as a student pointed out in the class.

"Sometimes, scientific knowledge is very abstract. We use mathematical models to make it understandable. For example, Schrödinger explained his model using a wave equation" Burin said (Field note No.B5).

Models and modeling have an important role and function in scientific inquiry. But they should not be presented in the science classroom in only one dimension. A variety of models and modeling are recommended for teachers to value and use in their classrooms. By working with mathematical models and modeling, students could develop their understanding of scientific inquiry as well as scientific concepts in the same manner as scientists. It has reduced the gap between school science and real scientific enterprise.

2.3.2 Understanding Methods and Evidences that Scientist Used to Construct Atomic Models by Investigating the Atomic History

Lesson 2 A Journey to Atomic History aimed to develop students' understanding of atomic models in a holistic view before studying them in detail later. This lesson acquainted students with the historical context of atomic evolution from the ancient Greeks up until the accepted atomic model in present use. Using an historical approach, this part of the ASIU aimed to give the students an understanding of the historical perspective of how atomic theory changes and evolves over time. Existing research recommended the infusion of stories during regular instruction, for example, The science stories (Toa, 2003), vignettes, science stories, historical case studies, scientific narratives, thematic approaches, story line, and dialogues (Stinner *et al.*, 2003). This lesson also provided students an opportunity to appreciate how scientists work as well as the progress of scientific ideas. Students investigated 6 atomic stations that represent the places where atomic models were developed. Students assumed that they followed the map (figure 5.5) to visit each place of philosophers and scientists' work.

Figure 5.5 Map for students to follow that represents the 6 stations presented in the activity handbook, which introduced students to A Journey To Atomic History activity

Viewing the details of each station, the students had to explore the information and take notes, discuss as a group and answer the questions in their activity handbooks. There were 5 questions asking who, what, why, when and where. The question of ‘who’ asked the students “Who was the scientist that developed the atomic model in this station?”. The question of ‘what’ asked the students “What were the methods (e.g. experiments, observations) and evidence the scientists used to support their ideas?”. The question of ‘why’ asked “Why the scientist were interested to explore or conduct the experiments/observations?”. The question of ‘when’ asked “When was the time that the models were developed and what technology was available at that time?”. The question of ‘where’ asked “Where was the place or community of scientists that affected their work?”. And the last question of ‘how’, asked “How the atomic model can or cannot explain or predict the phenomena?”. After finishing the lesson, the students were then asked what was the importance of learning the history of models in this lesson based on the five questions. Students selected the answer from first question. They emphasized on the development of methods to construct the atomic models. The students agreed that changes in thinking, experiment and technology were the basis of change in atomic models. Burin identified the causes of atomic model development as:

> ...Philosophers from ancient eras used only imagination and rational thinking, but in later eras atomic models were very much based on experiment such as Thomson and Rutherford's. Now, an atomic model comes from sophisticated mathematics and high technology.
>
> (Burin informal interview post lesson 2)

His view was much in accordance with Benja's. As he said:

> ...For me, the evolution of atomic models was very interesting. Firstly, with ancient philosophy they relied on their own reasoning. After that, the scientists used data derived from experiments as the evidence. Now, the model, which is very abstract we call quantum theory.
>
> (Benja informal interview post lesson 2)

For Buttree, her ideas on the history of models addressed the used of evidence to model the atom. She commented "Scientists had used evidence to support their ideas since the study of Dalton, up to the present moment. Similar to lesson 1, the use of higher technology in experiment, resulted in a more complicated atomic model. Perhaps the model may change in the future" (Buttree informal interview post lesson 2). Students pointed out that the methods used to construct the model were responsible for atomic model evolution because they were understandable for them at that time (the second lesson of the ASIU implementation). These conclusions were the basis for understanding the concepts in further detail. At this point, students came to know the physical characteristics of the model, as they could explain their shape and constituents in their activity hand books. They conceptualized methods and evidence that scientists used to construct atomic models. The remainder for them, in the next lessons, was to understand the connection of experiment/observation result to the construction of atomic models. This was the next step to the further understanding of models, modeling and atomic structure that the ASIU is based on.

2.3.3 The Observation and Inference of Cathode Ray Tube Video Clips for Construction of Thomson Atomic Model

In lesson 3, All about Electrons, student watched 5 video clips which related to electrons' properties. After that, Banburi randomly called on students to share their observations and inferences of 5 video clips. Three students' observations and inferences in their activity handbooks were checked as they could reveal the students' understanding of Thomson's experiment and his atomic model. During writing what they had observed, Benja and Buttree talked to each other about the inferences. Despite Buttree having similar answers to Benja, she had not merely copied Benja's answer. She had discussed her ideas with him to ensure her answers. Students could make an observation from video clips 2-4 (Table 5.4). Though for video clip 1, which displayed many kinds of cathode ray tube but all giving the same result, students could not conclude the reason. The teacher commented on video clip 1 later, stating that "it was not clear to the students that the scientists had changed the types of electrodes or gases. Therefore, they could not deduce that electrons or cathode rays were a part from every atom." From Table 5.4, students could describe their observations but only partially making an inference. Students' inferences from video clips 1 and 5 were different from Thomson's. However, students could observe and infer the main contributing factors that lead to the construction of a new model. The inferences from video clips 2, 3 and 4 were cathode rays traveling in straight lines that caused a shadow because they could not pass the thin plate, cathode rays are particles and cathode rays have a negative charge. When they compared their inferences to Thomson's inferences, the students had to give challenge as to whether Thomson's observations and inferences leading to the construction of the plum pudding atomic model was reasonable or not. All students had answered that Thomson's modeling of his atom according to the cathode ray tube experiment was reasonable. They also pointed out the connections between observation and inference regarding The Thomson model. As Benja said "there are negative tiny particles embedded in an atom because cathode rays are negative as they move toward positive electrodes. They are particles because they spin the turbine”. This extended their understanding of Thomson’s model from lesson 2. Students now understood how the observations of cathode ray tube lead to the inference of an atomic model.

Table 5.4 Student's observations and inferences of 5 cathode ray tube phenomena compare to those of Thomson

VDO	Thomson's Observation	Thomson's Inference	Burin's Observation	Burin's Inference	Benja & Buttree Observation	Benja & Buttree Inference
1	Cathode rays' properties are independent of the cathode material, gas, or types of electrode.	Cathode rays are a component of all matter.	There were Many kinds of cathode ray tubes.	Scientists developed many kinds of cathode ray tubes.	Cathode rays were built in several figures.	There are several types of cathode ray tubes.
2	If an object is placed in the path of the cathode ray, a sharp shadow of the object is cast on the glowing tube wall at the end behind anode.	Cathode rays traveled in straight lines. Cathode rays behave like streams of particles Cathode travel from cathode to anode.	Cathode ray travel in straight lines.	Cathode ray travel in straight lines that causes shadow.	There is a green cathode ray in the glass tube.	Cathode rays travel in straight lines/could not pass through the thin plate.

Table 5.4 (Continued)

VDO	Thomson's Observation	Thomson's Inference	Burin's Observation	Burin's Inference	Benja & Buttree Observation	Benja & Buttree Inference
3	The cathode ray can push a small paddle wheel and move them.	Cathode rays behave like streams of particles. Cathode rays have mass	Cathode rays could move the turbine.	Cathode rays are mass which have energy.	Cathode rays hit the turbine and spin it.	Cathode rays are particles.
4	Cathode rays are deflected from a straight line path by an electric field and bend towards a positively charged plate.	Cathode rays are streams of negative charges.	Cathode rays direct to positive electrodes.	Cathode rays have a negative charge.	Cathode rays bend in electric fields.	Cathode rays have a negative charge.

Table 5.4 (Continued)

VDO	Thomson's Observation	Thomson's Inference	Burin's Observation	Burin's Inference	Benja & Buttree Observation	Benja & Buttree Inference
5	The cathode rays are deflected from a straight line path by a magnetic field.	Cathode rays are not light, because light is not affected my magnets or magnetic fields. Cathode rays are streams of moving charged particles.	Cathode rays bend in magnetic fields.	Cathode rays have the magnetic poles.	Cathode rays bend by magnets.	Cathode rays are repelled by magnets.

2.3.4 The Scattering Activity to Understand Rutherford's Gold Foil Experiment and his Atomic Model.

The concepts relating to Rutherford's atomic model in lesson 4 became one of the concepts where students expressed their understanding very well. As Banburi had commented, "The Trace Rutherford line was the most effective lesson that promoted the students' understanding of both science and the nature of science". Lesson 4 was a harmonious mixture of a model-based approach and a historical approach. Indeed, each activity of the lesson was a reproduction of Rutherford's famous historical experiments. After the activities, the students were able to explain the concepts of the experiment as Buttree point out the concepts of studying an unseen entity "He studied an unseen thing by an indirect method" (Buttree's informal interview, post lesson 4). Whilst performing the activity, students learned how to draw the shape of hidden object. For example, the following conversation between Benja and Buttree demonstrates this:

> Buttree: see there is nothing when launching [the marble] at this point. It passes through. There must be nothing below around here.
> Benja: let's launch the marble at the center.
> Buttree: It reflects but not in a straight line. The edge of this object might not be the planner.
> Benja: Therefore, do it again. Observe the angle carefully.
>
> (Classroom observation lesson 4)

Comparing what students did with Rutherford's experiment and the results. Students could connect the reflection of alpha particles to the atomic model Rutherford had proposed. Student also extended their understanding of the constituents of nuclease, the number of protons and neutrons, to isotope concepts. It was to be noted that the students' prior knowledge helped them in relating to the new knowledge. For example, Burin used his prior understanding of nucleus to further extend his understanding of the concept of isotope:

Burin: I think the isotope concept is not difficult. I have a trick for remembering this myself. The word 'Isotope' ends with 'P' so it has the same number of protons. From this activity, I've learned how to use this knowledge in science. It's very interesting. I'll look for a book about the use of isotopes.

Researcher: Did you know about the use of isotope analysis before?

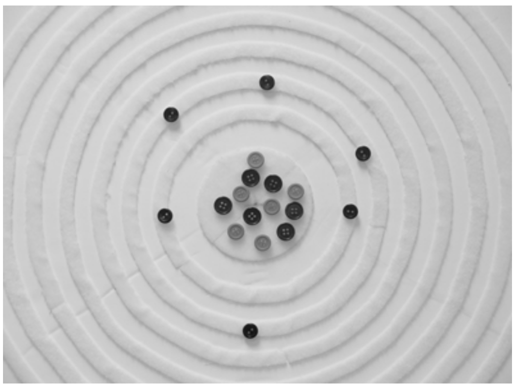
Burin: Yes, but I didn't know it was used to study meteorites. I only knew it was used to study fossils or bones like dinosaurs or mummies.

(Burin informal interview post lesson 5)

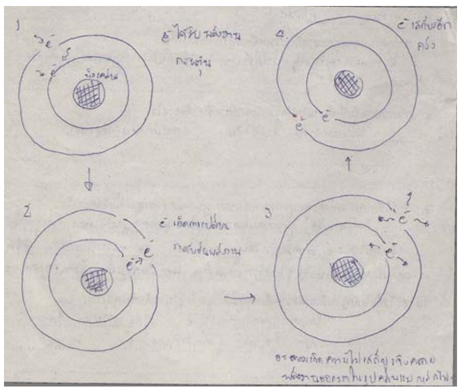
The students' direct experience in the activity reproduced from historical experiment, resulted with a permanent conceptual understanding. The students succeeded to maintain their understanding of Rutherford's gold tin foil experiment and the related concepts. One month after finishing their experiences the ASIU. All three students' understanding was categorized as conceptual-rational understanding (CRU) for the gold foil experiment, constituents of an atom, the relevance of atomic number and mass number and isotopes of an element.

2.3.5 Understanding Bohr's Atomic Conceptual Model Through the Analogy and Metaphor

Two lessons that were of concern and enhanced the students conceptual understanding were Bohr's atomic theory and his model, addressed in lesson 6, Can You See The Light as Bohr did? And lesson 7, Mix and Match For An Atom. There were three issues that were addressed. Firstly, the lesson ensured that the students would not use this planetary model. The physical characteristics of the planetary model were easier for students to remember than the electron cloud model. It might impede the study of an electron cloud model in the next lesson. Students, even though they had learned Bohr' model, had to realize that it was a historical model, which no longer was used in scientific explanation. Secondly, the lesson helped the students be aware that they conceptualized the concept within the planetary model, instead of merely remember shape, figure, or the arrangement of it constituents. The lesson emphasized potentials of the model to explain phenomena such as ‘flame color’ and ‘atomic spectrum’. Lastly, the use of a solar system as an analogy held both similarities and differences to the concepts within the planetary model. Students had to critique(evaluate) the functions that both shared together. At the same time, students identified functions within analogy that breakout(differ) when applied to the planetary model. The lesson related back to lesson 2, A Journey To Atomic History, with the timeline that they drew by themselves in their activity handbook. Students had to identify, which one was the consensus for the scientific model that is currently accepted, and they were asked which ones were the historical models that were superseded, modified, or changed already. Student identified Bohr’s atomic model as the historical model as it is no longer accepted. The second issue showed the students’ understanding of Bohr’s atomic model concepts, as it could explain the specific color of burning metal compounds. Students observed light from different sources such as sun light, computer monitors, televisions, candles, and burning metal compounds. They used both their eyes and a spectroscope. The spectroscope had the nanometer scale inside, so the students could draw the line spectrum at its actual wavelength. After completed their observation, the students participated in classroom discussion about using the planetary model (Figure 5.6A), they constructed a conceptual diagram to explain electrons transferred that causes(produces) the light emitting as an amount of energy, which was observed as line spectrum.



(A)



(B)

Figure 5.6 (A) planetary model used in classroom discussion of line spectrum (B) student’s explanation using planetary model.

The last issue involved learning how to understand analogy and metaphor models which scientists used to familiarize their ideas, student could then identify similarities and differences from Bohr's atomic model with the solar system. To do this, students used their prior knowledge from lesson 6 as Burin explained "...Electrons could move from one orbit to a higher energy orbit, and then they could move to a ground state orbit. The planets in a solar system couldn't move like that…." (Classroom observation and field note No.B7). After that, students created the analogy from others statements of Bohr's atomic theory, and then shared their result for the class. Students could give examples of familiar entities to Bohr's abstract theory of an atom. For example, Burin's group used the event of "people using an elevator" as an analogy to the discrete energy level of it??. From classroom observation, students experienced the activities and conceptualized Bohr's planetary model as a historical model, a conceptual model and an analogy model. With the same atomic model, students learned of the various functions and developed an understanding of the concepts within those models.

However, students had difficulty in calculating the interchange between wavelength and frequency of line spectrums they had observed, as Benja said "I know from the electromagnetic spectrum chart [in textbook] that different colors of light had different energy but the calculation is such difficult equation for us to understand. I followed the formula but I hardly understand what it [formula] means". Banburi gave her comment on students' difficulty as "the calculation is always students' problem. They will learn waves and energy again in physics. They need to practice and develop their mathematical skill in the future."

2.3.6 Electron Cloud and Atomic Orbital: Understanding of the Abstract Concept

Students' understanding of electron cloud models needed more attention from teachers because students tended to describe figure and the physical characteristics of a model. When asked to explain the functions or conceptions of the electron cloud model, students had difficulty in doing so. Quantum theory was very abstract. To master it, students needed both an imagination and mathematics conceptual background.

The objective of lesson 8 was to prepare and introduce students to the principles of the construction of the electron cloud model, including the explanation and relation of atomic orbital. From the classroom observation, students could describe the electron cloud model and explain atomic orbital but could not relate them together.

> Researcher: Explain about the electron cloud model?
>
> Benja: The Electron cloud model presents the probability of electron movement around the nucleus. One spot means one chance to meet an electron so close to a nucleus with a dense spot means a higher probability of an electron to be found.
>
> Researcher: and how about 'orbital' what is it?
>
> Benja: orbital was the exact region that electron occupied. They have various figures. For example, s orbitals have a spherical shape, p orbital have three of dumbbell.
>
> Research: Could you relate atomic orbital to the electron cloud model?
>
> Benja: the Atomic model doesn't have the border so it was fuzzy but orbital has an exact shape. Therefore, we know it is s or p orbital.
>
> (Benja, informal interview post lesson 8)

Even though the students failed to connect orbital to the atomic model, they understood a sub shell or orbital in different energy levels. They could stress(emphasize) on the orbital in an atom in terms of sub shell or orbital in different energy level for example "in the second energy levels, there are both s orbitals and p orbitals" as Burin said.

2.3.7 Electron Configuration and the Multiple Reflections of Students' Understanding

In Lesson 9, Modeling the Atoms (everyone can do it!) activity had the students engage in hands-on activity. It was found that students could develop an understanding of the concept of electron configuration and the link between microscopic chemistry to a macroscopic level using symbolic entities for atomic structure. From a classroom observation students had 3 opportunities to reflect their conceptions, first, while they built the atomic model by working with VAST, second, during group discussion in their learning community, such as the discussion where Benja tried to explain to Buttree about Hund's rule.

> Benja: First, we add an electron into orbital that have the least energy, what is it?
> Buttree: the smallest one s orbital.
> Benja: yes, as we know how many electrons that each orbital could contain?
> Buttree: 2 electrons...only
> Benja: yes that's right. After that, we go to the next energy level. Therefore, we start with 2s orbitals. Again [Buttree adds 2 black buttons] ….Right.
> Benja: and after that because we got carbon, we have 2 electrons left. What will we do?
> Buttree: add them in to p orbital [Buttree adds 2 electrons to p orbital]
> Benja: we cannot do that. Separate it into another orbital. Electron likes to stay away from each other because they have the same negative charge.
>
> (Classroom observation and field note B9)

After that, students finally reviewed their understanding in presenting their VAST model to the class and discussing their friends' questions. All groups had equal chance. Banburi let them talk approximately 3 minutes for each group. However, their understanding of electron configuration was not permanent. One month after class, the result from the ASCT showed that three students held alternative conceptual views in Aufbau principle, and rote memory in Pauli Exclusion

Principle. However, they held conceptual-rational understanding in Hund’s rule. Burin and Benja held conceptual-rational understanding in valence electron, while Buttree held AC. The results indicated that equal participation multiple times of reflections on electron arrangement, the students still had alternative conceptual understanding and rote memory in some subtopics.

3. Key Findings and Commentary on Results Derived from School B

3.1 Related to the ASIU Implementation

Students’ understanding of the nature of science and atomic structure indicated that Banburi’s practice of the ASIU was a success. Even though students had problems in some aspects of the nature of science, such as theory and law, other aspects students could understand conceptually. One strong point that supported her teaching was her characteristics. Banburi was the liberal teacher. Her obvious attitude was opened-minded and flexible. She also emphasized on creating a comfortable atmosphere for learning. Even though her extra responsibility as head of school finance made her lack teaching preparation, she used this disadvantage to encourage students how to explore and to conduct the activities by themselves. They learnt how to do activities, work in groups and engage in group discussion naturally. Banburi balanced between her teaching style and the ASIU lesson plans. She strictly followed the ASIU only in lesson 1. After that, she was more relaxed to conduct the ASIU in later lessons. Moreover, the success of the students’ perception of the sociocultural impacts on science come from Banburi’s very good and clear understanding of this topic. From the result of both phase I and phase III, the teachers’ understanding of scientific enterprise became one factor that promoted both teaching and learning the nature of science, especially when the teacher was committed to teach science and the integration of the nature of science.

3.2 Related to Students' Understanding of the Nature of Science and Atomic Structure

The findings showed that three students shared similar views on the nature of science but Burin several times had raised more sophisticated explanations of the aspects of the nature of science. An academic background and personal characteristics might be the reasons for this. There were three main points to the students' understanding of the nature of science. Firstly, they had the chance to discuss the impacts of society and culture on science. Secondly, the students established the connections amongst the aspects of the nature of science. They could relate some aspects to others, for example, they pointed out that observation and inference relate to imagination and creativity. Moreover, observation and inference also depend on scientists' subjectivity, for example "competence, experience, discipline and ability" as Benja said. Lastly, theory and law were excluded from the activity in lesson 2, A Journey To Atomic History. As Banburi did not introduce the topics to discuss, the students therefore did not have a chance to show or increase their understanding of theory and law. The alternative concepts of theory and law were gained as a result of didactic and implicit teaching of theory and law.

For the understanding of atomic structure, students could develop their understanding in functions of a model. Students put their emphasis on the function of a mathematical model. They developed their understanding of methods and the use of evidence that scientist used to construct atomic models by investigating the history of atomic models. Whilst studying the history of atomic modeling, the students pointed out that the atomic model changed depending on new technology used in and new ways of thinking. The students gained insight into scientific experiment by participating in the reproduction of historical experiment. For example, students did observation and inference of cathode ray tube video clips. They compared their observation and inference with those of Thomson's. After that, they connected Thomson's observation and inference to the construction of his plum pudding atomic model. Experiencing the reproduction of Rutherford's experiment, the 'scattering' activity, also enhanced students' understanding of the concepts behind Rutherford's gold foil experiment. They could connect the experimental process and result to the development of Rutherford's atomic model. Students could also develop their understanding of concepts within Bohr's planetary atomic model through the use of analogy and metaphor. There were two interesting points on students' understandings of the electron cloud model, the atomic orbital and the electron arrangement in an atom. Firstly, students could describe the figure or shape of an electron cloud model, but they failed to conceptualize(understood) the concepts of this atomic model. And the abstract nature of atoms and quantum theory was more sophisticated and advanced for students' complete understanding. Lastly, students, even though having participated in multiple activities of engaging in electron arrangement, they failed to retain their conceptual understanding in some parts, for example, Aufbau principle and Pauli Exclusion Principle. However, the activity in lesson 9 gave the students the hands-on experience that allowed them to manipulate the representatives of subatomic particles, such as an electron, protons, and neutrons. Students learned how to use symbolic objectives (VAST, buttons, fleece) to represent microscopic entity (atoms, atomic particles). Instead of merely writing down the electron configurations, students could use the VAST model filled with electrons into atomic orbital.

