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THESIS

DEVELOPMENT OF LEVEL 4 BIOLOGY STUDENTS' UNDERSTANDING OF THE NATURE OF SCIENCE IN THE CONTEXT OF THE UNIT ON RESPIRATION: EXPLICIT AND REFLECTIVE INQUIRY-BASED APPROACH

JURARAT LIANGKRILAS

A Thesis Submitted in Partial Fulfillment of
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The purposes of this interpretive case study were a) to investigate the impact of an instructional unit that integrated aspects of the nature of science (NOS) using explicit and reflective inquiry – based approach on students' understanding the nature of science as well as their knowledge of respiration concepts; and b) to investigate what ways teachers' teaching practices influenced students' understandings of the NOS and respiration concepts. The participants of this study consisted of three biology teachers at level 4 and their students, eight students per teacher, totally 24 students. The participants were purposefully selected from secondary schools at Pranakornsriayutthaya province. Interviews, classroom observation field notes, a respiration concept survey and focus groups were used as sources of data collection. The respiration instructional unit (RIU) was developed by integrating aspects of the NOS using explicit and reflective inquiry – based approach and was implemented to investigate students' understanding of the nature of science and key concepts of respiration and teaching practices. The study emphasized six aspects of the NOS including scientific knowledge based on empirical evidence, scientific knowledge as socially constructed, science as social activity, the role of creativity and imagination, the tentative nature of science, and diversity of scientific method. The respiration knowledge included four topics namely the definition of respiration, aerobic respiration, anaerobic respiration, and the relation between cellular respiration and gas exchange.

After implementing the RIU, the findings indicated that all students in this study improved their understanding of the NOS aspects and the knowledge of respiration. Most students held informed understanding of scientific knowledge as being based on evidence, scientific knowledge as socially constructed, and the diversity of approaches to research design that are labeled as the scientific method. All students exhibited partial understanding of respiration. The findings from three cases showed that teaching practices were an essential component of support for students' understanding both of the NOS and the knowledge of respiration. Among the three teachers, there was little consistency in the ways they assisted students in learning and constructing knowledge through the lesson. The different roles of teachers during discussion influenced the development of students' understanding. The results of this research support the finding that developing students' informed understanding of the NOS is a cognitive instructional outcome that requires an explicit and reflective instructional approach. This research demonstrates that the NOS aspects of the lesson are best accomplished when the teacher makes them explicit and reflective from the subject matter content knowledge. Integrating history of science into science teaching improves students' understanding the NOS if teachers are explicit in their teaching.

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Student's Signature Thesis Advisor's Signature

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Jurarat Liangkrilas
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CHAPTER I

INTRODUCTION

Background of the Study

The development of human resources in science is an urgent need of Thailand. As a result of the economic crisis beginning in 1996 and continuing into mid 1997 in Thailand, there has been a reduction of national development in all areas. Many problems that have an impact on the quality of life of Thai people are continued. Science is viewed as an important support to enhance our capability in economic development, the competitive global arena, and happy coexistence in a global community. At present, clearly the progress of science and technology already occurs in the 21st century all over the world. The advance in science and technology changes the world to become information-based societies in which the creation and dissemination of knowledge play critical roles in both individual and social development. This will impact and change public's lifestyle to one based on knowledge. Therefore, the development of human resources in science is emphasized as a major purpose of the National Economic and Social Development Plan beginning with the 7th Plan (1992-1996) and continuing through the current 10th Plan (2007 – 2011) (Office of the National Education Commission [ONEC], 2001; Office the Prime Minister, 2006).

Furthermore, there have been attempts towards education reform with an aim to develop education management to make it more consistent with the Thailand's need. The 1997 Constitution marked the beginning of the current development of Thailand's national education plan. Subsequently, the first National Education Act (NEA) was promulgated in August A.D.1999. The Act has forced the reform in various facets of education such as national curriculum and learning that provided the basic principles as well as challenging guidelines for the provision and development of teaching and learning (ONEC, 2000). Under the National Education Act of 1999, education is decentralized and compulsory and has been extended from six years to nine years. Government-funded education, including science education, is available to all Thai citizens from year 1 through to year 12. Basic education of Thailand is provided before higher education covering pre-primary, 6 years of primary education that divided to level 1 (grade1-3) and level 2 (grade 4-6), 3 years of lower secondary education or level 3 (grade 7-9), and 3 years of upper secondary education (grade 10-12) (Office of the Education Council, 2004).

The Science Curriculum A.D.1978 (Revised A.D. 1990) was implemented before education reform in Thailand. Science discipline was addressed in the subject group: Life Experience in primary education (elementary school, grade 1-6) and general science in lower secondary school (Mathayomsuksa 1-3, grade 7-9). In upper secondary education (Mathayomsuksa 4-6, grade 10-12), students were divided into the science stream and non science stream. The science stream students were those who intended to pursue higher education in pure science, applied science, technology and other science related areas. The non-science students were those who did not intend to pursue education in science and the science-related areas. The Biology, Physic, and Chemistry subjects were the core and elective subject groups of science for science stream students while non-science stream students learn physical science subject (e.g. solar energy, light, electricity) and biological science subject (e.g. food and health, medicine for life, genetics) (Ministry of Education, 1991).

According to the NEA of 1999, science education has been reformed. As for the basic education curriculum B.E. 2544 (A.D. 2001), science is the principal subject group in the basic education curriculum from primary education through secondary education (Ministry of Education, 2001). At the primary education and the lower secondary education levels, general science courses are offered as core-compulsory and elective ones for the lower secondary education. At upper secondary education, for the science-stream students, physics, chemistry, biology and environmental science are offered as compulsory elective and free elective courses. For the non-science stream, various units (modules) on physical and biological science are offered (Boonklurb, 2000).

Science education reform in Thailand aims to achieve two important goals namely increasing a prevalence of scientific literacy and establishing a more science society (ONEC, 2001). A scientifically literate person is able to apply their knowledge of scientific concepts and processes to the evaluation of issues and problems that may arise and to the decisions that they make in their daily life, about the natural world and changes made to it through human activity. As the same time, a science society is viewed as a learning society in which the members of the society use science in their daily life and use the scientific processes as a way of knowledge acquisition. These goals became the vision science learning which used for science education development to prepare all students have sufficient knowledge of science and understanding the scientific process and using scientific knowledge reasonably, creatively, responsibly, and ethically (Institution for Promoting of Teaching Science and Technology [IPST], 2002). According to the national science education standard in Thailand, at the primary and secondary education, science courses include eight basic sciences namely, 1) Living Things and Living Processes; 2) Life and the Environment; 3) Matters and Property of Matters; 4) Forces and Motion; 5) Energy; 6) Processes that Shape the Earth; 7) Astronomy and Space; 8) Nature of Science and Technology. The knowledge of biology is addressed in two principal sub-strands 1 and 2 (IPST, 2002). At upper secondary education, students study biology as particular science subject.

Biology education's aims, in Thailand, are directly translated from the goal of science education in general that focuses on scientific literacy and the preparation of students to live in a knowledge-based society. Thus, the aims of biology education are for students to become biologically literate. Students understand the knowledge of biology and are able to apply such knowledge in real life for problem solving and decision making about biological issues. Current societal concerns such as health, drugs, and environmental issues arise from the life sciences. The knowledge in biology area is integrated into other sciences, and vice versa in real life. Students come to the science classroom with their experiences about life sciences accumulating between waking up and going to bed.

Significance of the Research Study

1. The Nature of Science (NOS)

The NOS is seen as being an important goal in science education reform of Thailand and other countries (Lederman, 1992; American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996; Matthews, 1998; IPST, 2002; Toa, 2003). In Thailand, the NOS was not explicitly identified in the National Science Curriculum Standard before Thai education reform in 1999 although some aspects were implicit in the curricular aims. For example, one of the objectives of science education was to enable learners to develop an understanding of the characteristics, scope, and limitations of science. Now, the NOS is one of eight principal sub-strands, sub-strand 8: Nature of Science and Technology, as the core basic science which all students should learn (IPST, 2002).

The NOS has been much discussed and debated regarding the meaning and the aspects of the NOS that students should learn. There is no consensus among philosophers on a universal definition of science and that the nature of scientific knowledge formation differs from scientific discipline to discipline (Hogan, 2000). However, the NOS typically refers to the epistemology of science, science as a way of knowing, or values and beliefs inherent to the development of scientific knowledge (Lederman, 1992; Lederman *et al.*, 2002). The NOS involves elements of science both as an inquiry process and as a social enterprise. It includes an understanding of how scientific inquiry is conduced, of the different kinds of knowledge claims that scientists make, of the forms of reasoning that scientists use to link data and explanation, and of the role of the scientific community in checking and scrutinizing knowledge claims (NRC, 1996).