School C: Chonlada and her students (Cheewin, Chutima and Chaiyan)

1. Introduction

1.1 School Context

School C is categorized as an "extra-large" school because the enrollment exceeds 2500 students and serves Grades 7-12 (Mathayomsuksa 1-6). The school is under the administration of the District 2 Office of Education, under the Office of the Basic Education Commission (OBEC), the Ministry of Education. The school is located on 10 acres in a sub area of Bangkok. The land was donated by a local business family. The school was officially founded in March, 1978. During its first year, the school consisted of 12 classrooms, 527 students, and 22 teachers and by the academic year 2007, there were 4100 students and 170 teachers. There was a total

76 classrooms, 38 (12-14-12) in middle education classrooms and 36 (12-12-12) in upper secondary classrooms. The school presently has eleven buildings, seven of which hold classrooms. The other buildings are scattered around the school, and have multi uses such as a school hall, agricultural center, library, administration, and public relations building, etc. The school follows the national Curriculum of Basic Education, BE 2544 (2001 CE), providing six years of the 3rd and 4th education levels (Level 3 Mathayomsuksa 1–3, level 4 Mathayomsuksa 4-6). Subjects are grouped into eight standard subject areas, Thai language; mathematics; science; social studies, religion and culture; health and physical education; arts; vocation and technology; and foreign languages.

1.2 Teacher (Chonlada)

Chonlada (a pseudonym) graduated with a bachelor's degree in Education (Chemistry major) and a master's degree in Science Education. She has taught Chemistry and General Science for about 25 years at the time of the study. She started teaching science in a remote area in the northern part of Thailand. Later, she moved to this school and taught only Chemistry. In this semester, Chonlada taught Chemistry in Grade 10 for 3 periods. Chonlada has been successful in her profession and has received many promotions and is presently a lecturer in the professional development program for teachers in the school C educational district. At the time of this study, Chonlada is a professional teacher. She was interested in doing research about how to evaluate students' understanding of chemistry before and after finishing her course. She was looking for an instrument that could elicit students' conceptions of science learning experiences before they entered her class.

1.3 Students

According to Chonlada's comments, the students in this class had some slight behaviour problems. At the beginning of the ASIU implementations, some students complained about the activity. The ASIU consumed more time than a regular lectured-based classroom. Their complaints against participating in the ASIU were ignored.

Cheewin is 14 year old student who came into Grade 10 Chemistry with a good academic background from middle school. He showed an interest in both science and mathematics. Chonlada often asked him to answer her questions. He usually presented his ideas to the class by writing them down on the blackboard because this is how the teacher asked him. Cheewin usually sat in the front of the class and attentively participated in the lesson during both the hands-on activity and the lecture sections.

Chutima is 14 years old and from her middle school academic background, she was classified as an average student. In fact, she turned out to be a very good learner and during the hands-on activity and lecture she listened and concentrated quite well. There were several times during the lessons that she could explain answers better than Cheewin. However, she described herself as a person who needs more time to internalize what she has learned. When she had difficulty understanding something, she found it very hard for her to explain things. When asked which type of learning activity best helps her to understand what she is learning, she replied the hands-on activities because they make the experience more real.

Chaiyan is 15 years old and he is a very talkative person even during the lesson time. His academic background indicated a lower than average ability which may be a result of or caused by this inappropriate behaviour in class, but the situation did require special assistance from the classroom teacher. Unfortunately, his attitude towards the teacher was not very good. During the 2nd workshop, his teacher had to talk to him about his inappropriate reactions in class and that he needed to meet with the school counsellor. The teacher commented that it was very difficult to get him to focus in class and participate responsibly in the lesson’s activity. If he could be motivated to participate through the ASUI then this would be the first step to success for both him and the teacher.

1.4 Classroom Setting

There were two locations used for teaching the ASIU. One location was a laboratory classroom and the other was in a section of library which was connected to the library computer room. The laboratory consisted of ten tables set in two columns and five rows (Figure 5.7 A), and the library section consisted of two long tables set in two columns. Each side of the column could contain 14 chairs (Figure 5.7 B).

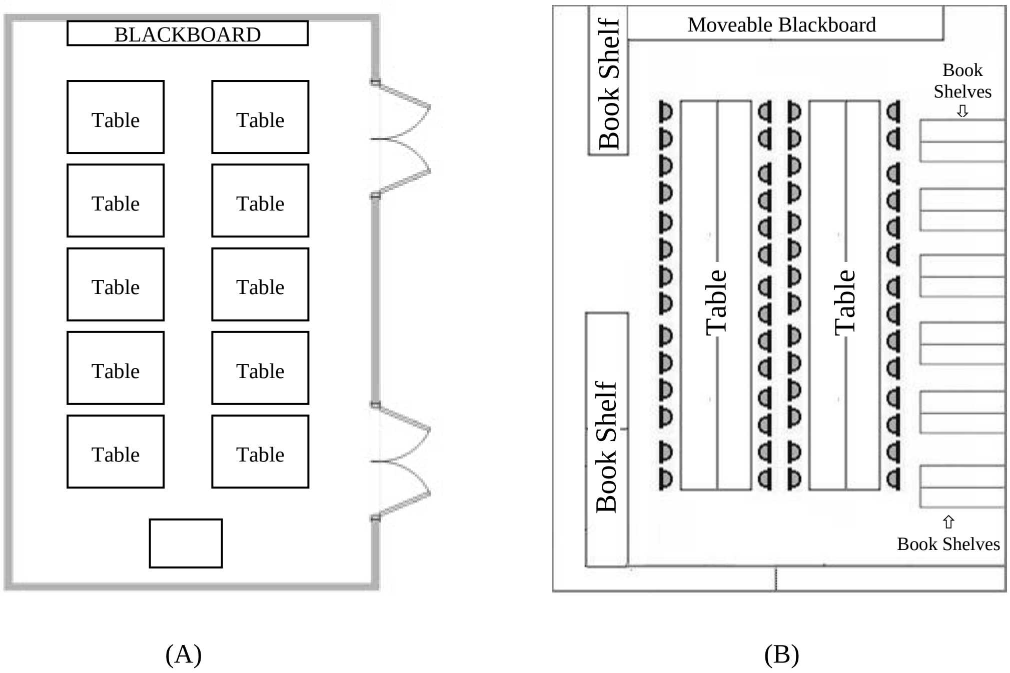


Figure 5.7 Science classroom of School C (A) the laboratory classroom (B) the library section

2. Themes of Research Findings from School C

2.1 Chonlada’s Implementation of the ASIU

2.1.1 The Process of Changing and Unchanging when the Teacher Implemented the ASIU

The issues that emerged from Chonlada's implementation of the ASIU related to two main themes, those that she could easily change and those that were more fixed or rigid. The changes that would need to occur in order for her to implement the AUIS; were her teaching methods would still need to meet the standards, her lead role as the teacher would have to change to be teacher as a supporter of the learning. The more fixed or rigid areas included: the table arrangement which did not support the hands-on activity learning method, the students' abilities to participate in discussion was limited by the seating arrangement, and the use of lecturing as the main teaching method would have to be reduced. How these things changed or remained unchanged during Chonlada's participation in the AUIS were reported using field notes from classroom discussions and quotes from interviews and were based upon the research questions possessed in this study.

2.1.2 Teaching Methods to Meet the Standards

At the beginning of Chonlada's implementation, she attempted to follow the ASIU as much as she could. She was very serious about following the ASIU lesson plans. She asked the following questions about her implementation in the post lesson 3 informal interviews. "Did my teaching meet your expectations? Did I follow the method of implementation as outlined in your lesson plan? (Chonlada informal interview post lesson 3). At the beginning Chonlada believed that it was her responsibility to implement the ASIU because she volunteered to participate, but she did at first believe that it could be beneficial to her students. She even spoke about her reluctance to following the ASIU. "I just don't know whether the ASIU will be a successful teaching method for A student. I'm afraid if it will be that causes your research to fail." (Chonlada informal interview pre lesson 3.) However, during the implementation of lesson 3, All About Electrons, she began to change her point of view. After implementing lesson 4, she stated for the first time that the students seemed to be getting comfortable with the model-based approach. By informal interview post lesson 4, she stated that her teaching was smoother than her earlier lessons. By the following week, after the implementation of lesson 4, she was satisfied with teaching the ASIU.

At beginning she had many concerns regarding her use of the ASIU. She was concerned that her students would not concentrate on the scientific content which she believed they would do if she used the lecture teaching method. Because using the ASIU required more time other classrooms were finished before and had moved on to new topics such as the periodic table. Her students were concerned that they would be left behind because the modeling approach to learning atomic structure took longer than using the lecture approach. Chonlada was concerned that the students in the other classes would have a better understanding of the atomic structure than the classes learning by lecture. But in the end she discovered that this was not true and that teaching using different styles and/or different activities can be used to meet the same curriculum standards. (Chonlada informal interview pre lesson 5).

Chonlada expressed the view that diversity in teaching methods can meet the same science standard. This change of view influenced her implementation of different teaching methods in later lessons. Her classes became more flexible and they were no longer teacher-oriented but became more student-oriented. The students also became more open to trying new types of lessons such as the modeling activity used in lesson 4.

2.1.3 From Teacher as having the leading role to the Teacher in a more supporting role

Chonlada's role of the teacher as leader to the teacher in more of a supporting role was beginning to change during her implementation of the ASIU. Now she was providing help and suggestions to the students and her classroom was becoming less rigid. Previously she didn't like the classroom to get out of control and she even admitted when she made the students wear name badges to assist the researcher in recognizing the students that even she didn't always remember the names of the students (Chonlada informal interview pre lesson 1). Later, she decided not to give the students name badges because it took too much time out of the class's allotted time. During the first hour of class most of the students only sat in their seats and listened because during this time Chonlada had the major role. She started the lesson by explaining how to see the unseen through the model and how to arrange the seats to best accommodate this activity.

> ...Students… sit in groups like in previous classes, 6 people for each table, but you will work in groups of three. Every table will have two groups. Three students in the same group will sit together in the corner while the other three students will sit in an opposite corner. Other students must follow this pattern of grouping.
>
> (Classroom observation, Field note C1)

After that, Chonlada talked about the lesson's objectives. She read the objectives from her lesson plan and elaborated upon each. She assigned one student from each group to pick up the needed materials. The room was very quiet and teacher controlled. Chonlada spent almost 20 minutes explaining how to conduct the whole activity and even demonstrated how to measure the depth of the black box. During this period, the activity stopped when the students had collected the data and constructed a 2 D model of the unknown landscape inside the black box.

The next class was conducted in the computer room next to library section used in a previous class. Chonlada still had the lead role because she began the class by explaining how to manage the data by using a computer program. At this point it should be noted that the students constructed the 3D computer models step by step as Chonlada explained the steps to them. Her role in lesson 2, A Journey to Atomic History, was also as leader of the activity. She spent most of the time during the 52 minutes, talking about the introduction and how to conduct the activity. The high level of formality in the early part of the ASIU implementation didn't support the students learning in groups. Even sitting in groups, the students rarely talked to their friends and the room was so quiet. As the students worked in groups measuring the depth of the black box and collecting data, they didn't walk around and interact with each other, only the teacher walked from group to group. At first glance the activity doesn't look like it is successful (Field note C1).

The result of the teacher maintaining such a high level of classroom discipline resulted in a rigid classroom. This rigid classroom is important when maintaining a teacher-centered approach, but this type of approach does not motivate students to become engaged in the modeling activity. They didn't find it very interesting. Chaiyan said, "I didn't understand the activity. I just did what the teacher assigned. It was very boring." (Informal interview post lesson 2).

By lesson 3, All About Electrons, the students started to do the activity by themselves in the second hour. During this lesson Chonlada only talked a short time about how to do the activity. She also used only 5 minutes to sort out the seating plan. She had some difficulties with allowing the students to share ideas. She gave her reasons as "Sometimes I have to complain about the students' behavior. I know it makes the students view me negatively, but if I can't control the class conducting the activity will be a problem." (Chonlada informal interview post lesson 2.) After lesson 3 Chonlada spoke about this new lesson briefly:

> ...Lessons 1 and 2, I don't think I did a good job. Everything seemed a struggle. I feel I have learned a new teaching method, but I am not confident I implemented it correctly. Sometimes I had to learn along with the students. In this lesson, both I and the students had to adapt. We're now all familiar with the model-based approach.
>
> (Chonlada informal interview post lesson 3)

Since lesson 3, Chonlada appears to develop more confidence in her students. Both her practices and her comments on lesson 4 indicate her change. Chonlada spoke briefly of the whole activity. She just guided her students to be engaged in the "Trace Rutherford's Lines" without demonstration as she did in lesson 1. Later she gave this comment on the change:

> …I found that when I let them do the activity openly, they expressed their own learning style. They did the same activity, but it was quite different in the details. Letting them do the activity without too much guiding from me

allowed me to see them do new things.

(Chonlada informal interview post lesson 4)

As Chonlada moved from a leading role to a guiding role or supporter, she also decreased the formalized atmosphere in the classroom. The flexible classroom resulted in more students learning. For example in lesson 6, Can You See the Light as Bohr Did, it was the first time that students could do the activity freely in terms of place. The student could walk from one room to another. This had never been allowed to happen in Chonlada's class before. The learning atmosphere has change since lesson 6, and students are now free to move, walk and talk while they are engaged in activity. Such as:

> …Students walked from the multimedia room in which they used the spectroscope to observe spectrum from television light to the next room to observe a candle then go to the computer room to observe a computer monitor light and then go outside the building to observe sunlight.
>
> (Classroom observation field note C6)

Students had opportunities to talk using the microphone for the first time. Students now took lead role when they talked and Chonlada faded her role into one of supporter and then only to elaborate on students' answers.

> …After asking student to show their ideas of analogy and metaphors of Bohr atomic theory, Chonlada passed the microphone to the students groups. The representative of each group talked about their analogy and metaphors. Some students were shy to talk, but later they improved in later presentations. At this point, students really were taking the lead role in classroom discussions.
>
> (Classroom observation field note C7)

Students used the overhead projector to explain their orbitals to the class. Field notes taken from lesson 8, My Probability, My Orbitals described.

> …Students from each group then have to present their orbital in front of the class. Each group has a transparent sheet to present on the overhead. The first student puts her work on the overhead and delineates the spot on the sheet, but the marker has faded so the teacher asks another group to change pens.
>
> (Classroom observation field note C8)

Even during the last lesson, Chonlada allowed students to walk and talk freely while they were using the VAST model in lesson 9, Modeling the Atoms, (Everyone Can Do It!).

> ...Students do the hands-on activity by working with the VAST model. During this time, the students walked and talked to other groups exchanging model information such as number of electrons, protons and neutrons including how electrons were arranged. ”
>
> (Classroom observation field note C9)

Chonlada’s changing of teaching practices started from lesson 3. After that, it was noticed that she gave more opportunities for the students to freely engage in the lesson’s activity.

2.1.4 Using the Library Space does not Support Model-Based Approach

Besides being a science teacher, Chonlada was also the librarian and therefore had her office there and so she often used a section of the library as a classroom, but it was not an appropriate place for learning science due to the arrangement of the area. There were rows of book shelves on the right side of the tables and two tables were arranged in column in which students’ seats were 4 rows. The room was not set up as a space appropriate for group work either, but more as a meeting room because the focus of the room was at the front where the presenter would speak but very difficult to see the students sitting in the back. Chonlada preferred having her students to study in this room because it was convenient in term of time, materials and classroom management. She said “I told students to come here [library] because it saved time. During class transition time the students always arrived late to class.” (Chonlada informal interview pre lesson 2). The students also liked to study in the library space because “even thought it was cramped, but it was cool. “I like to study in library more than the laboratory.” (Chaiyan informal interview post lesson 5). This cramped space allowed for some activities to be done easily, but the narrow spacing of the tables between the book shelves didn’t allow them to talk and communicate with other groups. Moreover, this particular arrangement supported the lecture method of teaching, but not the hands-on activity approach.

2.1.5 Step by step to do science

Chonlada’s methods of classroom management were quite obvious the first time I observed her teaching. She required each student to wear a name tag as a formality during this first observation. Along with the formality of wearing a name tag her teaching also was quite formal and this helped with her ability to control the students’ behaviour. She maintained tight control of the class and the lesson by reading the directions of the activity step by step to the students even though the steps could easily have been followed by the students on their own. She addressed every step of measurement and even described the depth of the black box, how to subtract the box heights by the depth of each hole and recorded the heights of the landscape of each hole in a table. She even told the students which colours to use for the 2D model by matching the colours and scales.

For all 9 lessons of the ASIU implementation, Chonlada didn’t once mention to her students that the universal way in which scientists search for knowledge is by using the scientific method. She emphasized that science was conducted by using multiple methods in lesson 8, My Probability, My Orbitals. Her teaching style emphasized a teacher centered role which meant she had to outline the steps verbally to the students and she employed this method in almost every class. Sometimes she took a very short time to explain the steps, but most often it took 10-15 minutes at the start of each class to do this.

The result from her implementation of the ASIU from a focus of step by step description of student tasks by the teacher changed the perception of students 2 and 3 from conceptual understanding to an alternative conception. Cheewin and Chaiyan used to believe that there was more than one method to do science changed their minds after experiencing the ASIU. In the post-ASIU administration of the NOSQ, they thought that there was only one method to do science. The universal method which was used by scientists and students was the scientific method.

2.1.6 The Degree of Independent Student Discussion was Limited

From lessons 4-9, it appeared that Chonlada was continually changing her role as she implemented the ASIU. She gave students more time to participate in activities by reducing the time needed for activity description. Students had more opportunities to work in groups, but she still limited the time for students to discuss independently after finishing the activity. After participating in the hands-on activity of the lesson, students need to discuss and reflect upon what they have done relating to the atomic structure concept and the target of the nature of science emphasized in a particular lesson. For example, in lesson 7 Mix and Match for an Atom, the Bohr atomic theory was the target concept. The target of the nature of science was the role of creativity and imagination in scientific study. The activity for this lesson was the analogy and metaphor of 5 important statements in the Bohr atomic model. Students worked in groups and constructed their analogies and metaphors. One student from each group had a chance to present their group’s ideas, but in the end the conclusion was given by Chonlada herself. In the lesson, the students engaged in the activity, answered the questions in the student handbook and presented their answers. The discussion and reflection was rarely conducted by the students themselves especially in lessons 1-3. But, Chonlada’s central leading role was decreasing as she was giving the students more opportunities to express and discuss their reflections of the activity.

2.1.7 The Constant Use of Lecturing in the Lessons

Chonlada's first lesson implementation was very long. It took 4 periods to finish the lesson which used up a total of 6 teaching hours. The first lesson, Chonlada used the information about atomic structure found in the textbook to teach students about the role of models in the study of atomic structure. She gave the students a worksheet that she developed by herself. This worksheet asked the students about the content of chapter 1 in the textbook. Even though she tried to follow the lesson plans, she still concentrated on the content that the students should know and understand to meet the National Science Curriculum Standard. Several times she used the lecturing method and even though she could have reduced her lesson time using other methods she still kept using the lecture approach. However, in later classes she did reduce the amount of lecturing she did. She did however continue to focus her classes upon content outlined in the standards and even increased the amount of content by adding some concepts from the textbook that she felt were important.

> ...There are other content issues that I want to address in atomic structure. I added some content that was in the textbook. In chapter 3, after the discovery of an electron, students should also learn about the discovery of the proton too. Another concept is I want the students to be able to calculate the interchange of energy and frequency so I added this into chapter 5.
>
> (Chonlada informal interview pre lesson 2)

As Chonlada added some content she continued to use the lecturing method and this was not because she didn't trust the model-based approach, rather, she thought the activities could lead to a better understanding of the science concept s. In her view, engaging in modeling activity and followed by teacher discussion was the most effective method to teach scientific knowledge. Lecturing was used before an activity began. As field note described:

> …The calculation of energy, frequency and wavelength was added into chapter 4 Atomic spectrum and Bohr Atomic Model. It related to lesson 6, Can You See the Light as Bohr Did? The teacher started the lesson by giving the students textbooks. Students receive and return textbooks to the teacher every class. After that she asked the students to open to page 19 in Chapter 4. Then, she she lectured for 35 minutes during which the students read along with her in the textbook and took notes. One student is not following and is doing his mathematics homework. Chonlada asks him to stop and leave the class and warns him not to do this again. Finishing lecture, the teacher continued to talk about lesson 6, Can You See the Light as Bohr Did? She used approximately 10 minutes to introduce the lesson, briefly explaining the activity and elaborating on the activity's question before letting the students go to observe light from different sources.
>
> (Classroom observation and field note C6)

Actually, Chonlada wanted to add more concepts into the lesson as a consequence of the ASIU implementation. She gave comments on the 2nd workshop:

> …In lesson 2 [All About Electrons] I saw many additional things that could be addressed in that class from video clips of the cathode ray tube experiment. As a teacher that has taught for many years, I could see something that would benefit the students. I'm disappointed that I couldn't do this because of time limitations.
>
> (Focus group from the 2nd workshop)

Chonlada meant by adding that she meant giving a longer lecture. She continued to reflect on why she preferred the lecture approach. Even from the implementation of the ASIU, she couldn't change her method even during classroom discussions.

2.2 Chonlada's Implementation of the ASIU and its Influence on the Students' Understanding of the Nature of Science

Throughout informal interviews, students could not connect science with the nature of science aspects. Their explanations of science were based mostly on the context they were in and most often explained that science is just a subject to learn. They could explain the nature of science aspects individually, but could not relate them to the content of other science disciplines. Some aspects coud be inter-related, but the students could not point any of these relationships out. Some aspects even contradicted the nature of science and thus in conclusions their explanations were unconnected to real science and had a lot of conflicts.

2.2.1 Students' Contextual Views on Science

Students in School C explained their understanding of what science is by thinking back to their science experiences in the classroom. They explained science using their experiences in a "content based school classroom" because they thought science was "school science". Cheewin actually asked about the credibility of science topics. He said "every country accepts science ascredible knowledge... I can say that science is taught in almost every classroom in the world. He indicated that science was accepted widely". When asked to explain why scientific knowledge became accepted, Cheewin replied "evidence....scientists had evidence to support scientific conclusion because many scientists came up with the same conclusion. It's congruent". In his view, the credibility of science made it important to teach in school. Scientific knowledge could have both advantages and disadvantages, but those should already be proven through the scientists actions. "What we learn in science has already been proven to be true, for example the existence of the atom". When Chutima was to explain what proves there is an atom she said that "scientists' experiments proved the existence of the atom, any experiments such as Thomson's and Rutherford's experiments." The answer from Chaiyan was quite different from Cheewin and Chutima. Chaiyan viewed science merely as subject to learn which was difficult and complicated. When we asked him, "Why he (and all students) have to learn science? He answered that science is beneficial to students to use as entrance examination and knowledge." He also pointed out that science is believable because it is the truth. "Everybody knows it is true so we learn science. Many scientists have proven scientific knowledge already before it is taught in school". In his mind, proof equals evidence that makes science credible.

2.2.2 Observation and Inference: the Inference was Needless when Observing meant Seeing

When we asked the students to compare and distinguish between observation and inference they explained both concepts based upon their experiences in the classroom. Cheewin and Chutima gave examples from the activities. Cheewin pointed that the depth of the black box in lesson 1, Seeing the Unseen through Models, was observed through data. The data was based upon inferences gathered though the multiple models that were constructed. Chutima's answer was similar to Cheewin's. She explained that "the observation was the measurement of the depth of black box while the model we constructed by computer was the inference." (Chutima informal interview post lesson 1). Chaiyan's answer for this question was quite different from the first two students. For him, observation was the visible thing while inference was the invisible thing. Chaiyan emphasized the word "observation" as only by seeing. Unfortunately, 4 lessons address observation and inference used seeing as the main sense of observation. Even though the first lesson relied on measurement the teacher didn't point it out as it being also one kind of observation. Observation and inference was addressed again in lessons 3, 4 and 6. Like the first lesson, students still used their lessons to explain observation and inference. For example, Chutima stated "observation and inference were different. In this lesson, what we observed was the scattering line of the marbles while the figure of the hidden object we drew was the inference". (Chutima informal interview post lesson 4).

When Chutima was asked to explain the differences of the students' work in each group, she answered "the shape of the hidden object was not the same”. When asked if it is possible to draw the different shapes from the same hidden object, she said that it would be. Her reason was “because the data they obtained was not the same… or there was some error in the scattering line”. When asked if she applied her imagination and creativity to figure out the shape, Chutima said “ No.. the data was obvious.”. For her observation and inference was not related to creativity and imagination because when she observed, she got clear data upon which to draw an inference. Her answer was similar to those of Chaiyan in lesson 3. After engaging in lesson 3, Chaiyan was asked to identify the causes of the inconsistency between Thomson’s and his own conclusion. This question allowed him to relate observation and inference to other aspects of the nature of science such as subjectivity in science or the role of creativity and imagination. However, Chaiyan stated that “because we saw the cathode ray tube experiment by video while Thomson performed the experiment himself” and the last question, “Do you think Thomson used imagination and creativity in his observations and inferences”. He said “no. I think he used imagination and inference in designing the process”. His answer was congruent with the informal interview post lesson 1. Observation very much relies on seeing sense. The data from “seeing” was clear enough so the was no need to apply any creativity and imagination. In summary, the students viewed that both observation and inference didn’t use creativity and imagination. Observations were conducted using their eyes. It didn’t apply any creativity and imagination. For inference, the data from observation was obvious too so creativity and imagination was needed in the process. For the same phenomena or object, scientists must observe the same way. If inconsistencies occur, it must be from the errors in the observations.

2.2.3 Scientific Theory is Subject to Change and is Not Law

Even though students experienced the lesson that addressed theory and law, students held the AC about theory and law. Both Cheewin and Chutima distinguished law from theory by the level of truth. For them, law had the highest level of truth as they called “fact”. In their understanding, law is equal to fact which was always true. For Cheewin’s answer from the NOSQ after having engaged in the ASIU NOSQ, law was undisputable. For the same question, Chutima gave a more sophisticated response on NOSQ. She explained that “theory was from the conclusion of an experiment. It was used to explain phenomena. Law is truth in nature which is unable to change”. A part of Chutima’s explanation was similar to Chaiyan’s answer. Both before and after engaged the ASIU, Chaiyan’s answer was constant. He emphasized the changes and rigidity of theory and law. In the same lesson, their understanding of law and theory was related to another aspect of the nature of science, subject to change within the characteristics of science. However, students specifically viewed theory as something that could change. For a law however, they thought that it would never change because it was fact. The relationship of these two aspects of the nature of science, were contradicted. The classroom observations in lesson 2, A Journey to Atomic History, could perhaps portray how students developed their understandings.

The introduction of lesson 2 allowed the students to arrange six models of an atom freely using their won criterion. After, the students presented their ideas for their chosen arrangements. They arranged the models from the less complicated model to the most complicated model with using more details of it constituents. In other words, the students used the timeline of atomic development to arrange them. From this point, students were introduced to the development of atomic structure over the time. In this lesson, students reviewed six atoms in terms of time, the scientists or philosophers who studied it, the reasons that former atom was broke out and the phenomena that atomic model succeeded to explain. From this activity, students investigated atomic models and their change. The change of atomic structure was an example of scientific knowledge being changed when new evidence is made available as well as the introduction of new technology. This change was obvious to the students because all three students used the change of atomic models as an example of a change in scientific knowledge. As Chaiyan said, “scientific knowledge can change. The atomic models changed several times as the scientists discovered new things”. (Chaiyan informal interview post lesson 2). The students accepted that scientific knowledge was subject to change, but that the change occurred only with theory to support the change. They thought that theory could change because it was uncertain and needed to be modified until it became law. When theory became law, it could not change anymore because it had been transformed to another kind of knowledge. This kind of knowledge, called law, had a higher hierarchy than theory.

2.2.4 Science needs Creativity and Imagination, except in the Scientific Method

All three students agreed that science uses both creativity and imagination. They directly linked this characteristic of science to the study of an atom. The students expressed that science needs creativity and imagination after they engaged in lesson 7, Mix and Match for an Atom. The students' understanding was permanent. One month after the ASIU experiences, NOSQ was administered to the students again. Cheewin and Chutima had insight into how scientists use their creativity and imagination when drawing atomic models from the data they obtain. They thought scientists used creativity and imagination for the process when interpreting the results from their experiments. For Chaiyan, he thought scientists used creativity and imagination in the process of data analysis.

However, the students believed that the use of creativity and imagination in science were selective. The students' understanding of creativity and imagination didn't apply to the other aspects of the nature of science, especially, the aspects of the scientific method. Only Chutima held the conceptual understanding that there was more than one method to conduct science. For Cheewin and Chaiyan, they understood that there was only one method to search for scientific knowledge called the cientific method. In Chaiyan, pre and post the ASIU, he continued to believe both aspects of creativity and imagination and the step by step scientific method were used to do science. Contrary Cheewin, before engaging in the ASIU, had a conceptual understanding that there were many methods to conduct science, later his understanding changed. His answer on NOSQ pointed out that there was only one method to do science which was the scientific method. It was surprising that the students even thought that creativity and imagination played an important role in science, but this disappeared when they talked about the scientific method. It seemed that student had a multifaceted view of the nature of science. They accepted that science needed creativity and imagination while at the same time, science very much relied on the scientific method which scientists had to follow step by step without any imagination and creativity in the application of their work. The notion that the scientific method was the universal science study method came after they were engaged in the ASIU. Cheewin before, had the view that scientists used more than one method to do science. He gave examples using the experiments of Galileo and the discoverys of Newton. Later, Cheewin changed his view. He thought that "there is only one method to do science and it is the scientific method." Fortunately, Chutima could maintain her conceptual understandings before and after her experiences. She still maintained the view that science was conducted using several methods. She was resistant to changing her original beliefs.

2.2.5 The Effects of Subjectivity and Cultural Milieu on Science

The students' understanding of the impacts of subjectivity and cultural milieu on science had 2 levels. The first impact was from the scientists themselves called subjectivity. Two students understood that scientists' work can be directly affected from internal influences. Before and after engaging in the ASIU, the questions from the NOSQ asked the students if it was possible for scientists in different groups to derive their conclusions in different ways despite the fact that they had access to and the use of the same set of data**.** Answers from the three students were different. Cheewin and Chutima explained that two groups of scientists could propose different theories despite having the same evidence because of the subjectivity among individual scientists and groups of scientists. According to the students' answers, the reasons for different conclusions from scientists could come from human factors such as, Cheewin stated, "Scientists' thoughts and conclusions" and Chutima answered "the different inferences could come from scientists".

From the understanding of subjectivity in science, Cheewin was the only student from the three that could understand another aspect, the effects of social and cultural milieu on science as he said "definitely, science reflects social and cultural values". In the case of Chutima, she understood that scientists' work might be affected by the subjectivity of themselves on their work but only when shifted to a social level. She refused to believe that scientists' work was impacted by social and cultural milieus. For her "science reflects the truth" and "science is always true". Her answers were constant both before and after she engaged in the ASIU. Oppositely Chutima and Chaiyan thought that social and cultural milieu did affect scientists' work. His answer was constant before and after having experienced the ASIU. But switching to the question of subjectivity in science, Chaiyan first gave an ambiguous explanation in the pre-NOSQ. For the same question, he later reasoned that inconsistencies among scientists studying the same evidence, was from "incomplete data".

The three students had the same experiences which attempted to develop their understanding of scientific enterprise related to subjectivity in scientists and impacts from social and culture milieu. However, their understanding was unchanged. The students who had a conceptual understanding could maintain their proper views. Chutima in the aspect of social and cultural impact on science and for Chaiyan on the subjectivity in science aspects there were no changes. It could be concluded that Chonlada's implementation of the ASIU made hardly any change upon their beliefs. When looking back to lesson 4 and 5, even though the three students participated in the activity, the process of reflection and discussion was absent. Cheewin, Chutima and Chaiyan didn't have an opportunity to talk, present or reflect their understanding of the nature of science related to scientific enterprises. Classroom discussion was limited to only some students and those three were not included. In addition, the conversation of the students in the class was not quite classroom discussion. It looked like the teacher asked for the answers of students done in their activity hand book. There was no dialogue among students in this part of activity. Nothing left behind except their prior understanding which consisted of both conceptual and alternative conceptions.

2.3 Chonlada's Implementation of the ASIU as Influenced by the Students' Understanding of Atomic Structure

From the ASCT results, Cheewin had the CRU for 17 concepts of the atomic structure which was the same as Chutima. His understandings also were categorized as RM and AC as 4 concepts and 1 concept respectively. Chutima had 2 concepts that were RM and 3 concepts of AC. Chaiyan had conceptual understanding on 9 concepts, RM 5 concept and AC 8 concepts. The details are presented in Table 5.5.

Table 5.5 Concepts of atomic structure and School C students' understanding categories

Concepts	Cheewin		Chutima		Chaiyan	
	Pre-ASIU	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**
Dalton's atomic theory	CRU	CRU	CRU	AC	AC	CRU
The nature of cathode ray tube	RM	CRU	AC	CRU	AC	CRU
Observation and inference of cathode ray experiments	AC	CRU	AC	CRU	CRU	AC
Thomson's atomic model	AC	CRU	AC	CRU	AC	RM
Gold foil experiment	RM	CRU	CRU	CRU	AC	CRU
Constituents of an atom	RM	CRU	CRU	CRU	AC	AC
Atomic number	CRU	CRU	CRU	CRU	AC	CRU
The relevance of atomic number and mass number	RM	RM	RM	RM	RM	RM
Isotopes of an element	CRU	CRU	CRU	CRU	RM	CRU
Nuclear symbol	CRU	CRU	CRU	CRU	AC	AC
Atomic spectrum	AC	CRU	AC	AC	AC	AC
Bohr's atomic model	AC	CRU	CRU	CRU	AC	CRU
The probability of electrons in an atom	AC	RM	RM	CRU	AC	RM
Quantum mechanics model	RM	RM	RM	CRU	AC	RM

Table 5.5 (Continued)

Concepts	Cheewin		Chutima		Chaiyan	
	Pre-ASIU	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**	**Pre-ASIU**	**Post-ASIU**
Atomic orbitals	RM	CRU	AC	CRU	AC	AC
Energy level of an atom	AC	CRU	RM	CRU	AC	AC
Sublevels in energy level	AC	AC	AC	AC	AC	AC
The nature of atomic orbital	AC	CRU	CRU	CRU	AC	AC
Aufbau principle	AC	CRU	RM	CRU	AC	CRU
Pauli exclusion principle	AC	CRU	CRU	CRU	AC	CRU
Hund’s rule	RM	RM	RM	RM	AC	RM
Valence electron	AC	CRU	CRU	CRU	AC	CRU

From these results, the three students had CRU on the concepts of: the nature of cathode ray tube, gold foil experiment, atomic number, isotopes of an element, Bohr’s atomic model, Aufbau principle, Pauli Exclusion Principle and valence electron. The concepts that Cheewin and Chutima had CRU but Chaiyan had an AC were: observation and inference of cathode ray experiments, constituents of an atom, nuclear symbol, atomic orbitals and energy level of an atom. For Thomson’s atomic model and the nature of atomic orbital concept, both Cheewin and Chutima had CRU while Chaiyan held RM. Three students had RM in the concepts of the relevance of atomic number and mass number and Hund’s rule. Cheewin and Chaiyan share the same category, RM, in the concept of the probability of electrons in an atom and quantum mechanics model while Chutima had conceptual understanding. All students held the AC of sublevels in energy level. In addition, both Chutima and Chaiyan had AC of Atomic spectrum while Cheewin had CRU. The ASCT the classroom observations and informal interviews provided us with insight into how and why the students conceptualized. The interactions in the classroom such as the dialogues between the teacher-student and student-student reveal why students had CRU, RM or AC in particular concepts.

2.3.1 The Atomic Model as Representation of the Atom

Students reflected upon their understanding of a model in the study of atomic structure using multiple models. After lesson 1, Chaiyan thought that atomic models were of several types depending on how scientists selected to use them but he changed his mind after lesson 2. “Atomic models change according to a scientist’s work… they are what scientists think not the real thing so they can be changed several times”, he stated. Cheewin and Chutima could explain that atomic models were constructed to represent an atom which they couldn’t see using their eyes or even when using a high powered microscope. They said that scientists constructed atomic models to study the atom and explain its characteristics. “They use atomic structure to explain its phenomena,” Cheewin explained. And those atomic models were changed when the original atomic model failed to explain the phenomena clearly. Cheewin commented that the picture of an atom constructed by computer using the scanning probe microscopy (SPM) was a photo of atoms (Figure 5.8). “I think it is a photo of atoms,” he said and pointed out “that even though this picture came from a computer construction, it’s like you took a photo using a special camera and the displayed using the computer”.

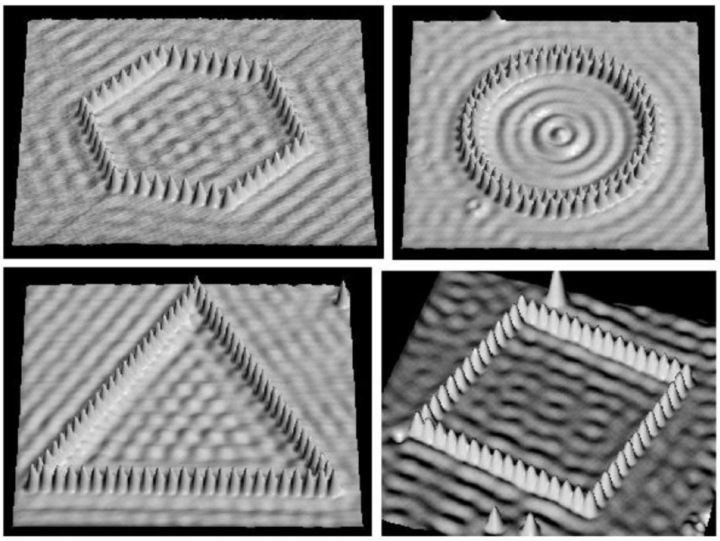


Figure 5.8 The pictures that Cheewin referred to constructed on the computer using SPM

Cheewin’s idea was similar to Chaiyan. “Scientists could take a photo of an atom. Atoms must look like in the picture”. It was only Chutima who explained that the computer picture was only a model and not what an atom really looks like. “This picture was the same as the activity we did [lesson 1 Seeing the Unseen through Models]. It is not a normal photo. Scientists used a special scanning technique.” Chutima coined the word “scan” referring to the scanning probe microscopy technique which appeared in the student textbook. When we asked them whether this picture was a model or not, Cheewin and Chutima answered “Yes”. Cheewin’s reason was “it is just a representation of an atom”. For Chutima, she thought that the picture wasn’t an exact copy of an atom. “A picture does not always look like the real thing. Even in pictures of people, sometimes they look better or worse than they do in real life. Pictures of atom are the same,” Chutima said. For the same question, Chaiyan was showed reluctance before giving his answer. “Hmm… I’m not sure. It might be a model because it was constructed on a computer.” In the end, all the students understood that the model was not actually a real atom, but a model of it. Models are representation of the original phenomena which is not necessarily exactly like what the phenomena might really look like, but a model does represent some characteristics of the original phenomena and is therefore useful.

2.3.2 The Timeline of the Atomic Model made Students aware of the Historical Model and that Views must Change Overtime when New Information is Discovered

Students learned all about the atomic models in lesson 2, a journey through atomic history. This lesson aimed to introduce students to the historical well known atomic theory developed by the ancient Greeks and take them through the changes to it until the currently accepted atomic model. First the students became familiar with the models and then in further lessons learned about them in more detail. In the introduction, students got a set of the models as shown below in Figure 5.9. Chonlada asked them to sort the models by using their own criteria. Most of students in the class sorted them by timeline as to how they were developed. Once they completed that task they investigated the development of atomic theory. There were six atomic model stations. Students by group explored the information and took notes, discussed in their groups and answered questions. From studying the atomic model in a holistic view, students could identify the historical models and current ones accepted by scientists. As Cheewin explained in the post lesson 2 informal interview “The electron cloud model is the accepted model now. The rest are no longer accepted”. When he said “the rest” Cheewin pointed out the timeline of atomic models (Figure 5.10) from Bohr’s atomic model and moved across all the historical models.

When asked to discuss the purpose of learning the history of the various models even though are no longer acknowledge as being a correct representation of atomic structure, students shared a similar view regarding this question. All three students believed that by studying the development of the modesl from the original to the one most accepted in today’s modern world, helped them understand more about the concept of atomic structure. Chaiyan stated “It [the timeline] showed us the background of atomic theory and this made the study of it [atomic structure] interesting.” Cheewin mentioned the same and added “understanding more about the scientists’ work and how they developed the models is just as important as learning about the models themselves.” and Chutima said “the scientists’ work was interesting and if we understand their work, it will better for us than just remembering the conclusion of their work.”

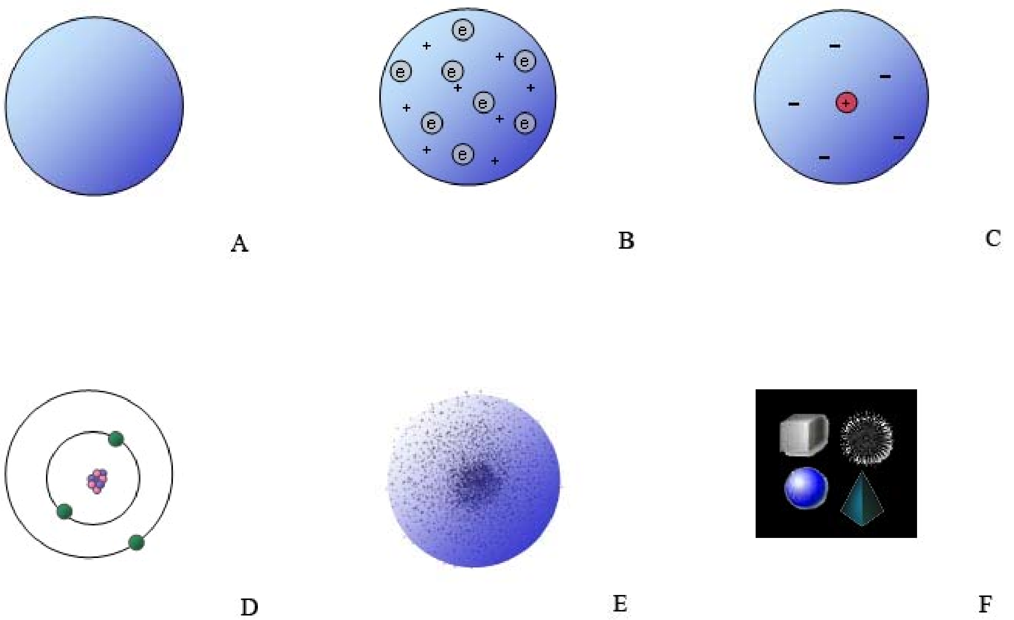


Figure 5.9 Pictures of atomic models from ancient time to the present that the students used to sort using their own criteria

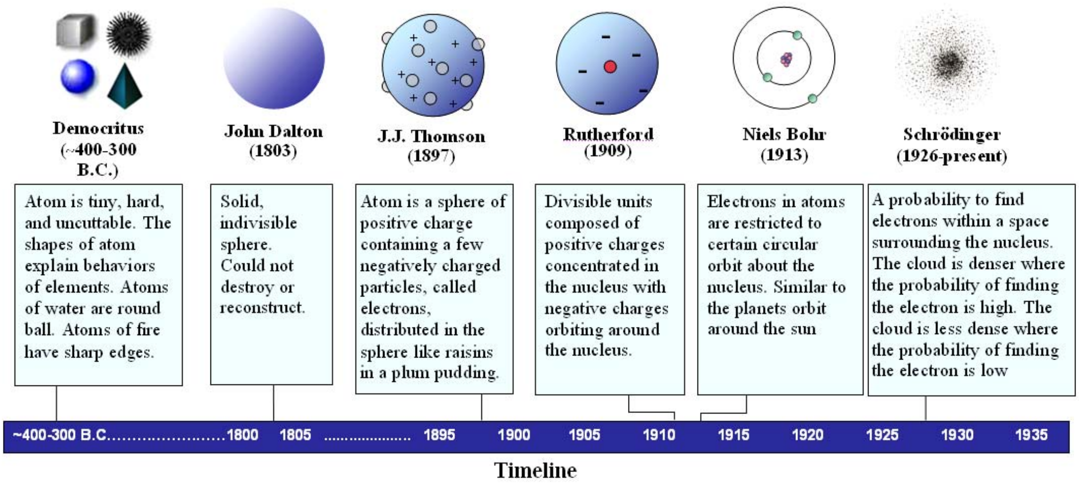


Figure 5.10 The atomic models timeline sorted by the year they were proposed

2.3.3 The Scientists' Experiments relating to Atomic Structure

Four scientific experiments were addressed in the ASIU, Thomson's cathode ray tube, Millikan's oil drop experiment, Rutherford's gold foil experiment and the flame test experiment. Those experiments were not duplicated, but rather, each of the lessons discussed each original experiment with highlighted concepts. In Thomson's cathode ray tube experiment emphasis was put on the observations of the cathode ray phenomenon. Later, the inferences of the data lead to the discovery of the electron as the fundamental component of the every atom. Millikan's oil drop experiment put emphasis on determining electron charge in an atom. Rutherford's gold foil experiment addressed the concept of studying the unseen by using the indirect method. After each activity, students were asked to indicate the most important part of the lesson that they discovered doing their activity and how it connected to the development of the atomic model by the scientists themselves. From focusing on Thomson's experiment, Cheewin opened his handbook and pointed to the picture of the plum pudding atomic model. He said "Thomson discovered that there were electrons in an atom." Cheewin explained more about the properties of an electron "electrons have negative charges because they move to a node and we can see them because they emit light". Chutima explained by using her handbook the same as Cheewin did but she had a more sophisticated explanation regarding the properties of an atom. "Each electron of every atom is the same. They have a negative charge, mass, and bend in a magnetic field" Chutima said. For Chaiyan's explanation, he pointed out that "electrons have negative charges". When asked to explain more, Chaiyan said, "Thomson found that electrons were in every atom and he also found that electrons had negative charges". When asked we them to explain the concept of Millikan's experiment, both Cheewin and Chutima could describe what happened inside the chamber while Chaiyan idea was very confusing. He didn't understand why dropping oil could stay in the air instead of falling with gravity. "I have no idea," he said. It was not surprising that Chaiyan couldn't explain, because when the teacher showed the video clip of the oil drop experiment, Chaiyan was talking to his friends the whole time and was not concentrating on the lesson. The second question asked the students to explain how Millikan determined electron charge. Both Cheewin and Chutima could explain the calculation of electron charges using Millikan's technique.