Important reasons have been put forward by science educators for emphasizing the NOS. First, the NOS is a primary component of science literacy (NRC, 1996; Bybee, 1997). An understanding of the NOS is crucial to an individual being a responsible personal decision maker and effective local and global citizen. To understand the characteristics of scientific knowledge and how it is acquired, the argument proceeds, citizens will be able to evaluate claims and apply scientific knowledge that may affect their everyday decision about things such as health, diet, choosing energy resources and to reach informed views on matters of public policy (Bell and Lederman, 2003) regarding these areas. Second, research indicates that the knowledge of the NOS, understanding of the structure of scientific knowledge and the forms of argumentation used by scientists assists students in learning science content (Songer and Linn, 1991; McComas and Olson, 1998). For example, Schommer (1994) claims that two elements are involved in the passive learner: knowledge is absolute, and authority has the knowledge. Students who understand how science is constructed tend to learn science as inquiry. In contrast, the students who see science as simply a collection of facts tend to try to memorize those facts without understanding them.

The researchers have consistently shown that students have inadequate understanding of the NOS (Lederman, 1992; Abd-El-Khalick and Lederman, 2000). Many studies in Thailand employed surveys to assess students' understanding of the NOS (e.g. Ganchungat, 1999; Kommul, 1999). For example, Ganchungat (1999) found that students understood the NOS at a moderate level in terms of the creative and imaginative nature of scientific knowledge. Similarly other research regarding students in secondary schools, showed that students do not readily acknowledge that scientific knowledge is constructed (Sandoval, 2005). Young students tend to report that scientific knowledge resides directly in experimental result, whereas older students talk about ideas as being definitely right or wrong. These findings have shown that the curriculum or instructions have not been effective.

As for developing the curriculum or instructions for enhancing students' understanding of the NOS, there are three general approaches, a historical approach, an implicit approach and an explicit and reflective approach (Lederman, 1992). A historical approach suggests that incorporating the history of science in science teaching can serve to enhance students' understanding of the NOS. Learning science through the history of science might influence students' ideas of a tentative nature of scientific ideas and their relationship to the social and cultural contexts within which they were developed. However, the effectiveness of the historical approach is at best inconclusive. The implicit approach is using hands-on, inquiry-oriented activities and/or science process skills instruction that underlie the assumption that student would automatically develop better understanding of the NOS as a by product of instruction. Researchers have consistently shown that the implicit approach was not effective in helping students develop informed NOS understanding. In contrast, the reflective and explicit approach shows to significantly increase students' understanding of the NOS. This approach is attributed to an understanding of the NOS as should be considered as a cognitive learning outcome and should be taught explicitly rather than expected to be a natural consequence of engagement in inquiry activities (Abd-El-Khalick and Lederman, 2000). This approach emphasizes student attention to aspect of the NOS that relates to the inquiry activities in which they are engaged, and students are provided opportunities to reflect their ideas about the NOS in these activities (Khishfe and Abd-El-Khalick, 2002; Schwartz, Lederman, and Crawford, 2004).

However, the developed instructions seemed to give different results with different teachers and context. Much research on teacher understanding of the NOS showed that many teachers held inadequate conceptions of the NOS. Even though, more recent research claim that teachers could hold adequate understandings of the NOS, but their teaching of the NOS may still be ineffective due to a range of factors such as institutional and curriculum constraints and teaching practices (Lederman, 1992; Abd-El-Khalick and Lederman, 2000; Sandoval and Morrison, 2003).

2. Students' Understanding about the Respiration

In biology, respiration is one important topic in Sub-Strand 1: Living Things and the Living Processes (IPST, 2002). Based on the national standard, to understand the fundamental unit of living things and the relationship between structure and functions of various systems that work together, the knowledge of respiration is addressed in all levels of the content standard (level 1-4). Respiration is essential not only in humans but also in most living organisms. It provides them with the essential energy to perform work, everyday tasks and all bodily functions. The process of respiration which is a basic process of organisms is fundamental to a complete comprehension of many aspects of living systems such as the digestive system, and the circulatory system. The mechanisms of respiration enable understanding within the context of energy flow in natural ecosystems. Food chains and food webs begin with photosynthesis and end in respiration. It is an essential process in the most basic processes of all matter cycles such as the carbon cycle (Anderson, Sheldon, and Dubay, 1990).

Research about student's understanding scientific concepts in the past few decades indicated that students held many ideas that are different from generally accepted by scientists. These different conceptions generated by students have been called alternative conception (Arnaudin and Mintzes, 1985). In biology, respiration is one area of biology in which students commonly had alternative conceptions (Haslam and Treagust, 1987; Seymour and Longdon, 1991; Sanders, 1993; Songer and Mintzes, 1994; Mann and Treagust, 1998; Sornsakda, 1998; Sukteeka, 2000; Yip, 2000).

The word "respiration" is used in different meanings. In general the term, respiration describes at the body system level, a process in which an organism takes in oxygen and releases carbon dioxide, one in which the circulating medium of the organism (e.g. the blood) comes into contact with air or dissolved gases. In human cases, the meaning of the term is extended to the transfer of oxygen from the lungs to the bloodstream and, eventually, into cells or the release of carbon dioxide from cells into the bloodstream and thence to the lungs, from whence it is expelled to the environment. This meaning involves the mechanism of breathing and gas exchange (Knight and Schlager, 2002). In biology, respiration means cellular respiration, at the cellular level, is a series of chemical reactions within cells to break down the organic compounds (e.g. glucose) into simple molecules and thus release energy. Some of the energy is used to make ATP. The energy in ATP is then used by cells to do work (Postlethwait and Hopson, 2006). In some cases, students defined respiration as inhaling oxygen and exhaling carbon dioxide or as breathing or as an exchange of gases. Those students transferred this meaning to other organisms and held alternative conceptions about the respiration of microorganisms. They understood that microorganisms did not perform respiration. They were not able to recognize yeast as a living organism because yeast does not have organs to respire (Songer and Mintzes, 1994).

Students hold many alternative conceptions about cellular respiration. Students thought that oxygen is used in all steps of glucose reduction reactions and glucose is the only substrate used in cellular respiration (Songer and Mintzes, 1994). Anaerobic respiration provides more energy for muscular contraction than aerobic respiration; the muscle stops aerobic respiration during vigorous activity; and there is a shortage of oxygen supply during exercise (Yip, 2000). These alternative conceptions might impact on understanding new concepts that are relevant to respiration and vice versa (Anderson *et al.*, 1990). There seems to be confusion between the two concepts of photosynthesis and respiration. For example, students understood that plants respire only at night and photosynthesis happens during daytime (Sornsakda, 1998; Sukteeka, 2000). Students understood that humans use oxygen for respiration while plants use carbon dioxide (Sander, 1993).

Understanding of metabolism at a cellular level is very important because each cell is a unit of life and contributes to the health of the whole individual. The process of cellular respiration has been identified as a topic that is difficult in terms of teacher instruction and student learning because it is an abstract biological process and one of a chemical nature (Anderson *et al.*, 1990; Wongwan, 2002). Corresponding with my observation of two classrooms from two schools in Pranakornsri-Ayutthaya province during teaching the respiration on grade 10, I found that two teachers used lectures supplemented with diagrams in order to communicate about the process of the cellular respiration, for example, the Glycolysis or the Krebs' cycle is explained by using the symbolic representations (e.g. diagram, chemical equations). Furthermore, teachers just emphasized with students to memorize the amount of each product from the process of the cellular respiration. Teachers did not relate any respiration concepts to other concepts or to real life. They only used the lecture method even though most students failed in this topic using this method. It implied that they have no idea how to use and implement the inquiry-based approach in this topic.

3. Inquiry-based Approach in Science Curriculum

The inquiry-based approach is viewed as a central strategy of science education (AAAS, 1993; NRC, 1996; IPST, 2001, 2003a; Abd-El-Khalick *et al.*, 2004).

It is accepted in science education that no single teaching method is appropriate in all situations, for all students. Teachers need to know how and when to use a variety of strategies. However, science teachers are encouraged to use the inquiry-based approach for their students for several reasons. Science education research claims that students who participate in the inquiry-based approach support their understanding of concepts and contents (Wallace *et al.*, 2003) much better. Moreover, students develop an understanding of the process of scientific inquiry and the development of inquiry skills (e.g. identifying problems, generating research questions, designing and conducting investigations) (Krajcik *et al.*, 1998; Wu and Hsieh, 2006), positive attitudes toward science (Gogolin and Swartz, 1992) and an understanding of the NOS (Schwartz *et al.*, 2004).