> Cheewin: Electron charge is the least amount that could be subtracted the predetermined number.
>
> Researcher: What is the number?

Cheewin: Can I open the book?

Research: Yes

Cheewin: [opens his handbook] It was 1.60218×10^{-19} coulomb

(Chaiyan informal interview post lesson 3)

Chutima's answer was slightly different from Cheewin. For her the electron charge was "the least amount of electric charge from droplets in the chamber". In the case of Chaiyan, he answered this question by opening the book and searching for the number. "Here, is the electric charge of one electron, 1.60218×10^{-19} coulomb. Millikan performed his experiment and calculated it," Chaiyan said.

The next lesson was about Rutherford's experiment. Students were asked with the same question as in lesson 3. All 3 students had similar responses to this question. All of them answered that "the discovery of the nucleus" was the most important in Rutherford's work. The probe question followed, what was his result that made Rutherford believe in the existence of a nucleus in an atom. All the students could answer this question. Cheewin said, "The deflection of the alpha particle." Chutima answered, "The alpha particle deflected straight back," and Chaiyan stated, "Some of the alpha particle deflected."

2.3.4 Using the Atomic Model to explain the Phenomena

For the final topic, the students expressed their understanding of the scientists' work connected to the atomic model. In this topic, students used atomic models to explain the phenomena in lesson 6. Bohr's atomic theory based on the atomic spectrum, pointed out the use of microscopic magnification to explain the macroscopic phenomena. For Bohr's planetary model, all three students were able to explain the figure and its inherent characteristics. When asked to explain the atomic spectrum using the atomic model, the students gave different answers. Cheewin was the only one who could use the orbits of an electron to explain the emission of light. Chutima's explanation was very confusing regarding the concept of orbits in an excited or ground state. Even though she could explain the atomic spectrum using Bohr's atomic model, she still believed that "ground state meant the nearest orbits while the farther orbits meant the excited states." Her explanation was based only on one electron in an atom. She didn't realize that there are other electrons in other orbits such as $n = 2$, $n = 3$, and so on. Chaiyan was unable to explain the atomic spectrum using Bohr's model. "I need to read more and get my friends teach me," he stated. When explaining why he had problems understanding he stated that he didn't pay attention enough in class and would need to have his friends explain further."

In the next lesson, My Probability, My Orbitals, the students were introduced to the quantum mechanics model or electron cloud model as it is usually called in the IPST textbook. Only Chutima could explain the concept of the electron cloud model. She explained the electron cloud model by tracking it back to the activity.

2.3.5 Representation of the Microscopic Properties

In lesson 9, Modeling the Atoms, (Everyone Can Do It!). The three students were in different groups from the previous activities. Each group arranged electrons into the VAST model according to the stick elements they selected randomly. Cheewin's group got Silicon while Chutima and Chaiyan's group got Sodium and Phosphorous respectively. They kept their elements confidential from the other groups and checked by counting the number of constituents. Working in groups, they put black buttons which represented electrons into the right orbitals. Arranging the electrons in the Sodium atom was not difficult for that group, but it was difficult for the Silicon and Phosphorus groups. In Cheewin's group, after one member constructed the nucleus they begin to put the electrons into each orbital.

> Cheewin held the ball stick that had the red and blue buttons. He asked his friends to make sure that the number of protons and neutrons was 14.

Friend 1: I did it. Count them first and then attach them. [Talks to another member] close it [the box] up. I don't want to be confused with the rest of the red and blue buttons.

Cheewin: Did you count these? [Points to the black buttons]

Friend 2: Yes. Put it into the s orbital. The smallest round sheet.

Cheewin: So this is the 2s orbital…attach 2 electrons to this

Three boys help to attach the electrons into the orbital until 2 electrons are left

Cheewin: Here's the Pauli exclusion, separate them into each of the 3p orbitals

Friend 1: Which ones?

Friend 2: Any, two of them, that's ok but do not stick them together keep them separate. There are still available p orbitals.

(Classroom observation C9)

In Chaiyan's group, they were successful in arranging the electrons. After they finished, Chaiyan and his group members went around the room to examine the models of the other groups. All the students had to fill in the electron configuration of 15 elements, from carbon to calcium, and complete the worksheet. After the lesson, the three students were asked to give an example of the elements they had to arrange, according to Pauli Exclusion Principle and Hund's rule. All three students were able to the electron configuration of their element using Pauli Exclusion Principle and they could explain why each orbital occupied up to 2 electrons. Chaiyan gave the reason that "in the same orbital, one electron spins up and one electron spins down there are no other electrons." Cheewin and Chutima gave a little more sophisticated answer, but similar to Chaiyan's . Cheewin explained that "the 3rd electron must not duplicate all 4 quantum numbers of formerly occupied electrons." However, when they were asked to link electron configuration to the phenomena all students were unable to give an example.

3. Key Findings and Commentary on the Results Derived from School C

3.1 Related to the ASIU Implementation

The findings of Chonlada's implementation of the ASIU showed some changes in her teaching practices. In the beginning, she was hesitant to follow the practices outlined in the ASIU, but because she was a participant in the research she started to follow the ASIU's suggested teaching practices and it changed her views regarding her own teaching practices. She accepted that multiple teaching methods could result in meeting the teaching standards. She no longer worried about being content-driven and began to use more and more activity-based teaching practices. She went from delivering teacher focused lessons to more teacher supportive lessons, but she did state that some of her teaching behaviours continued to impede a successful implementation of the ASIU. For the first 3 months of the ASIU implementation (May-July) she just couldn't give up totally on the lecture method of lesson delivery and her classroom management techniques continued to be an obstacle to her using the model-based teaching approach. Another impediment was having lessons in the library space which meant the room needed to be silent, neat and tidy at all times and this was not conducive to learning using the model-based approach. Her classroom management requirement of having a silent classroom also did not allow well for in class discussions because these kinds of activities meant more noise and the possibility of students not paying attention and going off topic with their friends.

3.2 Student Understandings of the Nature of Science and Atomic Structure

The data from multiple sources such as classroom observations and informal interviews showed that students' understanding of the nature of science heavily depended upon their experiences in school science. Unavoidably, students held the notion that science was simply a subject to learn in school. For them science was taught in schools because scientific knowledge was already proven to be correct. Scientists had evidence to support that scientific knowledge is true. Some students also had the view that science was not related to society and culture. Students also had misconceptions regarding scientific theory and law, and the universal method to do science called ‘the Scientific method’ which scientists followed step by step when doing experiments.

The findings from the ASCT administered to the students a month after the ASIU implementations showed that high and middle achieving students held the same number of conceptual-rational understandings, but slightly different ones in the RM and in the AC. It was found that low academic level students appeared to grasp the number of AC the same as using the RM. The exploration of students insights into atomic structure when they were engaged the ASIU found that students could develop their understanding that an atomic model is just a representation of an atom and not reality. The three students from school C also used their experiences in the activities and were able to explain the experiments that were related to the development of the atomic model, for example, the cathode ray tube experiment and the gold foil experiment. After they learned how the atomic model was constructed based upon research findings, they used were able to use the atomic model to explain related phenomena such as a line spectrum from a burned metal compound. Lastly, students were able to use Styrofoam balls and buttons as modeling tools to represent atomic particles. They learned to identify the crucial relationships that make an analogy useful and were able to indicate the strengths and limitations of model representations.

The Common Findings from the 3 Schools

1. Teachers Implementation of the ASIU

Each of the three teachers had their own characteristics and teaching styles. Their attitudes toward science education goals determined their classroom practices. The following factors were seen to influence the differences among the three teachers.

1.1 Teachers' Characteristics and Background

The three teachers' implementations were influenced by their characteristics, personalities, and academic backgrounds. Their student expectations, professional development experiences and special duties were also factors that impacted on their implementation of the ASIU. From the findings, the teachers who were open and flexible were more capable of teaching using the ASIU while those who were more rigid had more difficulties implementing the ASIU. Teacher expectations also had an affect on the teacher abilities to implement the ASIU. Arunee and Banburi wanted to engage students in hands-on activities while Chonlada wanted her students to have a different experience than from the normal classroom. However, she still emphasized the content achievements. This expectation heavily influenced her chosen teaching approach when implementing the ASIU. Two of the three teachers had participated in a professional development program. Arunee participated in the action research project with a university lecturer. She had a good perception regarding the values of integrating the nature of science. The implementations of the ASIU coincided with the prior knowledge she had gain from her professional development. Chonlada participated in some school district professional development. However, she didn't comment on how her previous experiences as a demonstrator related to her implementation of the ASIU. Lastly, teachers' special duties also influenced their implementation of the ASIU in different ways. Arunee's special duty as the vice head of the science department affected her teaching preparation in that whenever she to take time out to meet with the school board she didn't time to prepare and therefore used the lecture method of teaching because it required the least amount of preparation. Banburi's extra duty was head of the school finances and this position kept her very busy. She had no time to prepare for her teaching duties, but she solved this problem by letting the students explore their learning by letting them conduct the activities themselves. Sometimes she even recalled her understandings of the lessons along with students. This teaching style had some excellent results as the students had more time to talk and share their understanding of the activity, its content and the nature of science. Compared to other schools, Banburi's students had more time to do activities and participate in discussion more than those of school A and school C.

1.2 The Determination of Teacher's Commitment to Change

To implement the ASIU, all three teachers had to make some changes and some of these changes were the same in some cases. They had to change their role in the classroom from being the leader of the activity to one of guiding the students. They all tended to give lectures and made the conclusions for the students. Later, the teachers went from taking a leading role to a one of commentator or supporter who walked around the classroom and assisted students. For conclusion procedures, the teachers changed their position from standing in front of the class to the side. Students took the lead role in classroom discussions. They presented their conclusions and exchanged their ideas with other students in the class. At this point, the teachers acted to only preside over classroom discussions. Even the teachers made conclusions for the lesson were generated by the students. However, the level of change of teachers' role in the class was different in all three cases. The more the teachers could reduce their lead role, the more they reduced using the lecture format and this meant the students were more engaged in model-based learning. It was Banburi who was the most successful in changing her role. Arunee changed her teaching style by motivating her students to become active rather than passive learners. She gave major time for students to do the activities. Banburi changed her activity management behaviours by moving from a normal classroom environment to the computer laboratory or school meeting rooms because those areas better supported the model-based activity approach to teaching. She also changed the length of time she gave the students in class for reflection and discussion to be equal to the amount of time she gave to do the activity. For Chonlada, the key change was her view on which teaching method would best meet the science standards. Once she understood what the implications of the ASIU were on her students she understood that she could move from the lecture approach of lesson presentation to another type and still have her students meet the objectives of the national standards. Her implementation of the ASIU went more smoothly after she made this realization.

1.3 Teachers' Understandings of the Nature of Science

The teachers' implementation of the ASIU was influences by their previous understanding of the nature of science. Comparing the implementation of the ASIU to the teachers' understanding of the nature of science in phase I, the data showed some interesting issues that will be discussed here. Even though the all teachers passed through the 3 workshops that convinced them about the congruent nature of science aspects they nevertheless avoided teaching the theory and law. For example, Arunee asked the students to answer a question about theory and law. After that it was she who gave the answer key to the students. For Chonlada, she gave a lecture on theory and law using the textbook while Banburi just skipped teaching theory and law altogether. Tracking back to the findings from the first phase, all the teachers' understandings of theory and law were categorized as alternative conceptions while their teachings were categorized as deficient. For the nature of science regarding society, culture and science, the teacher who had a good conceptual and alternative understanding of it used different teaching techniques. Banburi, who understood well about the impact of social and cultural milieu on science, was able to teach the ASIU according to the outlined lesson plans. She also changed her teaching procedures by letting groups of students have equal opportunities to present their ideas. Banburi's implementation of the ASIU in this aspect was related te to her informed understanding in phase I. Arunee had an alternative understanding which was based really in misunderstanding and thus did not let her students have time for discussion and she only talked to the class about the aspects of the nature of science for a very brief time and because it was so brief the students didn't really grasp it. Chonlada's implementation of the ASIU in this aspect was similar to of Arunee's in that her step by step teaching style wasn't congruent with the multiple teaching methods in which science can be taught and this impeded her students' understanding in reference to the scientific method.

1.4 Teacher's Familiarity of the Lecture Teaching Method

The teachers' familiarity of the lecture as a method of teaching had a direct affect on their implementation of the ASIU. Arunee commented that the hardest part of teaching the ASIU was learning how to get the students to discuss and make the conclusions on the specifics of what happened in class rather than having her do it all. The lecture method was a quick way for teachers to point out the important things the students should know and the other methods take much more time. But they learned that the lecture approach was not the best way for enhancing the students' understanding of atomic structure or the nature of science. Students' conceptions from lecturing, even after the activity, felled into rote memory or alternative conceptions. Several times, lecturing about the nature of science or left the students with nothing beyond their prior knowledge before experiencing the ASIU. In the worst case, students' conceptual understandings even changed to an incorrect alternative conception. The use of lecture in the ASIU lesson was different according to each teacher. Chonlada was the teacher that used the lecture explicitly usually lecturing before and after the activity. She even integrated lecture method in the introduction and conclusion of the lesson. In Arunee's case, the lecture was used when she didn't have time to prepare for her teaching. She also used the lecture method when she wanted to get across very difficult concepts such as the calculation of atomic mass. Banburi avoided giving lectures and this reduction of using the lecture resulted in an increase of students reflection and discussion time which was the key success of the ASIU.

2. Teacher's Implementation of the ASIU Influenced on Students' Understanding of the Nature of Science

Nine lessons of the ASIU focused on 8 aspects of the nature of science. The students in the 3 different schools had different understanding of the nature of science. Student understandings of the nature of science were varied and it depended as well on which aspect they were discussing. Their understandings could be divided into 3 groups. All students had conceptual understandings about what science is and that science relies on evidence, as well as the creativity, imagination and subjectivity of the scientists themselves. The areas of the nature of science that some students had ambiguous understandings were the use of multiple methods to do science, observation and inference and effects that come from society and culture on science. But all students had alternative understandings regarding the area of theory and law. Their understandings of the nature of science as a consequence of experiencing the ASIU showed different results and will be discussed in the next section.

2.1 The Nature of science aspects that all Students had conceptual Understandings

If the science in the classroom was experienced via the model-based approach and the students could apply their learned knowledge to understanding natural phenomena then the students could explain science more openly and their explanations went beyond just school science. In other hand, students viewed science like school science which is a subject to learn if they experienced the rigid and content-orientated classroom. Students viewed experiment result as the main evidence of science, but they also explained scientific evidence as related to other aspects of the nature of science. For example, scientists make an inference on their observed data using their creativity and imagination; however, scientists still rely heavily on the evidence and this emphasis on the evidence makes science credible.

Students accepted that creativity and imagination play important roles in science, but they selected areas where it is used and not used. Creativity and imagination were used when designing experiments, making analogies and interpreting the data. Moreover, students used creativity and imagination to reason other aspects of the nature of science like observation and inference. Students could understand the nature of science using the aspect of subjectivity in science. They perceived its impacts on scientific enterprise. Students pointed out that subjectivity in individuals is influenced by creativity and imagination as well as has influence on how scientists design methods to seek the knowledge. From the activity, students commented that an existence of subjectivity has an impact on the process of validating scientific knowledge claims.

2.2 The Nature of Science Aspects Concepts that Students hold are Ambiguous Understandings

Student understanding of the aspects that scientific knowledge is tentative had two categories, conceptual and alternative. In Conceptual understanding students explained that the reasons for change are based upon other aspects of the nature of science such as the development of new experiment or new interpretations of the same data. Students who held alternative conceptions used the tentative characteristic of science as a criterion to distinguish law and theory in terms certainty. For them, scientific theory was subject to change. A theory changed until it became law which couldn’t be changed anymore because it was now certain.

Students had both conceptual and alternative conceptions of the multiple methods to do science. The differences between students who had a conceptual understanding and those who had an alternative conception were the activity atmosphere and the interdependence of the nature of science aspects. Students who experienced rigid and guided activity tended to struggle with the universal method to do science, the scientific method. While students who experienced open and flexible activity, tended to understand that science was conducted under various methods in order to seek for knowledge. In addition, students who could make this connection understood the interdependence among nature of science they could understand that methods to do science were influenced by scientists’ subjectivity, creativity and imagination, methods to analyze the data, the interpretations, and mathematical ability.

Students understood that observation and inference were influenced by their understanding of the modeling activity, they had engaged in. Students developed their understandings of these aspects further after they were engaged in a lesson that focused on observation and inference by making relationships to other aspects. For students who held ambiguous and alternative concepts saw observations as only using their ‘eyes’ and didn’t know how to “make the inference”.

Students who experienced the ASIU had different ideas about the influence of social and cultural milieu on science in both a conceptual and alternative view and this depended upon how the lesson was present to them. Students who had a conceptual understanding in the interaction of science, society and culture experienced lessons that were full of discussion, the opportunity to reflect on the issues of science, society and culture derived from activity. On the other hand, students who held alternative conception had classroom experiences in which discussion of the interaction of science with society and culture was omitted. The alternative conception remained despite students having experienced the activity or read the issues on the effects of society and culture on science. Furthermore, the rigid, content-orientation classroom combined with the limitation of group or class discussion, and reflection changed students’ conceptual understanding prior to the ASIU to a better understanding after participating in the ASIU.

2.3 The Nature of Science Aspects in which all Students held Alternative Understandings

Theory and law were aspects that all students held the alternative conceptions. This aspect of the nature of science was resistant to change. Teachers seemed to avoid talking about theory and law. Often times theory and law were overlooked in the classroom and left the ambiguous which left students with many misunderstandings. Students’ alternative understanding, for example, theory could change but law couldn’t change, and law, had a higher hierarchy than theory.

3. Teacher Implementation of the ASIU Influenced on the Students Understanding of Atomic Structure

Concepts regarding atomic structure in the ASIU were divided into 7 main topics consisting of model and modeling of an atom, evolution of atomic theory, Thomson's atomic model, Rutherford's atomic model, atomic spectra and the Bohr Atom, The quantum mechanic model and electron configuration. The conclusions of students understanding of atomic structure as a consequence of the ASIU experiences is presented in the 7 topics below:

1. Student views on models and the modeling of an atom were varied. They viewed the atomic model as a representative of an atom. There were students who viewed atomic models having physical properties such as its figures and constituents. However, some students had more sophisticated views regarding models and the modeling of an atom. Students after experienced the ASIU, were able to develop a better understanding of the functions of models and modeling in science, for example the mathematical model.

2. Students viewed historical models and modeling with multiple opinions. Students could make connections between the scientists' experiments to the inference of atomic models. Others students were aware of historical models and could understand the idea of change in the models by their discussion of the atomic timeline. Moreover, students were able to indicate methods and evidence that the scientists used to construct the atomic models by investigating the atomic history.

3. In Thomson's atomic model, students could explain Thomson's cathode ray tube experiment and connect his results to the plum pudding atomic model. Students made observations and inferences regarding the cathode ray tube by watching video clips on the construction of Thomson's atomic model. Some students used a sophisticated explanation of the model by explaining the concepts within Thomson's atomic model.

4. By studying Gold's foil experiment and Rutherford's atomic model, students could understand both the concept of the scattering experiment and us them to study unseen entity and the concepts within Rutherford's model. Students could match the experimental result such as "the Alpha particle deflected straight back toward" to the proven existence of the atomic nucleus which had a high density and a

positive charge. However, students with alternative conceptions and tended to use rote memory in extending the concepts from Rutherford's model such as atomic number, to the relevance of the atomic and mass number, and nuclear symbol.

5. The students viewed the planetary model as an explanatory model because of its effectiveness in explaining atomic spectrums. The need an explanatory model was the reason for change from Rutherford's model to Bohr's model which was used to understand atomic spectrums. Students also conceptualized the concept within the planetary model instead of merely remembering shape, figure, or the arrangement of it constituents. However, some students were confused about the concept of orbits in an excited state and ground state even though they could explain atomic spectrums using Bohr's atomic model.

6. The students could explain the physical characteristics of the quantum mechanic model and the concept of constructing. They explained the principles of the quantum mechanics model which related to a chance meeting of moving electron around the nucleus. Nevertheless, they could hardly explain concepts within the electron cloud model. They totally couldn't explain any phenomena using this concept. Students failed to connect the orbital to the atomic model. The lack of clarification of the extended quantum mechanics model to related concepts resulted in many students developing alternative conceptions in the topic of the energy levels of an atom. It was found that the abstract nature of the electron cloud model and quantum theory was just too sophisticated for the students' conceptualization.

7. The hands-on activity that emphasized electron arrangement in an atom engaged students to use the VAST model a method on which to represent microscopic entity. Students realized that the study of atomic structure always employs symbolic features as a bridge between the macroscopic and microscopic world. Students worked with the VAST models and used them to study electron arrangement in an atom which focused on Aufbau principle, Pauli Exclusion Principle, Hund's rule and valence electron. However, students failed to extend their conceptions in some parts. For example, with Aufbau principle and Pauli Exclusion Principle, despite, their

participation multiple times in activities related to these topics they could not extend their knowledge. This indicated that hands-on activities must also cooperate with minds-on activities. Furthermore, the electron configuration seemed meaningless to the students because they were unable to give an example of the phenomena as it related to electron configuration.

Summary of the Chapter

This chapter presents the findings of the research in phase III. The findings were presented in four parts: the findings from school A, B, C and the common findings derived from three schools. Each part presents the teacher's implementation of the ASIU, its influence on student understanding of the nature of science and atomic structure. It was discovered that teacher characteristics, background, teacher commitment to change, understanding of the nature of science and the teacher's familiarity of the lecture teaching method, had influences on a successful or unsuccessful implementation the ASIU. For student understanding of the nature of science, the nature of science aspects that all students held a conceptual understanding of were what science is that science relies on evidence, creativity, imagination and subjectivity. The nature of science aspects that students held both conceptual, ambiguous alternative conceptions in were that science was tentative, there are multiple methods to do science, observation, inference and the effects of society and culture on science. The nature of science aspect that all students had an alternative conception was the theory and law aspect. The ASIU had an influence on the students' understanding of the atomic structure by developing their conceptual understanding of by using models and modeling an atom, historical models and modeling that included the evolution of the atomic model. Students could make connection between the scientists' experiments regarding atomic models. However, the students still tended to use rote memory or developed an alternative conception of sophisticated models such as electron cloud model. They also had difficulty understanding abstract concepts such as the energy level of electrons in the cloud model. Moreover, students failed to use orbitals and electron configuration to explain the phenomena.

CHAPTER VI

CONCLUSIONS, DISCUSSIONS AND IMPLICATIONS

This chapter contains three main topics related to the results of the research. The conclusions of each research phase are discussed first and are reported in relation to the research questions, followed by a discussion of the interpretations of the interesting issues of this study. The last section of this chapter, deals with pedagogical implications based upon the results of discussions with the teachers who implemented the ASIU. In addition, implications for students understanding of the nature of science and atomic structure are discussed with recommendations for future practice and research.

Conclusions of the Findings

1. Conclusion for Phase I Research Questions

The conclusions in relation to phase 1 research questions, “What is the current situation regarding teaching and learning of atomic structure integrating this learning with the nature of science in 3 classrooms in Bangkok?” will be described here in terms of three topic areas: teacher understanding and practices as related to the nature of science when teaching atomic structure concepts prior to the ASIU, teacher perception of the problems in teaching atomic structure concepts integrated with the nature of science and student conceptual understanding of atomic structure and the nature of science prior to implementation of the ASIU.

1.1 Teachers’ Understanding and Practices of the Nature of Science when Teaching Atomic Structure Concepts Prior to the ASIU

This phase of research was conducted in order to study the teachers’ understandings and reflections as they related to the nature of science in their teaching of atomic structure. It was found that the teachers understood three aspects of the nature of Science: science needs evidence to support it, science is tentative, and imagination and creativity are important to science. However, they believed that science follows a single scientific method. The notion that science is universal and independent from social and cultural influences was also held by the teachers. Classroom observations found that teachers rarely reflected upon the nature of science in their classrooms, even in the areas they understood well such as what science is and subjectivity in science.

1.2 Teachers' Perceptions of the Problems of Teaching Atomic Structure with the Integration of the Nature of Science

For the teachers in this study, difficulty with teaching and learning atomic structure was that the concept was very abstract and not concrete in appearance. The students usually used rote memorization to learn the concept, but this really gave them no true understanding of the difficult concepts which often led to alternative conceptions regarding the phenomena later on. Experiments were not often used to teach the concept and teachers didn't have access to experimental equipment, materials and more understandable models to use when teaching the concept. Teachers felt that learning the concepts needed imagination on the part of the students that their imagination skills were very limited. Teacher' pointed out that students studied these particular science concepts without really understanding the basics behind them. For example, when they studied the electron cloud model they didn't really understand the origins of the theory behind the model. The most difficult topics for students to learn in the teachers' opinions, were the Thomson's cathode ray tube experiment and his atomic model, the Rutherford experiment, the calculations about light and energy as related to the atomic spectrum, the electron cloud model and the orbital concept. The expectations of the teacher for the students to learn beyond the scientific content was met by teaching the students how to use inquiry in gaining scientific knowledge and in understanding that science can be used to solve everyday life problems and provide skills for mental modeling. The teachers believed it was possible that students would have a better chance of learning and understanding difficult concepts and activities mentioned above if they could use teaching materials that would make the concepts more concrete and visible for the students. They felt that teaching materials like models could best reflect the theories inherent in atomic structure. The teachers also listed other examples of teaching materials that would help such as computer programs that used modeling or animation with programmed instructions that the students could manipulate easily as they learned difficult concepts independently.

1.3 Students' Understanding of the Nature of Science Prior to the ASIU

Students' understandings of the nature of science elicited using the Nature of Science Questionnaire (NOSQ) found that students could point out the nature of science if they used the following aspects: what is science, science relies on evidence, science is tentative, and is based upon observation and inference. However, students held many alternative conceptions about the nature of science when discussing these aspects: the multiple methods in which to do science, the meaning and construction of theory and law, subjectivity in science and the influence of social and cultural milieu on science.

1.4 Students' Conceptual Understandings of Atomic Structure Prior to the ASIU

The ASCT was the instrument used to study and assess students' understanding of atomic structure. Their understanding could be categorized into 3 groups: conceptual-rational understanding, rote memory understanding, and any alternative conceptions they developed. The results showed that students tended to remember without understanding when they used rote memory to learn. The 12 concepts that they memorized were: characteristics of the mode, Dalton's atomic theory, observations and inferences of the cathode ray experiments, atomic number, isotopes of an element, atomic spectrum, Bohr's atomic model, the quantum mechanics model, atomic orbitals, Aufbau principle, Pauli Exclusion Principle and valence electron. In terms of their development of alternative conceptions, there were six concepts that students had difficulty understanding**:** the role of the model in atomic theory, the gold foil experiment, nuclear symbols, the probability of electrons in an atom, energy levels of an atom and sublevels in these energy levels. There were 6 concepts that were categorized as students having a conceptual-rational understanding**:** the nature of the cathode ray tube, Thomson's atomic model, the constituents of an atom, the relevance of atomic number and mass number, the nature of atomic orbital, and Hund's rule.

2. Conclusion for Phase II Research Questions

The findings in relation to the research question, "What is the process of developing of the instructional units to teach atomic structure with the integration of the nature of science?", and "How is the instructional unit to be modified to take into account teacher responses?" are concluded as follows.

2.1 The Process of the ASIU Development

The development of the ASIU process consisted of two parts, the process of designing and the process of development. The design of ASIU started with a review of curriculum documents. The Thai National Education Act suggests learning theory for Thai education and the ASIU was designed in accordance with the paradigm of constructivism as suggested by the above mentioned document. The National Science Curriculum Standard determines the goals of learning and these were implemented into the design of ASIU. Sub-standard 8: The Nature of science and Technology and Strand 3: matter and properties of matter set the objectives of the learning unit. The IPST chemistry textbook and teacher handbook was used along side as a resource to compare allotment of teaching time in lesson measurement, lesson order and depth of the research and as a guide in the development of the theoretical framework of the ASIU. The teaching strategies employed by the ASIU were centered around the model-based approach. Other teaching approaches such as inquiry teaching, constructivism and historical approaches were all used in creating the lesson plans in the ASIU. Both teacher and student alternative conceptions were also considered when developing target activities. Some students' alternative conceptions such as the difficulties with Bohr's planetary model affected the arrangement of topics. At first, all models known starting from the earliest Greek model to the most modern models developed were shown to the students as a whole in order of their development. Later lessons presented the models in greater detail. The theoretical framework of a model-based approach in this study consisted of 5 principles: model and modeling, explicit and reflective nature of science concepts, atomic theory, history of science and scaffolded technology enhancement.

Model and modeling activities in the ASIU consisted of the construction of multiple models such as mental models, physical models, conceptual models, mathematical models, explanatory models, analogy, and metaphor. The idea of multiple model construction was introduced in lesson 1 as the students built 3 types of models from the same data. A model-based approach allowed students to work with models and use models as a conceptual framework for generating and answering questions. Model and modeling activities encouraged students in terms of observation, questioning, dialogue, critiquing, and prediction. Furthermore, model and modeling activities also addressed functions of models, such as explanation, prediction, making a decision and communication.

Explicit and reflective nature of science meant that the ASIU not only engaged students in the process of scientific inquiry, but also enabled them to "reflect on what they have done" in the activities. Students participated in the scientific process by making observations and inferences, collecting and analyzing data, creating models to critique and revise, and presenting the findings to peers. Students also explicitly discussed and reflected on the nature of science, how and why scientific knowledge is established. The explicit and reflective nature of science appeared in every lesson of the ASIU.

Atomic theory was the focus concept of the ASIU and lessons portrayed atomic structure as it has been developed through various social and cultural context as reflected in the atomic timeline in lesson 2. The lesson not only presented atomic theory in terms of the important and necessary scientific knowledge but also the fascinating story and interesting history of remarkable philosophers and scientists. For instance, lessons included the story of Greek era related to the development of atomic theory, or the study of atomic structure in relations to real world settings and its influence on the intellectual development of humankind.

History of science embedded in the ASIU portrayed the origin of inquiry questions and how and why atomic structure concepts have been developed and changed over time. For example, in lesson 2 students compared models in the historical context and engaged in a reproduction of historical experiment in lesson 3, 4 and 6.

Scaffolded technology enhancement was included in the model-based approach because model and modeling, especially in modern science, are often conducted by high level technology. In the ASIU, model and modeling used available technology such as computers and projectors. For example, the students used the computer to construct models in lesson 1 and 5. Besides these, they watched video to make inferences from the observed data 3 times. This consisted of 5 video clips, computer animation and edited movies respectively.

The final version of the ASIU consisted of four components: the lesson plans, the textbook, the student handbook and the teaching materials. The lesson plans were developed around nine activities. The textbook was developed based upon its fit with the goals of the ASIU and was called The Chemistry Textbook for the Nature of Science as a Modeling Activity: Atomic Structure. It consisted of six chapters with 85 pages. Lastly, because the models to teach concepts related to the nature of science teaching were not available for purchase, the materials were developed for this research such as a black box of hidden landscapes, video clips of the cathode ray tube experiment, a scattering plate set, an edited copy of the movie ‘Eight below’, flame color and line spectrum testing sets and VAST models.

2.2 The Modification of the Instructional Unit to Take into Account Teacher Response

Three teachers reviewed the ASIU documents before the first workshop. After, the first workshop the teachers were introduced to the overview of the research, the findings from phase I, the documents of the ASIU, the teaching materials and the scope of the ASIU. Following that, the teachers, the science educators together with the researcher discussed the lesson plans. In the first workshop, the discussion focused on lessons 1-5. The second workshop emphasized a review of/and modifications to lessons 6-9. The teachers also reflected on their implementations of past lessons. The last workshop was a discussion based upon the findings from classroom observations and the teachers’ reflections on all of lessons they had implemented thus far. From the 1st and 2nd workshop, the lesson plans were further modified according to teacher responses. The modifications of the ASIU took into account teachers’ responses regarding time, contents, and directions for the activities, exercises and key answers. The teachers agreed to set 13 periods of nine lessons for the implementation. However, they agreed that the time could be adjusted according to the reality of the actual teaching situation and any other unexpected events. For the content, all teachers agreed with the content to be taught in the ASIU. In the details of the subtopics, some teachers wanted to add more such as the calculation of line spectrum energy. The teachers wanted the activity directions to be clear and such that they could guide the students in every step. As a consequence, the activity directions in the student activity handbook were revised according to the teachers’ comments. The teachers also wanted the answers for every exercise question as well as every discussion question given in the handbooks. Because most of the questions in discussion activities were open-ended question, the teachers suggested adding examples of directions or conversations that might occur during the lessons. For example, how to comment or respond to the students’ answers which weren’t supposed to be judged right or wrong by the teachers. Their comments regarding data were similar and they requested examples be outlined as to how the data should be collected.

3. Conclusion for Phase III Research Questions

The study in phase consisted of two main questions “How do teachers implement the Atomic Structure Instructional Units?”, and “How do the teachers’ implementations of the Atomic Structure Instructional Unit influence students’ understanding of atomic structure concepts and the nature of science?”, which are concluded as follows.

3.1 Teacher’s Implementations of the ASIU

There were four main themes related to the determination of effectiveness of the ASIU implementation. First, teachers’ implementations of the ASIU were influenced by teachers’ characteristic and background. Those characteristic and background were personality, expectation, professional development and special duty. Second, the effectiveness of the ASIU implementation was determined by teachers’ commitment to change. Three teachers had some degrees of change in common during their practices of the ASIU. Changes established how they achieved the ASIU objectives. The common changes found in this study among the teachers were shifting from passive to active teaching, activity organization, a more coherent view on teaching methods in relation to science standard and change in the role of the teachers from a leader to a supporter. Third, teachers’ understandings of the nature of science affected the ASIU implementations. Teachers who held accurate conceptual understandings of the nature of science in phase I tended to emphasize those aspects explicitly, while teachers who held alternative or ambiguous conceptions tended to teach those aspects implicitly or didactically. For example, a teacher who understood the sociocultural based nature of science had the strength in teaching scientific enterprise to allow students to have group and classroom discussion. In addition, the teacher who was accustomed using scientific method step by step tended to apply this approach to classroom activities throughout the ASIU implementation. The fourth theme centers around teachers continued use of lecture in the implementation of the ASIU. Lecture was a familiar teaching method. Therefore, teachers couldn’t entirely leave this teaching method behind. However, the degree of reliance on lecture was diverse. One teacher wanted to reduce lecturing and use classroom discussion instead. By contrast, for another teacher, lecture appeared when she felt a lack of teaching preparation or the need to important concepts in her view. Finally, in another pattern of lecturing, a teacher emphasized lecture in almost every lesson. Lecturing could be used before or after the ASIU activities. It could be short or long but it existed simultaneously and continuously with other methods.

3.2 Teacher's Implementations of the ASIU and its Influence on Student Understanding of the Nature of Science

The eight aspects upon which the nature of science was focused were taught in nine lessons of the ASIU. Students had conceptual understanding of the following aspects of the nature of science: what science is and that science relies on evidence, creativity and imagination and subjectivity in science. They held both conceptual conceptions and alternative conceptions in the following aspects: science is subject to change, multiple methods to do science, observation and inference and effects from society and culture on science. All students had alternative conceptions regarding the nature of science as it related to theory and law. Students' understanding of the nature of science was determined by the way they participated in each activity of the ASIU. This was different depending upon the characteristics of the teacher and the classroom context. In detail, student understanding of the nature of science as a consequence of the ASIU implementation is described below:

1. After experiencing the ASIU, most students could explain science in a more open minded way and their explanations went beyond just being school science. Students could give examples of science in terms of credibility, methods of thinking and science value. Views on science were developed during classroom discussion after modeling activities such as the investigation of historical models and the mathematical modeling under individual subjectivity. The characteristic of a model-based approach that encouraged multiple views on science was used of the modeling activity under meaningful context, such as investigations of historical models and historical contexts when those models were developed. However, there

were students who viewed science as school science which was a subject to learn. This notion came with the rigid and content-orientation of some classroom. This classroom atmosphere was very much dependent on a teachers' characteristics. Focusing on aspects of evidence in science, students held the view that science relies on evidence but their understanding diverged in details. Students viewed experiment results as the main evidence of science. This probably was the result of the experiments addressed in the ASIU such as cathode ray, oil drop, and gold foil experiments. Furthermore, the modeling activity in the ASIU was evidence-based such as the modeling of unseen landscapes in the black box. Moreover, the dependent feature of the nature of science encouraged students' understandings of evidence as the basis of science. Students could explain scientific evidence related to other aspects of the nature of science, for example, scientists make an inference of the observed data using their creativity and imagination.

2. Students' understandings of the idea that science is subject to change had two categories, conceptual and ambiguous conceptions. For conceptual understanding, students explained that the reason for change was based upon other aspects of the nature of science such as the performing of new experiments or new interpretations of the same data. It was found that students could develop their understanding that science is subject to change via investigation of atomic models by comparing them in the historical context in lesson 2 and then engaging in a reproduction of historical experiments in lesson 3, 4 and 6. The Comparing models, model reasoning and the atomic modeling via reproduction of historical experiments, students not only found that scientific knowledge could change, but they also pointed out that the methods of study, such as experiments, also changed. However, there were some students who held ambiguous conceptions. Those students used the tentative characteristic of science as a criterion to distinguish between law and theory in terms of their certainty. For them, scientific theory was subject to change. A theory could be changed until it became law where it could no longer be changed. This notion was attached primarily longer to alternative conceptions associated with theory and law. To change this ambiguous conception was as difficult as changing the alternative conception of high hierarchy of law over theory.

3. Theory and law was the aspect where all students held alternative conceptions. This aspect of the nature of science was resistant to change. Although the ASIU addressed theory and law explicitly, the practices were not effective to enhance students' understanding of theory and law. From classroom observations, the lesson fell somewhere in the middle of being implicit and didactic in its approach of theory and law. Furthermore, the teachers seemed to avoid talking about theory and law. Sometimes, they didn't bring this idea into classroom discussion or reflection. Since theory and law were overlooked in the classroom, this left the students with ambiguous and alternative conceptions. It was to be noted that all teachers held alternative conception regarding theory and law in phase I results.

4. Students had both conceptual and alternative ideas regarding multiple methods to do science. The differences between those students who had a conceptual understanding and those who had an alternative conception was dependent upon the activity atmosphere while the teacher implemented the ASIU. The students who experienced open and flexible activities, tended to understand that science was conducted using various methods to seek knowledge while students who experienced rigid and guided activity tended to struggle with the notion of a universal method to do science, the scientific method. It was found that a model-based approach that engaged students to construct student orbitals followed by a thought experiment was effective with teachers who implemented the ASIU in a relaxing classroom environment. On other hand, even the teacher followed the ASIU lesson plan and emphasized multiple methods to do science this aspect was overshadowed by teachers who emphasized a formal classroom atmosphere. This formality was consistent throughout the ASIU implementation. Another factor was the interdependence of the nature of science aspects that students reflected on and discussed. Students who could understand the interdependence of the nature of science, also could understand that methods to do science were related to subjectivity in the scientist's work, creativity and imagination, methods to analyze the data, their interpretation, and their mathematical abilities.

5. Students developed their understandings of observation and inference from their reflections on actively engaging in modeling activities. The ASIU consisted of four activities that heavily used both observation and inference. These were lesson one, three, four and six where students explored physical models, conceptual models and explanatory models. Even thought the models were different, the concept of observation and inference was addressed through processes of observation, collection of data, analyzing, questioning, dialogue, creating models, critiquing, prediction or revising, and presenting the findings to peers. Those processes were key features of the model-based approach in this study. They encouraged students to conceptualize the crucial distinction between inferences as scientific claims and observations as evidence on which such claims are based. This was the case, for example, in the construction of 2D, 3D and computer model that used the same measured data. Furthermore, when the teachers connected observation and inference to other aspects, students developed their understandings of this aspect even further after they engaged in the lesson that focus by making connections to the other aspects. However, the findings showed that there were some students who held the ambiguous and alternative conception about observation and inference. For students who held a more ambiguous and alternative understanding, they believed that observation was only what you actually saw with your eyes and no inferences could take place.

6. Students accepted that creativity and imagination played an important role in science, but they selected certain parts where it could or could not be appropriate. Student understood that creativity and imagination are used when designing experiments, making analogies and interpreting the data. The part of the ASIU that supported students' conceptions in the regard were emphasis on a process of model reasoning such as the inferences of cathode ray tube observations in, which needed students to create their own explanatory model for the phenomena. Another part of the ASIU that influenced students' understandings of imagination and creativity was the creation of analogy and metaphor. From the reproduction of historical experiments, the students also saw the creativity and imagination needed in designing experiment. Moreover, in the reflection and discussion, students used creativity and imagination to reason other aspects of the nature of science such as

observation and inference, subjectivity in science and the multiple methods that scientists use to constructed knowledge.

7. All students could understand the nature of science with respect to subjectivity in science. They understood its impact on scientific enterprise. Students pointed out that subjectivity influences individual creativity and imagination as well as how scientists design methods to seek knowledge. Their understandings were fostered by aspect of the ASIU which encouraged students' understandings of subjectivity through mathematical modeling in real world settings. For example, the reflection and discussion of subjectivity in science in relation to the Eight Below connected isotope concepts with scientists' work, and lead to students' enhanced understandings of factors that influenced scientists' work. Moreover, modeling under the condition of ethics and feelings encouraged students to critique the idea that subjectivity can impact the process of validation of scientific knowledge claims.