Inquiry teaching remains a rarity in science classroom and has not met with more success (IPST, 2001; Anderson, 2002; Roehrig and Luft, 2004; DeBoer, 2006). The difficult part for success is changing teacher practices from perceived traditional ways of teaching (e.g. lecture, textbook approach) to more inquiry-based approach. Implementing the inquiry-based approach, particularly in the secondary classroom, demands a significant shift in what teachers typically do in a science lesson. The most important why inquiry teaching is not success is its essential nature is often misunderstood (DeBoer, 2006). Inquiry- based approach has to often been confused or equated with the students performing activities, hands-on activities without intellectual commitment by students. These perspectives often reveal a single teaching strategy or method as the defining characteristics of inquiry.

There is no single method of inquiry (NRC, 2000). Inquiry activities can vary according to the degree of direction that the teacher provides and the degree of independence the students are given. There are many levels of inquiry. It depends on the roles of teachers and students, the intellectual development of the students, and even the classroom learning climate (Colburn, 2000; Martin-Hansen, 2002). For instance, Martin-Hansen (2002) described four levels of inquiry. Considering the different forms of inquiry along a continuum, starting with the most teacher-directed techniques and leading to the more sophisticated, student-directed techniques are as following: 1) structured inquiry, the teacher selects the topic, the question, provides the materials and procedures while students are only required to analyze with their teacher to reach their own conclusions based on supportive evidence; 2) guided inquiry has the teacher do the same structured inquiry, but students are required to design the investigation, analyze the results, and reach supportable conclusions; 3) in coupled inquiry or learning cycle, the teacher begins the activity with an invitation to inquiry along with guided inquiry that leads to open inquiry; 4) open inquiry, students are asked to take responsibility for every part of the process beyond the selection of the general topic to be studied. Not all students will be engaged in open inquiry, but teachers should understand how to help those students who have the interest, drive, and ability to pursue true research. Questions of how much inquiry teaching and what type of inquiry teaching is appropriate must be answered by individual teachers in the context of the goal they have for their own students, and always with an eye toward the student's level of intellectual engagement (DeBoer, 2006).

4. The Rational for Developing Curriculum for Understanding of the NOS in Context of Respiration

The aims of science education in Thailand might then be summarized as: 1) to develop students' understanding of scientific concepts and knowledge; 2) to develop students' understanding of the NOS; and 3) to help students to engage in scientific inquiry. The three aims are inextricably linked in science. Many science educators agree that it is not enough only recalling the scientific knowledge (e.g. scientific facts, laws and theories). Students should know the way such knowledge to be constructed and be trusted (Bell and Lederman, 2003). Student should learn science through engaging scientific inquiry for understanding scientific knowledge and the NOS (Abd-El-Khalick, Bell, and Lederman, 1998). It is worthy therefore of the inclusion of the three aims in the science curriculum. From these three basic ideas, importance of the NOS, respiration and the inquiry-based approach, this study was developed.

There are three assumptions guiding any previous research on the NOS. The first assumption is that both students and teachers have an inadequate understanding of the NOS. The second assumption is that students cannot understand the NOS as a product or implicitly through engaging in the inquiry-based approach. They should learn explicitly and have opportunities to reflect their ideas about the NOS in an activities context. The third assumption is that the effectiveness of the developed units is different from teachers and context (Lederman, 1992; Abd-El-Khalick and Lederman, 2000). A crucial gap in the study of the NOS is its concepts which are assessed independently of specific subject matter. The knowledge is viewed as existing depending upon the situations in which it is used. Current research has been conducted to investigate how students respond or reflect about the NOS when scientific context is specified at the class level (Leach *et al.*, 2000). The study of the NOS within a specific context is important to understanding how particular kinds of educational experiences affect student development (Smith and Wenk, 2006). The inquiry-based approach is recommended as a central strategy to improve conceptions of the NOS (AAAS, 1993; NRC, 1996). However, very few studies using the explicit and reflective inquiry-based approach have been undertaken to develop secondary students understanding of the NOS (Khishfe and Abd-El-Khalick, 2002). Moreover, there has been little research on teacher practices during implementation of the explicit and reflective inquiry-based approach to support students understanding the NOS.