8. The ASIU addressed explicitly that model and modeling activities must be based on real world settings. A model-based approach according to this study encouraged students to reflect on the nature of science in relation to the specific modeling activities they had done. For example, students reflected and discussed the impact of social and cultural contexts associated with the mega-project of particle accelerator at CERN. However, students who experienced the ASIU held various conceptions on the influence of the social and cultural milieu on science. The students had both conceptual and alternative conceptions which depended on how the lesson was presented to them. Students who had a conceptual understanding of the interaction of science, society, and culture experienced a lesson that was open for them to discuss and reflect on the issues of science, society and culture that could be derived from the activity. On the other hand, students who held alternative conceptions experienced a classroom where discussion on the interaction of science, society, and culture were omitted. An alternative conception remained despite the fact that students had experienced the activities or read about the issues of the effects of society and culture on science. Furthermore, the rigid content-orientated classroom, combined with the limitation of group work, classroom discussion, and reflection

changed students' conceptual understanding prior to the ASIU to alternative conceptions after they engaged the ASIU.

3.3 Teachers' Implementation of the ASIU and its Influence on Students' Understanding of Atomic Structure

Concepts of atomic structure in the ASIU were divided into seven main topics consisting of the model and modeling of an atom, evolution of atomic theory, Thomson's atomic model, Rutherford's atomic model, atomic spectra and the Bohr Atom, the quantum mechanic model and electron configuration. The conclusions with respect to students' understandings of atomic structure as direct consequence of experiencing the ASIU are presented in the seven topics below:

1. The ASIU aimed to enhance students' views on models and modeling of an atom in various types and functions. The activities introduced students to simple- physical models such as 2D and 3D model. A subsequent lesson based on the evolution of atomic theory, engaged students in understanding more sophisticated modes, such as conceptual models, explanatory models, mathematical models, analogy and metaphor. The ASIU exposed students to diverse views of various atomic models as the representative of an atom. The ASIU also encouraged students to develop sophisticated views of a model and modeling of an atom. After experienced the ASIU, most students could develop their understandings of functions of models and modeling in science, such as mathematical model as a illustrated in lesson five. The ASIU tended to promote students' understanding of various models such as physical models and conceptual models, Students understood models differently depended on how they experienced the ASIU and how they reflected on their understandings of these experiences.

2. Investigating historical models and modelings were two of the teaching strategies used in one lesson of the ASIU. It was found that the lesson encouraged the students' awareness of historical models. For most students, their holistic views of change in models developed through discussion of the atomic

timeline. Most students were able to make connections between experiments with the inferences in atomic models. Other students were aware of historical models and understood the changes of the models over time because of their chance to discuss these models. Moreover, some students indicated that the methods and evidence that scientists used to construct the atomic models were based upon discovery through out history.

3. In Thomson's atomic model, most students could explain Thomson's cathode ray tube experiment and connect the results to the plum pudding atomic model. A teaching strategy which emphasized the cathode ray tube experiment and Thomson's atomic model, was model reasoning by means of observation and inference of a historical experiment. Model reasoning focused on how observations of cathode ray tube phenomena lead to the inferences of Thomson's model. This activity influenced most students' ability to develop their explanations of Thomson's cathode ray tube experiment and their ability to connect the results to the plum pudding atomic model. In this activity, students made observations and inferences related to the cathode ray tube video clips for construction of the Thomson atomic model by themselves. After that, they compared their inference to those of Thomson. Students had to critique Thomson's inferences on the cathode ray tube phenomena in terms of reasonable or not reasonable. During this activity, some students gave sophisticated explanations of the model by explaining the concepts within Thomson's atomic model.

4. From studying the Gold foil experiment and Rutherford's atomic model, students could understand concepts of the scattering experiment to study the unseen entity and the concept within Rutherford's model. The ASIU focused on this topic by using a reproduction of historical model as a learning activity. The scattering activity resembled Rutherford's gold foil experiment. The ASIU not only adapted the physical properties of scattering experiment, but also adopted principles of studying an unseen particle which later developed into another discipline of science - particle physics. By experiencing this activity, students could match the experimental results such as "Alpha particle deflected straight back toward" to the existence of an atomic

nucleus which has a high density and positive charge. However, a few students had alternative conceptions and tended to use rote memory in the extended concepts from Rutherford’s model such as atomic number, the relevance of atomic number and mass number, and nuclear symbol. Those concepts were not the main concepts. Sometimes the concepts were deemphasized or left out after students had learned the main concepts.

5. The students viewed the Bohr’s planetary model of an atom as an explanatory model because of its effectiveness to explain atomic spectrums. The ASIU introduced the concept of how Bohr atom was related to atomic spectrum to students, with model and modeling of an explanatory model. This type of model was an extension of the conceptual model that was used to explain phenomena such as line spectrum of an atom. It was found that after most students experienced the lesson, they viewed the planetary model as an explanatory model because of its effectiveness to explain atomic spectrums. The need for explanatory model was the reason for the change from Rutherford’s model to Bohr’s model which was used to further understanding of atomic spectrums. Students were also able to conceptualize the concept within the planetary model instead of merely remembering shape, figure, or the arrangement of its constituents. However, some students were confused regarding the concept of orbits in an excited state and ground state even though they could explain atomic spectrums using Bohr’s atomic model.

6. The ASIU aimed for students to develop their understanding of the quantum mechanics model in terms of both its physical features and concepts within. The model-based approach in this lesson used the construction of conceptual models as a teaching strategy. The findings revealed that most students could explain the physical characteristics of the quantum mechanic model and the concepts of constructing it. They could explain the principles of the quantum mechanics model as it related to a chance meeting of moving electrons around the nucleus. Nevertheless, some students found it difficult to explain concepts within the electron cloud model. They totally could not explain the phenomena using this concept. Students failed to connect the orbital to the atomic model. The lack of clarification of the extended

quantum mechanics model to related concepts resulted in some students' developing alternative conceptions with respect to topic of the energy level of an atom. It was found that the abstract nature of the electron cloud model and quantum theory was too sophisticated for students to conceptualize.

7. The ASIU lessons that emphasized electron arrangement in an atom had students use the VAST model to help them visualize the macroscopic to microscopic entity. By participating in this activity, most students realized that the study of atomic structure always employs the symbolic features in a way to bridge the divide between what is macroscopic (able to see with the naked eye) and that which is microscopic (invisible to the naked eye). Students worked with the VAST models and used them to study electron arrangement in atoms focusing on the Aufbau principle, Pauli Exclusion Principle, Hund's rule and valence electron. However, the students had difficulties in terms of prolonged understanding of their conception in some parts; for example, in terms of the Aufbau principle, and Pauli Exclusion Principle, despite the fact that, they participated frequently in electron arrangement activities. This indicated that hands-on activities must coincide with the students engaging conceptually in ways which enable them to internalize the concepts being taught through the activities. The electron configuration activity seemed meaningless to some of the students because they were unable to relate it correctly to the actual phenomena.

Discussion of the Findings

1. Discussion of Phase I Findings

1.1 Teachers' Understanding and Practices of the Nature of Science and the Perception of Problems when Teaching Atomic Structure Concepts Prior to the ASIU

The findings indicated that teachers whether they had informed, ambiguous or alternative conceptions, rarely reflected upon the nature of science in their classrooms. Most of the teachers in this study were classified as deficient when it came to teaching the following nature of science aspects: characteristics of science, scientific inquiry, and, especially in connecting scientists' work with society, everyday life and the culture that surrounds them. More precisely, the society and culture aspect was understood the same way by both teachers and students. Therefore, there was a need for further study regarding the development of learning and teaching methods which could work to develop student understanding of the nature of science and atomic structure at the same time. A previous study (Mathews, 1994) suggested many approaches such as implicit teaching, explicit teaching and the historical approach which were successful in teaching nature of science aspects alongside scientific content. The suggestions that came out of his research set the framework that guided the direction of teaching and learning of the nature of science. But each classroom has different context and this is especially true in Thai classrooms. The student learning of the nature of science aspects alongside science content needs to be studied in terms of continuous development of curriculum over extended periods of time.

1.2 Students' Conceptual Understandings of the Nature of Science Prior to ASIU

In this study, Students' conceptions about science determined were a reflection of their personal epistemologics of learning science, consistent with the research of Eylon and Linn, 1988. Understandings of the nature of science shaped the way students learned science, scientific inquiry, problem solving and their views on nature. For example, when students viewed scientific inquiry as only using the scientific method, they tended to follow this method step by step. The creativity, imagination, and challenge in learning science started to disappear. This was similar to their views on scientific enterprise. When students viewed science as being universal and free from internal factors (subjectivity from scientists) and external impacts (social and cultural milieu), students tended to accept any scientific claim without an analysis of the credibility and sources of that knowledge. Temporary science was claimed widely in commercial (research on products) or politics (the project of nuclear power plant) (Ben-Ari, 2005). Furthermore, most students viewed the scientific method as the only method scientists employed because they didn't have an opportunity to experience other methods of scientific inquiry. They were used to following the experiment directions step by step like a cookbook. As mentioned previously, students held alternative conceptions regarding science law and theory. These alternative conceptions were also present in the teachers' understandings, similar to studies conducted by Yutakom and Chaiso 2007. The students separated school science from real life and didn't concern themselves with the impacts of society and culture on science because the lesson didn't bring these issues into the classroom. For example, during early parts of the tomic structure lesson, the teachers could point out that Democritus' theory of an atom wasn't accepted by the people during the Greek era. Contrarily, they accepted Aristotle's theory because his theories (philosophy, natural philosophy, politics, and aesthetics) had a paramount influence upon the society his ideas were supported by Alexander (Principe, 2003). The integration of the science story into the lesson didn't consume much time. Student achievement didn't lower that the regular classroom (Irwin, 2000). The findings in regard to student conceptions of the nature of science indicated a need for much critical improvement. Students needed to experience activities that reflected multiple aspects of the nature of science such as methods in which to do science and the impacts of society and culture on science. Lessons should not only emphasize scientific content, but teaching strategies must be diverse, open for all students to inquire knowledge, be taught with many teaching methods beyond experimentation, science should be shown to relate to society and everyday life and should involve interesting social issues such as global warming (Chamrat *et al.*, 2008).

1.3 Students' Conceptual Understandings of Atomic Structure Prior to ASIU

It was found that for most of the topics most students tended to know facts without being able to clearly understand the concepts. In addition, the students could not connect the concepts to the processes of doing science. Most of the students used a rote memory to answer questions and they failed to support their correct answers with correct reasoning. The most problematic concept was the concept of the role of a model in the study of atomic theory. Students thought that models were used to support and explain atomic theory and didn't perceive a model as having important functions such as the explanatory power which could explain phenomena such as chemical reaction. Another concept where students held both rote memory and alternative conceptions was in relation to scientist's experiments leading to the construction of the atomic models. Most students usually memorized these without making any connections. Another problematic concept was with the quantum mechanics model or electron cloud model. Most students' understandings were either in the area of alternative conceptions or rote memory. This finding was congruent with Harrison and Treagust (1996, 2000). They found that students believed that the electron cloud was like a cloud in the sky and that the electrons were like droplets of water in the cloud. This alternative conception affected understanding of the next concept, electron arrangement in an atom. Similarly, Tsaparlis and Papaphotis (2002) found that grade 12 Greek students had difficulty in learning and understanding the orbital. They confused and interchanged their ideas about energy, subshell and orbital, including orbits (Nicoll, 2001; Nakiboglu, 2003). In their study, Student conceptions appeared to be resistant to change over time and students were passed from grade to grade without understanding even the basic concepts. This problem continued to impede the students' abilities to develop more advanced concepts (Ozmen, 2004). The findings indicated that the instructions and methods of learning atomic structure need to be considered and improved for meaningful instruction and learning to occur.

2. Discussion of Phase II Findings

2.1 The Development and Implementation of the ASIU

The design and development of the ASIU relied on a set of theoretical ideas. This framework guided and determined the goals of the unit. The theoretical framework employed the constructivist philosophy of education and the National Science Curriculum Standard, inquiry, the historical and model-based approach. The Thai National Education Act of B.E. 2542 was consulted and this Act described a concrete attempt at education reform in Thailand. The Act attempted to direct the theory of teaching and learning towards the constructivist philosophy of education and the ASIU adopted the essential features of the constructivist classroom. Those features were (1) students were encouraged to participate actively and physically in model and modeling activities (2) the ASIU lessons linked school science to real world situations for example the discussion of the particle physics experiments by LHC at CERN which later became the 1st of top 10 scientific discoveries of the year 2008 (Kluger, 2009) and was the top science news in Thailand in the same year. Students are able to express their existing knowledge of historical models before, during and after engaging in the activities. Students already knew about the existence of the notion of atomic structure before they engaged in activities. The ASIU was taught in relation to both subject matter (i.e., timeline of history atomic model in lesson 2) interdisciplinary connections (physics, mathematics), and real life knowledge such as the use of isotope to study meteorites. The ASIU used multiple sources of knowledge beside just textbooks such as articles, news, videos, movies etc. The ASIU didn’t explicitly present constructivism as the main teaching approach but its essential features were embedded in the ASIU teaching and learning procedures, which met the essence of the Education Act. The IPST documents that influenced the design and development of the ASIU were the National Science Curriculum Standard, the IPST chemistry textbook and the teacher handbook. The ASIU relied heavily on the IPST documents because (1) IPST was officially responsible for science education in Thailand (2) the National Science Curriculum Standard was an important curriculum document that influenced theory and practices about science teaching; the assessment of science education, science content, science education programs and science education systems (Bhasomsap, 2003). The IPST guided the scope of content to be taught and the time allotments.

The ASIU not only integrated the nature of science into teaching atomic structure, but also integrated teaching approaches that appeared to enhance students’ understanding of both the nature of science and atomic structure. The inquiry approach was the big umbrella of the teaching and learning approach of which models and modelings shared most of its features. Inquiry in this research referred to the

National Science Education Standard (1996) in which students were involved in observations, posing questions, examining information, planning investigations, reviewing what was already known in light of new experimental evidence, using tools to gather, analyze, and interpret data, proposing answers, explanations, and predictions, and communicating results. To be engaged in inquiry lessons students required the identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. All those types of activities appeared in every lesson of the ASIU within the model and modeling context. The model-based approach differentiated itself from the inquiry approach by emphasizing the model and modeling activities in every lesson with widely used multiple models. The historical approach also appeared in lessons because most of the lessons focused on historical models and modelings starting from ancient Greek. For example, the NRC (1996) emphasized that atomic structure demonstrates how scientific knowledge changes by evolving over time. The ASIU also consisted of arguments, counterarguments, and discussions about how scientists conducted the experiments and interpreted the data consistent with the recommendations of Niaz *et al*. (2002). Furthermore, the design and development of the ASIU was based on phase I findings about teaching and learning atomic structure integrating with the nature of science which were discussed in previous sections.

2.2 Lessons from the Modification of the ASIU Taking into Account Teachers' Responses

Teachers responded to four issues of relevance to the design of ASIU during the first and second workshops. The issues were time for implementing the ASIU, content to be taught and covered by the ASIU, directions of the activities and answer keys for the student exercises. Teacher responses to the issues reflected the teachers' individual views on teaching science. It is to be noted that the teachers didn't comment on the teaching approaches used in this study. They also didn't ask or talk about the integration of the nature of science into the lessons. This was congruent with the work of Lederman (1999), who found that teachers rarely consider the nature of science when planning for instruction or making instructional decisions. It was interesting to note that teachers selected to discuss implementation time before any other issues despite the fact that they knew how to solve the problems regarding time. As experienced teachers, they knew how to adjust time. They could speed up or slow down a lesson according to the Nature of Scientific content and the school context. The teachers were concerned that the time to implement the ASIU lessons would take much more than that allotted in previous years. The teachers reflected upon their concerns regarding the new teaching methods, and they wanted to know the exact time of implementation for these new teaching methods. Talking about time indicated that the teachers had doubts regarding implementation of the ASIU.

Another issue that concerned the teachers was the scope and depth of the content to be taught in the ASIU. But despite the teachers' concerns regarding the content related to atomic structure this did not affect the scope and depth of the content structure of the ASIU. Focusing on the content revealed their content-oriented views which resulted in teacher-centered teaching. The issue of the directions related to the activities was similar. This teacher concern implied the importance they place on a step by step manner of teaching. Both this content-oriented view and the step-by-step mode of teaching reflected the teachers' epistemologies which later had influence on how they implemented the ASIU. The last issue raised by the teachers was the answers to the student exercises. This revealed a positivist view stance that occupied the science teachers' paradigm. The workshops tried to convince the teachers that values and the integration of the nature of science with the new method of teaching was valid and possible. The teachers still unconsciously reflected their concerns falling back on their regular teaching style-teacher centered. The teachers individual epistemologies had a strong influence on their chosen teaching method as they viewed the activity direction and believed they should contain much detail and carefully guide the students by providing a step by step set of directions. For the answer keys, and even for the open ended questions or opinion questions, the teachers still relied on correct answers, which meant that they tended to judge students answers as being right or wrong and compared them the answers in the key. In science and in school science, knowledge can come from both right and wrong answers. This characteristic of gaining knowledge occurs best in a learning community such as a scientific community of scientists or group and classroom discussion by students. The responses from teachers suggested the need for the researcher and science educators to be aware of changing teacher beliefs regarding science and the teaching and learning of science. Teacher beliefs about science and the epistemology of science should be consistent. Perhaps once the teachers developed a deeper understanding of the nature of science a change of epistemology regarding science would occur simultaneously. Tsai (2002) suggested that changing teachers beliefs of teaching and learning science may be a prerequisite for changing their beliefs about teaching and learning science.

3. Discussion of Phase III Findings

3.1 The Implementation of the ASIU: Teachers as the Key to the Success of a Model-based Approach

The teacher was the most important factor that determined how effective the implementation of the ASUI could be. Existing research has emphasized teachers as a factor of teaching and learning the nature of science for decades (Lederman, 2006). The first research question of phase 3 of this study, aimed to investigate how teachers implemented the ASIU. The study was interested in studying how teacher implementation of the ASIU effectively or ineffectively influenced students' understandings of the nature of science and atomic structure. The discussion avoids judging teachers as to whether they were good teachers or not. Rather, the study focused on effective teaching as how it resulted in students' development in both the nature of science and atomic structure. Teachers' effective implementations were discussed as a way of showing the right way of developing students' conceptions of the nature of science in science education, especially, in a Thai context.

3.1.1 Teachers' Characteristic and Background

It was clear that teachers' characteristics had an influence on the implementations of the ASIU. The implementation of the ASIU by Banburi was a good example. Banburi was opened-mind and possessed flexible characteristics, which were classified as keys to effective teaching. Her implementation enhanced students' positive development of conceptions on both the nature of science and atomic structure. However, Banburi's characteristics and background at a glance could provide both support and obstacles to her implementation of the ASIU. Banburi never expressed her personal values regarding the nature of science during any conversations. She lacked teaching preparation time because of her special duty and that factor seemed to impede her effective implementation the most. However, Banburi had an advantage as she held the view that the ASIU activities would be of benefit to her students. She followed the ASIU and addressed the students' reflections and discussions so her teaching was student-activity oriented. Previous research supports Banburi's situation. Lederman (1999) teacher found that intentions, goals, and perceptions of the students are factors that influence their instructional attention to the nature of science. By Contrast, Chonlada demonstrated much more formality in her teaching science, yet the classroom atmosphere of the two teachers was very different. Chonlada's classroom in the library was quiet and neat. It made students sensitive to any talking and moving as Chonlada liked to keep the class quiet. Arunee's class atmosphere was in-between those two teachers. When she used lectures her class was similar to those of Chonlada's but when she let the students do activities, her classroom atmosphere was similar to Banburi's. The classroom environment that allowed students to work in groups, talk, reflect and discuss, was more effective in developing students' understanding of the nature of science and atomic structure. Teachers' expectation was another factor that influenced the implementation of the ASIU. Arunee and Chonlada implemented the ASIU under the expectation of it being content-oriented and geared to preparation for university entrance examinations. In addition, not only did Chonlada express her concerns regarding the content; her students also complained about her different methods of teaching compared to other non ASIU classrooms. For Banburi, there were no comments regarding exam preparation or content-oriented teaching. She expected the students to learn to their potential when provided with opportunities.

3.1.2 The Determination of Teacher Commitment to Change

During the implementation, some issues regarding the ASUI changed while other issues remained unchanged. The teachers' changes occurred just after implementing a few lessons. All teachers changed their roles regarding in the classroom from lead roles where they conducted or demonstrated activities to roles of activity guider, supporter or helper. Since the teachers changed their central role in the classroom, the students had more time to do the activities. They started to discuss what they did and why they did in their groups. Teachers presented the teaching materials in small steps with opportunities for more practice by the students and this was one of the more effective teaching characteristics noted in studies conducted by Borich (2004). As Banburi made changes in her classroom management techniques during student involved activities and procedures, the students began to be able to use knowledge they learned in many ways including building upon previous learned knowledge; and this created an atmosphere where scaffolding was possible. Borich (2004) also noted that using a variety of instructional materials and visual aids fostered an environment where teacher could incorporate student ideas and their engagement in the learning process.