In this study, teaching of respiration in biology is the focus for two reasons. First of all the process of respiration which is the basic process of organisms is fundamental to a complete comprehension of other aspects of living processes such as the digestive and circulatory systems in animals, photosynthesis in plants, and energy flow in a natural ecosystem (Anderson, *et al*., 1990). In addition, the topic of respiration is one of several topics that have been the central focus of attention in research over the past two decades and has found that students had alternative conceptions in several concepts that might impact on other topics which are related and vice versa.

Purposes of the Study

The purpose of this study is to: (a) explore teachers' understanding of the NOS and the inquiry-based approach and their practices; (b) investigate the impact of an instructional unit on the topic of respiration in Level 4 Biology that integrates aspects of the NOS using explicit and reflective inquiry-based approach on students' understanding the NOS as well as their knowledge of respiration concepts; (c) investigate what ways teachers' teaching practices influence students' understandings of the NOS and respiration concepts.

Research Questions

1. What understanding of the NOS is held by level 4 biology teachers?

1.1 What are biology teachers' general understandings of the NOS?

1.2 What are biology teachers' specific understandings of the NOS in relation to their knowledge of respiration?

2. What pedagogical understandings do level 4 biology teachers hold in relation to teaching of respiration?

2.1 How do biology teachers typically conduct their teaching of respiration?

2.2 What are biology teachers' general understandings of inquiry teaching?

2.3 How do teachers typically use inquiry when teaching the topic of respiration?

3. How do teachers' implementation of the instructional unit on respiration, which integrates the NOS aspects using explicit and reflective inquiry-based approach, enhances students' understanding the NOS and knowledge of respiration concepts?

3.1 How do students' understandings of the NOS develop over the course of an instructional unit on respiration?

3.2 How do students' understandings of key concepts of respiration change over the course of an instructional unit on respiration?

3.3 In what ways do teachers' teaching practices influence students' understandings of the NOS?

3.4 In what ways do teachers' teaching practices influence students' understanding of respiration?

Anticipated Outcomes

1. This research finding is evidence that explicit and reflective inquiry-based approach is an alternative way for science teachers to promote students' understanding of the respiration concepts and the NOS.

2. There will be benefits to science educators in professional development that emphasizes students' understanding of the NOS and knowledge of respiration concepts.

Operational Definitions of Terms

The Nature of Science

The NOS is the epistemology and sociology of science, science as a way of knowing, or values and assumptions inherent to the development of scientific knowledge which represents unique characteristics of science as describing and explaining about what the science is, how it works and how it is different from other disciplines, what the scientists have done in the society along the history, and how science interacts with technology and society.

Aspects of the NOS are including:

1. Scientific knowledge is constructed: scientific knowledge is base on empirical evidence and/or derived from observations of the natural world. Human imagination and logical reasoning contribute to create scientific knowledge based on observations and inferences of the natural world. Creativity plays an important role in the development of scientific knowledge. Scientific knowledge is socially constructed, and thus includes cooperation, collaboration, and competition.

2. Scientific knowledge is tentative and subject to change: current scientific knowledge is subject to change with new observations or with the reinterpretations of existing observations or with new competing ideas come to light. This changing nature of theories reflects the cultural and historical development of scientific theories.

3. Diversity of the scientific method: scientific methods are diverse. The diversity in method stems from the differences among scientific disciplines, as they explore different kinds of phenomena.

4. Science is social activity, both influencing and responding to social needs. The values of the culture determine what and how science is conducted, interpreted, accepted, and utilized.

Inquiry-based Approach

In this study, the terms “inquiry-based approach,” or “inquiry teaching” are used to refer to pedagogical approaches modeling the general process of investigation that scientists use as they attempt to answer questions about the natural world-scientific inquiry. The inquiry in this research follows the NRC’s (1996: 23) definition of inquiry that reflects on inquiry as a “multifaceted activity” and the five essential features of classroom inquiry outlined in “Table 2.6: Essential Features of Classroom Inquiry and Their Variations” (NRC, 2000: 29). According to this definition, in an inquiry-based approach, learners make observations, pose questions, and examine books and other sources of information to see what is already known. Based on these observations, learners plan investigations, review what is already known in the light of experimental evidence, and use tools to gather, analyze, and interpret data. Finally, learners propose answers, explanations and predictions, and communicate the results.