The above perspectives presented the teachers' changes that were externally driven. As the ASIU was implemented, by it seemed that the catalyst for role and behavior changes was the changes in teaching practices through implementation of the lesson procedures. A different kind of change in this study also emerged before and during the teachers' implementation of the ASIU. The internal-driven changes developed from the teachers' conceptions of teaching the nature of science, the characteristics of the ASIU, and the expectation placed upon the students. Banburi knew that the nature of science was best taught and learned when using the student-activity oriented methods. Once she decided to enroll in this study, she hoped that students engaged in the different learning contexts would move from being passive learners to active learners. For Chonlada, her change came after teaching three lessons. Her views on the ASIU changed from that of trying-out lesson plans to another method of teaching that could achieve the goal of meeting the science standards by using the traditional teaching method. Her view of her students was changed almost at the same time with as she made her discoveries regarding the appropriateness of the suggested teaching methodologies inherent in the ASIU lessons. Chonlada had more confidence in her students and believed that they could perform activities without a long introduction or demonstration of the materials by her before they became fully engaged in the activities. While some issues regarding the teachers' practice changed, others that did not. There were some issues that didn't change that affected the students' conception of the nature of science and atomic structure. The most obvious unchanged teaching feature, in spite of the implementation of the ASIU, was the usage of the lecture method by the teachers. It may have over optimistic to expect 25 year experienced teachers to change their teaching styles over night. The literature on teacher change is consistent in suggesting that change in teacher practices can be difficult to achieve in a short period of time (Adey *et al.*, 2004; Fullan, 2001). This is probably because a teacher needs time to reflect on and learn from their experiences. The positive results that the students gained in the area of the nature of science and atomic structure could perhaps be maintained by their teachers' momentum of change if this study was a part of an ongoing professional development program, suggested the need for longitudinal appointment for professional growth. However loud our rhetoric about the importance of the nature of science, it is but a tale full of sound and fury unless it is accompanied by a real change in the current nature of summative assessment used in science education in Thailand. The findings indicate that teachers, even if they have been teaching without any reflection regarding the nature of science for a long time, are likely to change their behaviour if they feel the change will be beneficial to their students. The confidence of the teacher directs resulted from belief in the instructional approach. Vice versa, the gain of students' conceptions make the teacher have more confidence to change, emphasizing the dialectical relationship between teachers' practice and students' learning.

3.1.3 Teachers' Understandings of the Nature of Science

Previous research found that teachers' understanding regarding the nature of science did not necessarily influence classroom practice (Abd-El-Khalick, Bell and Lederman, 1998; Lederman, 1992, 1999). The results of the present study showed a slightly different finding. Teachers' understandings of the nature of science in the past, influenced their teaching of the integration of the nature of science in the lessons. It was interesting because all teachers had been informed and understood aspects of the nature of science. They could express their own conceptual understanding of the nature of science during the workshops. During implementation of the ASIU, the teachers' teaching of the nature of science was selective. They emphasized only those aspects of the nature of science that they had an informed understanding of from Phase I. Regarding those aspects that they found ambiguous or possessed an alternative view of, they avoided or overlooked them when teaching the aspects of the nature of science. For example, Banburi gave students the opportunities to reflect and discuss the impact of social and cultural milieus on science. Banburi was the only one that had an informed understanding that society and culture influenced the practice of science, prior to the teacher workshop. By comparison, Arunee who held the notion that science was universal and free from social and cultural effects, omitted classroom discussion regarding this aspect. For theory and law, it was obvious from all the teachers' teaching that they avoided teaching this aspect explicitly. One teacher asked the question as it appeared in the student handbook and continuously revealed the answers from the answer key. Chonlada's understandings of the nature of science and her teaching practices regarding it were interesting as she let the students conduct the conic sections as an example of a thought experiment. She concluded that scientists sometimes used thought experiments in their work, using the example of Schrödinger. However, her emphasis of doing science step-by-step occurred in almost all her lessons. The short example of multiple methods to do science was overshadowed by her step-by-step implementation of the scientific method. In the same aspect, Arunee never mentioned multiple methods to do science throughout lesson 9 and the conic section activity. Teachers' understandings of the nature of science and their practices were more complicated. It was not easy to explore and make the understanding of the nature of science clear to them. It was complicated because there was more than one factor which affected their abilities to internalize these concepts and these factors consisted of classroom implications, teacher characteristics, teachers' prior knowledge, teacher's epistemology, and teachers' internal beliefs, etc. The findings related to the teachers' understandings of the nature of science in this research study both confirmed and modified previous research findings. This research found that teachers' understandings of the nature of science do not necessarily influence classroom practice if they didn't take the nature of science into account. Teachers' understandings of the nature of science mattered if the teachers intended to teach the integration of the nature of science in their science lessons. Nevertheless, teachers' intentions came both from internal and external motivational factors. Concerning the internal motivation of Arunee, she was ready to teach her lessons integrating the nature of science because she believed internally in its benefits for her students. In the case of Chonlada, she viewed herself as a participant of the research as she expressed early in the implementation of the ASIU. Lederman (1999) also reflected on the complicated relationship between teachers and the nature of science. He purposed that teachers' instructional intentions significantly affected what occurred in classroom practice, even though the teachers possessed what would be considered to be desired views of the nature of science (Lederman, 1999).

3.1.4 Teacher's Familiarity of Lecture Teaching Method

The teachers were familiar with traditional teaching methods, primarily lecture, and satisfied with the traditional goal of science education as being the key to opening the big gate of the university. Irrefutably, it is science that was the main subject that affected the entrance examination score (Wongwanich *et al.*, 2005). Its three main subject areas, physics, chemistry and biology, are enough to determine the future career choices of the students. However, the National Science Curriculum Standard addressed the explicit goal of science education was to develop science literate persons, especially in the additional science standard of strand 8 nature of science and technology. Teachers in this study began to question whether lecturing could indeed still be the most satisfactory teaching method to make students understand the nature of science. Large scale research has indicated the ineffectiveness of lecture teaching and showed that lecture is not an effective method for enhancing student knowledge of scientific concepts. A survey given to more than 6,000 students at several higher-educational institutions showed that straight lectures, whether boring or entertaining, were significantly less effective than more interactive courses (Hake, 1998). Other factors, such as class size and student preparedness, had little or no influence. Focusing on the implementation of the ASIU, the lecture, whether related to or dependent on the ASIU, was not the most effective method for enhancing students' conceptualization of both the nature of science and atomic structure.

Two of the three teachers in this study, relied on lecture. Arunee used lecture when she lacked teaching preparation time and when she felt the method was a better choice for teaching difficult concepts. Chonlada used lectures the most. For example, she lectured that science could be conducted by several methods on the thought experiments of the conic sections in lesson 8. The result was students who had alternative conceptions made no changes to their conceptions. Her students who used to have an informed understanding changed their minds, accepting the idea of "universal method in which to do science." This finding was similar to the study of Bell (2001). He reviewed much research and found that by experiencing laboratory and lecture, the majority of students came to class with deeply ingrained alternative conceptions about the nature of science. Many science educators, as well as scientists who teach college level science courses, believe that students will pick up current conceptions of the nature of science by osmosis from listening to lectures about science, engaging in discussions about science, or by 'doing' science, including hands-on, inquiry-based activities, but this has not proven to be the case. Results indicated that the nature of science is a complex topic, and students' alternative conceptions about the nature of science were resistant to change the same as, or even worse than their conceptions about other science content.

3.2 Teacher's Implementation of the ASIU Influenced Students' Understanding of the Nature of Science

3.2.1 Factors that Enhance Students' Conceptualization of the Nature of Science

The results of this study indicate that the model-based approach with integration of the nature of science was effective in enhancing student conceptions. The aspects that showed gains in conception by the students were: what science is/science relies on evidence, creativity and imagination, subjectivity in science, social and cultural milieu (in school B) and observation and inference. However, it wasn't in all aspects that students developed their understandings of the target aspects of the nature of science as outlined in the overview. It was only the aspect of theory and law that posed a challenge as the students continued to maintain alternative conceptions regarding that particular aspect. Through careful consideration of the essential factors for the effective integration of the nature of science with respect to enhancing conceptual understandings was revealed. It has been known for decades, as a result of many studies, that an explicit approach to teaching about the nature of science is the most effective method (Abd-El-Khalick and Lederman, 2000b; Bartholomew *et al.*, 2004; Schwartz and Lederman, 2002). In an explicit classroom, the lesson must be clear about what aspect of the nature of science will be addressed, through what activity or experience, what issues will be raised, and when students will have opportunities to reflect and discuss their ideas. For the ASIU, the reflection and discussion parts of the lesson were essential aspects of the learning and closing procedures of the lesson. The findings of the study lead to the conclusion that when teachers teach the nature of science they must make sure that the nature of science is reflected upon and discussed by the students regarding their experiences. The discussion or reflections regarding the target nature of science should never be remiss. As well, the nature of the topics to be taught is important as they will have an explicit affect upon the nature of science by their nature. For example the atomic structure concept was strengthened by observation and inference because studies of the atom since the scientific revolution have been based upon observations of related experiments and scientists made inferences based upon that observed data. The nature of science is interdependent among its aspects. Teachers might start with the remarkable aspects of the nature of science, e.g. creativity and imagination or observation and inference, and then extend this by connecting them to the other aspects. The nature of science could be taught in a manner which make the learning of the aspects cumulative. Reflecting and discussing back and forth between the aspects of the nature of science is an effective method of learning and teaching which occurred in school B. The students could explain the targets of the nature of science by relating back to previous lessons. As well, they could predict that the targets of the nature of science influenced or they could be influenced by other characteristics of science. For teaching the effects of nature of science on scientific enterprise, subjectivity in science and the impact of social and cultural milieu on science, the important factor was the teacher herself/himself. If the teacher held strong views of positivism, it was difficult for her/him to enhance students' reflection and discussion of sociocultural-based science. This is significant since teachers' understanding about science is likely to influence the image of science portrayed to students during science teaching (Brickhouse, 1990).

3.2.2 Ambiguous and Alternative Conceptions of the Nature of Science

An absolute view on scientific law influenced students' understandings of the idea that science is subject to change. This notion was ambiguous to most students because they had unstable conceptual understandings about the tentativeness of the characteristics of science. At first, all students could reason why scientific knowledge changes, and could give examples of those changes as they related to other aspects of the nature of science. This understanding became ambiguous when they used the tentative characteristic of science to explain the hierarchy of law over theory. Students pointed out that science possessed a tentative, changing characteristic regarding the idea of scientific theory because so far the knowledge has not been proven to be certain. They believed that once it was proven by multiple experimentations and testing then the theory would no longer be able change, but would become scientific law. Considering the students' actual conceptions, they indeed believed that certain scientific knowledge couldn't be changed. Law in their perspective was the truth or was fact. Theory was only one step further from hypothesis and could be a group of results from several experiments that was undergoing a proving process. The absolute knowledge of science portrayed in the school by a teacher usually lead to this alternative conception.

Another ambiguous aspect was the idea of 'multiple methods to do science'. The students in this study had all kinds of categories of conceptions related to this aspect: informed, ambiguous and alternative. Moreover, the students' understandings changed back and forth between the three categories. There were students who changed from an alternative to conceptual understanding. Several students maintained their understanding either as conceptual or alternative, but those students changed their explanations in much detail. Some students even changed from a conceptual to alternative understanding. The differences depended directly on their different experiences in the lessons and in the classroom context. Three students from a rigid and formal classroom held informed understandings before engaging in the ASIU. After lessons in which the teacher emphasized following the directions of the activity step by step, two students changed their understanding to an alternative understanding. Two students thought there was only one universal scientific method in which to conduct science. At another school, the teacher didn't address the scientific method as either an informed or alternative view. She let the students engage in the conic section activities, but she finished the lesson by revealing the shapes of the various sections before the students discovered them independently from her. She didn't mention methods to do science even the though she used thought experiment which Schrödinger used for initiating and developing the quantum mechanics theory. The results in terms of students' conceptions were diverse. One student maintained his informed understanding while another student gained nothing and hung onto her alternative conception. Interestingly, one student changed from an informed understanding to an alternative understanding. Even though the teacher expressed nothing regarding the scientific method, students likely intuitively grasped this universal scientific method. As Hodson (1998) cautioned extensive use of the algorithm recipes of laboratory work leads students to believe in a method of science. Also, the high success of school science experiments reinforces or shapes the illusion of certain knowledge in science. Changing the way in which scientific knowledge is practiced in school laboratory activities may be a promising way of helping students acquire more appropriate epistemological views about science.

3.2.3 Theory and Law Problems

As mentioned previously, theory and law appeared to be the most problematic of all the aspects of the nature of science. All students congruently held alternative conceptions that laws had a higher hierarchy than theory. Some students thought theory became law if it had been proven several times. According to these students the combination of several theories could transform all of them into law eventually. Students viewed law as having more certainty or credibility that theory. Law could be proven anytime, and it could not be changed. This finding was consistent with past research, which suggests that nature of science in the aspect of theory and law reflects the most alternative conceptions by both teachers and students (McComas, 1998b, Yutakom and Chaiso, 2007). Moreover, whenever controversies of science are related to society, politics or economics, the alternative conceptions about theory are usually viewed as speculation or uncertainty, such as the controversy regarding the evolutionary theory and the issues of global warming. Ben-Ari (2005) points out that the most frequent claimed phrase was “just a theory” which intended to discredit those theories by its typology. For scientists and people who understand the nature of science, they appreciate that both theory and law are important in science. Theory and law are just different types of scientific knowledge. A scientific law is a description of an observed, controlled, repeatable, and verified scientific observation or phenomena that shows consistency. A law is often presented as a simple or complicated mathematical formula. A theory is an integrated conceptual framework for explaining and reasoning about phenomena that have been observed. If constant evidence is present for supporting the theory, it becomes a consensus theory, which is the widely accepted as potential for verification, explanation, or even prediction grows. Accepted theories and laws are successfully tested against a wide range of applicable phenomena and evidence and possess appropriately broad and demonstrable effectiveness in further research. Considering the ASIU lessons and the teachers' implementations, theory and law were omitted in classroom discussions. The critics came later in the 3rd focus group. All teachers who participated in this study commented that if the lesson aimed to address the issues of law and theory, the unit should have had explicit activities that related directly to law and theory. The lessons in the ASIU were too implicit or at least 'didactic' and research shows that teaching teachers about the nature of science by didactic or implicit means had limited success (Abd-El-Khalick and Akerson, 2004). The findings indicated that teaching theory and law not only needed to be taught explicitly, but teachers also needed to clarify that terms 'theory' and 'law'. In science, their meanings are variable both in everyday life and in other school disciplines, such as mathematics.

3.3 Teacher's Implementation of the ASIU Influenced on Students' Understanding of Atomic Structure

3.3.1 Models and Modeling Activities

The ASIU resulted in student conceptualizations of model using more sophisticated views than merely understanding its physical characteristics. A model in science is a set of ideas that describe a natural process initially produced for a specific purpose. Such a set of ideas can be an object, an event, a process, or a system (Gilbert and Boulter, 1998). At first, most students were aware of the existence of models. They understood their role in science as being important in studying abstract concepts, ones that are not easily seen with the naked eye. Students understood the characteristics of models and their uses such as, investigating and distinguishing timelines of historical models and their changes. From the model and modeling activities students could understand the concepts within the models and use them to explain atomic phenomena. To do this, students used models as a way of explaining characteristics of phenomena. The characteristics of an effective model and modeling lesson shared the features of a constructivist environment which Jonassen (1991) identified. In summary, these were: (1) Constructivist learning environments provide multiple representations of reality. (2) These representations represent the complexity of the real world. (3) Knowledge construction is emphasized over knowledge reproduction. (4) Authentic tasks are emphasized in meaningful context (5) Real world settings or case-based learning is provided (6) Thoughtful reflection on experience is encouraged (7) Enables context-and-content-dependent knowledge construction (8) Supports collaboration and social negotiation among learners.

3.3.2 The Reproduction of Historical Experiments, Observations, and Inferences

The historical approach features integrated in the ASIU appeared to produce good results. The findings from classroom observations and interviews of students and teachers indicated that the main part of effective teaching came from the uses of the historical approach. The historical approach shed light on this study in terms of previous literature regarding wide acceptance of this approach. The researcher had the opportunity to participate in two special courses, History and Philosophy in Science Education conducted by Dr. Michael Matthews at Kasetsart University (5 days, February 2005 and 2007). His work in the field of history and philosophy of science had a great impact on this study. Matthews (1994) summarized the reasons for the inclusion of history of science in instruction as promoting better understanding of scientific concepts and methods and understanding of the nature of science. The integration of the history of science into the classroom not merely allowed for better knowledge gains, but also provided insights into historical contexts. The ASIU addressed several features of the historical approach in its lesson plans, the textbook, the student handbook, and the teaching materials. Those features, for example, demonstrated how scientific knowledge changes by evolving over time (NRC,1996); through arguments, counterarguments, and discussions about how the scientists conducted the experiments and interpreted the data (Niaz *et al.*, 2002) and historical reconstruction of the atomic model (Niaz and Rodriguez, 2004). The most effective feature of the historical approach employed in this study was the reproduction of historical experiments, observations, and inferences.

There were three historical experiments adapted and reproduced in this research- the Thomson, Millikan and Rutherford experiments. The findings indicated that after engaging in the reproduced historical experiments, the students could develop an understanding of the concepts of the experiments and the models scientists constructed and make connections from them. This is in contrast to the first phase of the study. Students tended to remember the atomic model and to link the experimental results to the construction of the atomic models. Emphasizing the timeline of the present historical model, were successful in preventing students from continuing to be stuck on the Bohr model as found in previous studies (Harrison and Treagust, 1996, 2000b; Nicoll, 2001; Nakiboglu, 2003).

3.3.4 The Use of Analogies, Similes and Metaphors in Science

Analogies, similes, and metaphors are widely used in science. Scientists use them often as way in which to represent their concepts. Kepler famously used several analogies to arrive at his laws of planetary motion (for example, his analogy between light and motion), and Bohr’s planetary atom analogy has been used very often in science education. Atomic structure is an important topic in high school chemistry, but the concepts involved are abstract and difficult for students to comprehend. Analogy, such as pedagogical analogical models can be used to make abstract concepts like atoms and molecules more accessible and concrete for students(Harrison and Treagust, 2000a). The pedagogical analogical models include iconic and symbolic models, mathematical models and theoretical models. Examples of iconic and symbolic models are chemical formulas and equations. All of them are used to build conceptual knowledge. These types of models need to be interpreted when using them to explain the phenomena. In this study, analogy was used to introduce its utility as a shortcut for organizing large bodies of conceptual knowledge and its limitation. Students were challenged to explain five statements regarding Bohr’s atomic theory using analogies from their experiences. The students had to develop their conceptions of Bohr’s theory before seeking analogies. However, to prevent the limitations of the analogies that could perhaps lead to alternative conceptions, students were asked to point out similarities and differences between the two systems. An analogy can have a weakness in that if the wrong analogy is created then the subsequent learning can lead to alternative conceptions using both systems. Therefore, the teacher must clear up misconceptions early and student interpretations must be checked to see whether they have imported unintended perhaps negative implications from the analogy into their working model. (Clement, 2000)**.**

3.3.5 Representativeness of the Model in Establishing Macroscopic to Microscopic Levels of understandings

Treagust *et al.* (2003) noted that the abstract nature of chemistry and the need for the learner to develop a personal understanding of the submicroscopic nature of chemical nature of matter necessitates the use of an extensive range of symbolic representations such as models, problems and analogies. They suggested that understanding in sub-microscopic and symbolic representations in chemical explanations can enhance students' understanding and ability to explain concepts. The use of a symbolic model bridges the macroscopic (abstractness) to a microscopic (concrete) level. Models as representations symbolize the actual complexity of the real world. Precisely, a model is used to connect sub-microscopic and macroscopic views for providing explanations of scientific phenomena. When learning about the arrangement of subatomic particles in an atom, students find it difficult to imagine, because electron configurations in particular is an abstract, difficult, and non-observable science concept. The traditional way of representing electron configuration is just simply to write down the arrow key, up and down, in boxes on paper or on a blackboard. The use of the symbolic features of a model could facilitate students' constructive processes in understanding electron configuration much easier. The VAST models employed in this study gave the students both hands-on and minds-on activities and experiences. Similar to Treagust and Thapelo (2003), the activities provided the use of symbolic and submicroscopic representations in explaining the macroscopic nature of this chemical phenomenon. Students used the VAST models to construct an atomic model that represented the electron arrangement in an atom. The VAST model consisted of buttons, a fleece sheet and Styrofoam balls that represented the subatomic particles. The VAST model was symbolic of the microscopic level of an atom. Johnstone (1991) claimed that understanding of chemistry can be classified into three levels; the macroscopic (chemical phenomena), the microscopic (particulate theory of matter), and the symbolic representation (chemical model). Problems with bridging from the microscopic level to a macroscopic level in this study came later. The lessons lacked a way for the macroscopic or chemical phenomena to be represented. It wasn't surprising that one month later, some students were still confused about the Aufbau principal and Pauli Exclusion Principle. Gabel (1993) found that students have three types of difficulties in developing a conceptual understanding of chemistry. First, chemistry teaching emphasizes a symbolic level and problem-solving at the expense of the phenomena and particle levels. Second, even though chemistry is taught at the macroscopic, microscopic, and symbolic levels, insufficient connections are made between the three levels and the information remains compartmentalized in the long-term memories of students. Third, even if chemistry is taught at these three levels and the relationships among the levels are emphasized, but not related to the students' everyday life, students may fail to understand chemistry. The use of VAST model needed to establish the connection among subatomic particles, models and chemical phenomena. The VAST model might be used to represent the further concepts such as chemical bond with relation to everyday life.

Implications

1. Implications for Classroom Practice

This study was begun in the academic year 2006 and the implementation process was completed in 2007. The strong points of this study can be found in the rich details of the classrooms. This thesis depicted the events and situations clearly that lead to the conclusions of the study. Multiple data sources were used as evidence to support the knowledge claims. This thesis depicted clearly effective and ineffective teaching and learning. With regard to classroom practice, the findings indicated that (1) The explicit and reflective aspect of the nature of science integration should be addressed in every lesson; (2) Students should take a leading role and group/classroom discussion should always be an integral part of all lessons; (3) The theory and law aspect of the nature of science, which was resistant to change, needs special lessons to address it; (4) The model-based approach enhances student change from passive to active learning, and (5) the use of hands-on activities is dependent upon teacher motivation. However, the study also found that even when students participated in multiple hands-on and mind-on activities, at times they still tended to forget and be confused about some concepts or aspects of the nature of science. This further implication for classroom practice is the addition suggestion of 'brains-on' activities that can motivate students to think about what they are doing during hands-on and mind-on activities. Hands-on assures that students have opportunities to do activities, such as modeling activities. Minds-on is well-established as a motivating technique for engaging students actively participating activities. Then, Brains-on means students think about the activities they have done. The doing of activities must support thinking about activities.

2. Implications for Curriculum Development

In the process of curriculum development, curriculum developers and teachers should aware of the integration of the nature of science as it is the one of eight strands in National Science Curriculum Standard. The study showed that the model-based approach could be employed to the design and development of curriculum or instructional units. However, the following issues suggested by the research findings, should be considered.

1. The integration of the nature of science into science classroom is congruent to the principle of national curriculum documents such as the National Education Act 1999 and the National Science Curriculum Standard. The designed curriculum using the model-based approach established the essential features of the constructivist classroom.

2. The nature of science is not content knowledge which are expected to be included in the science curricula in the form statements . The nature of science aspects are not of the content knowledge students must receive during science instruction. Rather, nature of science should convey to the students via curricular that include diverse activities and many opportunities for reflections.

3. The curriculum developments must take school and classroom context into account as well as characteristics of teachers, such as teachers' backgrounds and teaching style, including teachers' understanding of the nature of science. The goal of curriculum design should not focus only on what to address e.g. aspect of the nature of science or atomic structure concept, but also other factors. Teachers' responses on curriculum reflected teachers' beliefs regarding science and the teaching and learning of science which helped to develop and modify the curriculum.

3. Implications for Future Research

There are many strategies that may be used to convey the nature of science to students. The use of explicit and reflective teaching methods and learning based on a model-based approach was considered in this research. The nature of hands-on learning and teaching materials were able to raise student enthusiasm and encourage discussion about science and scientists' work. The use of models and modeling to investigate atomic evolution, scientists' experiments and models, and atomic theories made the lessons more meaningful for students. Making a decision and problem solving about the nature of science issues based on scientific information gave them opportunities to understand scientific world view, scientific inquiry, and scientific enterprise. This research demonstrated the attempt to transform traditional teaching, through a model-based approach. The new policies of science education in Thailand addressed by the Thai National Science Curriculum standard emphasize the processes and nature of science as well as scientific knowledge. Because of the limit of participants and time regarding the research, this study does not attempt to generalize its findings. Instead, it presents a feasible method of implementing the policy according to the National Education Act 1999. The Education Act 1999 has stated “unity in policy and diversity in implementation" (ONEC, 1999: 5) and this requires teachers and science educators to creatively think about what and how diverse teaching should be. Using multiple models and modeling could be one of those creative teaching strategies used to promote students’ understanding of the nature of science, the science processes, and scientific content. However, the participant teachers in this study didn’t design the units by themselves. They only reviewed and adapted the units to meet their teaching styles and school context. For the future, it would be interesting to see if teachers could (1) initiate and design an instructional unit from their own ideas (2) Design learning activities that will best integrate and target nature of science aspects with science content (3) professional development programs might be needed to help them perhaps in how to select appropriate issues about science and nature of science and (4) help them how to select or design teaching materials that will match with the target of the nature of science.

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APPENDICES

APPENDIX A

Teacher Interview Protocol

Teacher Interview Protocol

Introductory Protocol

To facilitate our note-taking, I would like to audio tape our conversations today. For your information, only researchers on the project will be privy to the tapes, which will be eventually destroyed after they are transcribed. Essentially, I will let you know that all information will be held confidential and I will send the transcript to you to prove it before analyzing. Thank you for your agreeing to participate.

Introduction

You will be interviewed today because you have been identified as someone who has a great deal to share about teaching, learning on atomic structure lessons. This research project as a whole focuses on the improvement of teaching and learning activity, with particular interest in understanding how to design instructional units enhancing students' understanding atomic structure and nature of science. This interview does not aim to evaluate your techniques or experiences. Rather, I will use the information to design and construct instructional units.

Interview Questions

a. Interviewee's background question

1. How long have you been a chemistry teacher?
2. How long have you taught atomic structure?
3. How many classes do you teach per week?
4. Do you have any other work besides teaching?
5. What is your field of study?

b. Teacher's understanding nature of science

1. What, in your view, is science?

Probe

(a) What makes science (or a scientific discipline such as chemistry, physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. Some people have claimed that all scientific investigations must follow the same general set of steps or method to be considered science. Others have claimed there are different general methods that scientific investigations can follow. What do you think? Is there one scientific method or set of steps that all investigations must follow to be considered science?

   Probe

If the interviewee answered "yes," there is one scientific method (set of steps) to

science. go to (a)
If the interviewee answered “no,” there is more than one scientific method to science. go to (b)

(a) What are the steps of this method?

(b) Please describe two investigations that follow different methods. Explain how the methods differ and how they can still be considered scientific.

3. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?

Probe

If the interviewee believes that scientific theories do not change go to (a),
If the interviewee believe that scientific theories do change go to (b)

(a) Please explain why.
(b) Explain why theories change. Explain why we bother to learn scientific theories.

4. Is there a difference between a scientific theory and a scientific law?

5. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus.
How are scientists certain about the structure of the atom?

Probe

What specific evidence **do you think** scientists used to determine what an atom looks like?

6. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses 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 years ago and led 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 these **different conclusions** possible if scientists in both groups have access to and use the **same set of data** to derive their conclusions?

7. Some claim that science is infused with 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.

Does science reflect social and cultural values?

Probe
If the interviewee answered **yes** go to (a),

If the interviewee answered **no** go to (b)

(a) You believe that science reflects social and cultural values. Explain why. Defend your answer with examples.
(b) You believe that science is universal. Explain why. Defend your answer with examples.

8. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?

Probe

If the interviewee answered **yes** go to (a),
If the interviewee answered **no** go to (b)

(a) Then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
(b) You believe that scientists do not use imagination and creativity. Please explain why. Provide examples if appropriate.

c. Teaching's using nature of science in teaching atomic structure.

1. How do you teach students to understand nature of science?

2. In your opinion, how can learning of atomic structure reflects aspect of nature of science?

3. Can you give me an example of activities of learning about nature of science in atomic structure lesson?

4. What is the assessment that you use to evaluate students' understanding atomic structure and nature of science?

d. Problems of teaching and learning atomic structure and nature of science

1. What do you do to enhance students learning abstract concept like atomic theory?

2. What topics do students find difficult to understand in Atomic Structure? 3. From research report there are students' misconception both in contents and in nature of science. In your own experiences, what are the causes of those problems? 4. Besides understanding contents, what do you expect students to learn in atomic structure lesson? 5. If you could design a lesson to teach atomic structure regardless preparing time, equipment or any obstacles, what would you design to teach?
Conclusion All right, we are finished. Thank you very much for spending time to talk with me. Your input is going to be very valuable to the continuing development of this research.

APPENDIX B

Reflective View on Nature Of Science (RVNOS)

Appendix Table B 1 Reflective View on Nature Of Science (RVNOS): Science relies on evidence

More Teacher orientation ⟷ More student orientation

Aspect of the Nature of Science	Deficient Level	Didactic Level	Implicit Level	Explicit and Reflective Level
Science relies on evidence: Scientific knowledge is based on natural phenomena, evidence, data, information, and observation (Sc.8: Students should be able to use scientific process and scientific mind in investigation and in problem solving).	Lack of activities or mention on the concept that science needs evidence to support.	Explaining that the body of scientific knowledge which students have learnt must be based on evidence, prediction, and logic to the natural world.	Engaging students to record or collect the results and data and then use them from investigations to provide the evidence to support explanations and conclusions.	Encouraging students to discuss the importance of keeping records of observations and investigations that are accurate and understandable on a particular activity they are engaged.

Appendix Table B 2 Reflective View on Nature Of Science (RVNOS): Multiple methods to do science

More Teacher orientation ⟷ More student orientation

Aspect of the Nature of Science	Deficient Level	Didactic Level	Implicit Level	Explicit and Reflective Level
Multiple methods to do science: Scientists used multiple methods to conduct science. There was not only a universal step-wise method called 'scientific method' that guarantees the generation of valid knowledge (Sc.8: Students should be able to **use** the scientific process and scientific mind in investigation and in problem solving)	Providing or explain students with only scientific method and mention that there is only one way to do science.	Giving explanations that there are no universal steps to do science, and an example of the scientific inquiry beyond appearing in laboratory directions or in textbooks.	Providing activities including multiple ways to create scientific knowledge .	Consistently integrating activities and lessons to convey the multiple ways to create scientific knowledge and let the student discuss about the different ways to do science.

Appendix Table B 3 Reflective View on Nature Of Science (RVNOS): Nature of scientific theories and law

More Teacher orientation ⟷ More student orientation

Aspect of the Nature of Science	Deficient Level	Didactic Level	Implicit Level	Explicit and Reflective Level
Nature of scientific theory and law: Scientific theories and laws are different kinds of knowledge, there are no a hierarchical relationship between theories and laws.	No mention of the terms, the functions and relationships between scientific theory and laws or giving students misconceptions involving theory and law.	Giving explanations and providing examples of conventions for research, evidence and explanation. Distinguishing laws, theories and hypotheses.	Teaching scientific theory and law or scientific explanation in lessons without mentioning the function and difference among them.	Involving students with activities in which they have opportunities to justify facts, predictions, theory, and law/principles in scientific investigations and to differentiate among them too.

Appendix Table B 4 Reflective View on Nature Of Science (RVNOS): Science is subject to change

More Teacher orientation ⟷ More student orientation

Aspect of the Nature of Science	Deficient Level	Didactic Level	Implicit Level	Explicit and Reflective Level
Science is subject to change: Scientific knowledge is subject to change and is never absolute or certain (Sc.8 The student should know that most of the natural phenomena have definite patterns, explainable and verifiable within the limitation of data and within instrumentation during the period of investigation)	Giving no mentions that science is subject to change and/or teaching science as absolute truth.	Regularly referring to historical events to illustrate fundamental aspects of the nature of science including the durable but tentative character of knowledge.	Providing examples of changes in science knowledge over times, referring to the historical development of foundational concepts in the teaching field.	Systematically involving students in inquiries pertaining to the nature of science including historical and philosophical changes that have shaped subsequent knowledge.

Appendix Table B 5 Reflective View on Nature Of Science (RVNOS): Observation and inference

More Teacher orientation ⟷ More student orientation

Aspect of the Nature of Science	Deficient Level	Didactic Level	Implicit Level	Explicit and Reflective Level
Observation and inference: The crucial distinction between scientific claims (e.g., inferences) and evidence on which such claims are based (e.g., observations)	No expressing of the terms observation and inference and/or no mention how to infer them from evidences that students/scientists obtain.	Addressing the observation versus inference aspects of the nature of science in the context of teaching. Explaining how and why inferences were different from observations.	Letting the student infer conclusions from the data or result. No mention about using observations and inferences in developing scientific knowledge.	Engaging students in inquiries that require them to develop concepts and relationships from their observations, data, and inferences in a scientific manner. - Discussing the nature of science after the activity is done to help students reflect on what they did in the lesson then asks questions to help them understand the observation versus inference aspect of the nature of science .

Appendix Table B 6 Reflective View on Nature Of Science (RVNOS): Subjectivity in science

More Teacher orientation ⟵⟶ More student orientation

Aspect of the Nature of Science	Deficient Level	Didactic Level	Implicit Level	Explicit and Reflective Level
Subjectivity in science: Scientific knowledge and investigation are influenced by scientists' theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations	Portraying that scientific knowledge and investigation are independent on beliefs, prior knowledge, experiences etc.	Providing students with science activities that influence personal and cultural beliefs.	giving a scientific discovery narrative, to describe how societal, cultural, and personal beliefs influence the investigation and its interpretation.	Engaging students with a scientific discovery and let them evaluate how different societal, cultural, and personal beliefs influence the investigation and its interpretation.

Appendix Table B 7 Reflective View on Nature Of Science (RVNOS): Impacts of social and cultural milieu on science

More Teacher orientation ⟷ More student orientation

Aspect of the Nature of Science	Deficient Level	Didactic Level	Implicit Level	Explicit and Reflective Level
Impacts of Social and cultural milieu on science: Science as a human enterprise is practiced within affects, and is affected by a lager social and cultural milieu (Sc.8 The student should be able to **understand** that science, technology and environment, are interrelated.)	Teaching science separately from social and cultural interactions and portray to student that science is universal.	Relating concepts of science to the personal lives and mention that science is human activities embedded in society.	Engaging students in activities and projects in which they are interaction among society , technology and science	Integrating discussion of interaction between social, economic, technological, cultural and/or environmental factors and the occurrence of scientific advances. Value relationships among them to form thematic strands that connect to science concepts.

Appendix Table B 8 Reflective View on Nature Of Science (RVNOS): Creativity and imagination

More Teacher orientation ⟷ More student orientation

Aspect of the Nature of Science	Deficient Level	Didactic Level	Implicit Level	Explicit and Reflective Level
Creativity and imagination: The generation of scientific knowledge involves human imagination and creativity	Giving no opportunity to students to see science as an exciting and creative pursuit. Teach science as a set of facts which is rigid and static.	Mentioning in the lesson with particular examples that science need both creativity and imagination, and describe how creativity comes into play during various stages of scientific investigations.	Letting the students create and design their own investigation such as: ask the questions, propose a solution, design an experiment and interpret the data.	Providing students with activities that reflect imagination and creativity and let them discuss that creativity, imagination, and good knowledge base are all needed to advance the work of science

APPENDIX C

Nature Of Science Questionnaire

Nature of Science Questionnaire

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. Some people have claimed that all scientific investigations must follow the same general set of steps or method to be considered science. Others have claimed there are different general methods that scientific investigations can follow.

(a) What do you think? Is there one scientific method or set of steps that all investigations must follow to be considered science? Circle one answer:

Yes, there is one scientific method (set of steps) to science.

No, there is more than one scientific method to science.

If you answered "yes," go to (b) below.

If you answered "no," go to (c) below.

(b) If you think there is one scientific method, what are the steps of this method?

(c) If you think that scientific investigations can follow more than one general method, describe two investigations that follow different methods. Explain how the methods differ and how they can still be considered scientific.

3. After scientists have developed a scientific theory (e.g., 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.

4. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

5. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about

the structure of the atom? What specific evidence **do you think** scientists used to determine what an atom looks like?

6. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses 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 years ago and led 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 these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?

7. Some claim that science is infused with 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.

(c) If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.
(d) If you believe that science is universal, explain why. Defend your answer with examples.

8. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?

- If yes, then at which stages of the investigations you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
- If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

APPENDIX D

Example of Thematic Analysis

Thematic Analysis

Teacher: Arunee (a pseudonym)

1. Familiarizing with the data: transcribing all electronic data to hard copy or electronic documents (Word processor), reading and re-reading the data, noting down initial ideas.

Participants	Initial Ideas
Teacher Arunee	ready to improve her teaching: - participated in university professional development project - Did a research in collaborative with university lecturers - Attended professional development workshops by government support: IPST, Ministry of education - Tried to be promoted for her professional rank. - Mad brief comments with researchers about lesson plans as time allowed - Changed her teaching style from lecture to hands on activity - Understanding of the nature of science in progressive

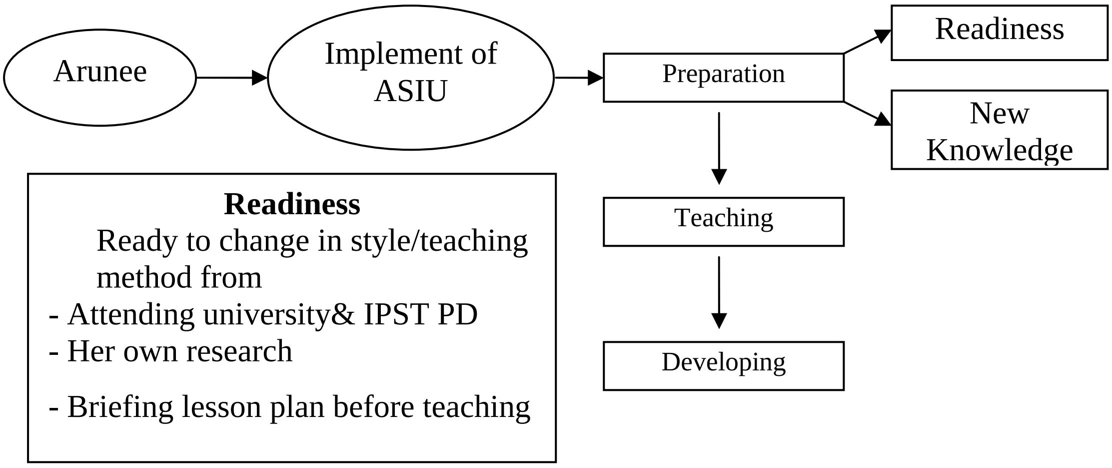
2. Generating initial codes: Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.

Participants	**Initial Ideas**	**Initial code**
Teacher Arunee	Ready to improve her teaching: - participated in university professional development project - Did a research in collaborative with university lecturers - Attended professional development workshops by government support: IPST, Ministry of education - Tried to be promoted for her professional rank. - Mad brief comments with researchers about lesson plans as time allowed - Changed her teaching style from lecture to hands on activity - Understanding of the nature of science in progressive	- <u>Changed</u> teaching style/teaching method - <u>Attended</u> University& IPST PD - <u>Attended</u> workshop - <u>worked</u> in her own research - talked about <u>lessons being taught</u> - opened to <u>new teaching styles/method</u> - Talked <u>about science</u> (not science content)

3. Searching for themes: Collating codes into potential themes, gathering all data relevant to each potential theme which was used as the evidences to support each theme.

Theme 1: The ASIU as a building on the experiences and on professional development.

4. Reviewing themes: Checking if the themes work in relation to the coded extracts and the entire data set, generating a thematic 'map' of the analysis.



5. Defining and naming themes: Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.

This theme is the first one to explain how Arunee implement ASIU. It was found that she began implement with her readiness of integration of the nature of science into her classroom, not because lesson plan forced her to do.

6. Producing the report: The final opportunity for analysis (1) Selection of vivid, compelling extract examples. (2) Final analysis of selected extracts by interpreting each theme by relating back of the analysis to the research question and literature producing. (3) A scholarly report of the analysis.

APPENDIX E

Example of Informal Interview

Akara's informal Interview post lesson 1

May 30, 2007

Interviewer: What do you think about the lesson today?

Akara: When I saw many of shoe boxes with holes, I know this would be fun. I expected to have something to play with.

Interviewer: Why do you want something to play? How about something to learn?

Akara: Think about a boring classroom in the afternoon, I try to look for some interesting activity to do.

Interviewer: How about the content?

Akara: If I don't' understand the concepts, I can read by myself or ask my friends to teach me.

Interviewer: Do you know or understand the purpose of this activity?

Akara: Yes, we have to know about the task before we assign the task to every member.

Interviewer: But during the task, did you get confused?

Akara: Yes, that's why you call it the puzzle box. Actually, I know the aim of this activity. My group members were confused about the direction. However, we could do that at last. The point that we were confused was the measurement and how to paint the color according to the landscape height. We were disappointed that we didn't have a chance to work with computer in computer room.

Interviewer: Is it better than work as homework?

Akara: Much better. I'm not sure that members of the group had done it by themselves. I mean there was a representative who worked with computer.

Interviewer: Tell me about the role of a model.

Akara: In this lesson?

Interviewer: In general, for example, atomic theory.

Akara: Atomic model was a physical model of atomic theory. Scientist used models to explain their ideas. In other words, model makes their atomic theory simply for other scientists and people to understand.

Apinya informal Interview post lesson 3

June 7, 2007

Interviewer: Do you want to talk about activity for today?

Apinya: Many activities passing by but I didn't see the experiment as I have done. When will we do the experiment? I expected chemistry is about chemicals and doing a laboratory.

Interviewer: What did you learn from this activity?

Apinya: Thomson's atomic model.

Interviewer: Can you explain more about his atomic model?

Apinya: It's like Dalton's model but plus negative as positive charge.

Interviewer: What is the most important of Thomson's model and experiment in your opinion?

Apinya: He discovered an electron as a fundamental particle of an electron.

Interviewer: Why did Thomson think electrons are parts of every atom?

Apinya: Even though he changed kinds of gas or electrode, the cathode ray still existed. So he concluded that cathode ray must come from any atom.

Interviewer: So, what is the important of the experiment, cathode ray tube?

Apinya: When Thomson changed cathode ray tube in several designs, for example putting magnetic field or wheel into the tube. Those designs lead to the discovery of an electron and also made him propose the new atomic model. If he hadn't done this, he might not have discovered the new atomic model.

BIOGRAPHICAL DATA

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Education:

2002	Graduate Diploma Program in Teaching, Naresuan University
2001	Bachelor of Science Program in Chemistry (B.S. Chemistry 2nd class Honor), Naresuan University

GRANTS:	**YEAR**	**INSTITUTE**
The Australasian Science Education Research Association (ASERA) , Brisbane, Australia.	2008	IPST and Graduate School, Kasetsart University
The National Science Teachers Association National Conference on Science Education, St. Louis, Missouri.	2007	IPST
The 1st international conference on Science Education in the Asia-Pacific, Bangkok, Thailand.	2007	Science Education Center, Srinakharinwirot University
The Annual Meeting of the Association for Science Teacher Education (ASTE), Clearwater, Florida	2007	IPST
ICASE Asian Symposium, Pattaya, THAILAND.	2007	Graduate School, Kasetsart University
Thesis Grants for Graduate Students	2006	Graduate School, Kasetsart University

SCHOLARSHIPS AND REWARDS:	**YEAR**	**INSTITUTE**
Scholarships for studying in Ph.D. from the Program to Prepare Research and Development Personnel for Science Education (RDSE)	2004-2009	IPST
Scholarships for studying in B.Sc., Grad. Dip. from the Project for the Promotion of Science and Mathematics Talented Teachers (PMST)	1997-2001	IPST
Honor brooch and certificate for outstanding the best graduate in Science (Major Chemistry).	2001	Professor Dr. Tab Nilanidhi Foundation
Honor brooch and certificate for outstanding first-year academic achievement in science	1998	Professor Dr. Tab Nilanidhi Foundation.