An Explicit and Reflective Inquiry-based Approach

An explicit and reflective inquiry-based approach intentionally draws students’ attention to the relevant aspects of the NOS through an inquiry-based approach. The term *explicit* is used in this study to emphasize that teaching about the NOS is treated in a manner similar to teaching any other cognitive learning outcomes. The reflective component involves students being provided with multiple structured opportunities to reflect on the aspects of the NOS in the context of science-based activities in which they are engaged or science content. They are learning to articulate their views of the target nature of science aspects and develop coherent overarching nature of science frameworks.

Key Concepts of Respiration

The key concepts of respiration are scientific ideas about respiration that corresponds with the Science Curriculum Standards of Thailand, Sub-strand 1: living things and living processes Standard Sc1: Understanding foundation of living beings, relationships between structures and functions of various systems operations consists of definition of respiration, definition of, components and their relevancy in the respiratory system, definition and processes of cellular respiration, aerobic respiration, and anaerobic respiration or fermentation, respiration in plants, respiration in animals and human being.

The Respiration Instructional Unit (RIU)

The Respiration Instructional Unit (RIU) is an instructional unit for teaching respiration in Level 4 (grade 10 – 12). The approach of the RIU is the explicit and reflective inquiry-based approach. The RIU consists of three parts. The first part is a teacher manual including principles, outcomes, instructional components, instructional directions, characteristics of the instructional units, and advice. In addition, the teachers' manual is designed to help teachers understand the pedagogical approach required to make this an effective instructional unit. The second part is the lesson plans that cover respiration and the epistemology of science. Each lesson plan consists of objectives (knowledge, attitude, and processes), content, activities, materials, assessments methods, and time allotments. The last part is the student worksheets.

Researcher Biases

I am a former biology teacher in level 4, grade 10 – 12, in Pranakornsriayutthaya Province, Thailand, with five years experience. As a beginning teacher I especially felt that I was facing an endurance task. I was having difficulty conveying the material to my students. Even though, I graduated with a Bachelors' degree in the field of biology, my teaching was not effective in certain content areas such as respiration and photosynthesis. There were many factors that impacted my teaching that included content knowledge such as student context, preparation and teaching time, and knowledge about teaching. I came up with many questions in my mind, as to what I was doing wrong, why my students just didn't seem to get it, and how to teach biology effectively.

One year later after my first year as a beginning teacher, in 1999, Thai education reform occurred which resulted in a new national science curriculum standard. At that time, I had been meeting with other secondary science teachers in the Pranakornsriayutthaya Education Service Area 1 about developing a science curriculum in our school level. We discussed about how to teach science to cover sub-strand 8, the NOS. Due to the newness of the words and standards most of the teachers, including me, believed that although it was emphasized in the old curriculum, now it had more prominence. The teachers stated three ways in which to teach the NOS. The first was it should be separated from learning science content because it involved scientific inquiry skill and processes. Students should learn the NOS before learning science content. The second was it should be integrated with science content. The third was it should be taught both ways. I believed that it should be integrated in teaching science content.

After, I entered the PhD program in science education, I had more time to search and understand about science education such as the theory of teaching and learning, and teaching science, and especially the NOS. I learned and believed that the NOS is more than scientific inquiry skill and process. It should be taught explicitly. I still believe that teaching the NOS cannot be separated from science content, and it supports student learning science content. I realized that I had never been taught to emphasize the NOS in my previous teaching. I behaved similarly to others teachers I spent time and paid attention to doing science with hands-on and scientific-based activities and thought that understanding the NOS was a natural process. My personal experiences resulted in my interest in the area of the NOS.

In the academic year 2005, I had the opportunity to observe three teachers' teaching biology using the respiration topic in grades 10 and 11. Through classroom observation I noted that all teachers used the lecture method of instruction the most along with instructional materials such as pictures and diagrams. During some periods, the teachers assigned students to search for information about the topics taught and they told me that this was part of inquiry teaching. I mentioned early, that respiration concepts were difficult to both teach and learn because of their chemical nature. I believed that lectures would not develop students' understanding of respiration concepts. All the teachers gave the same reason as to why they chose the lecture method of instruction instead of using the inquiry method to teach the topic cellular respiration. Inquiry teaching was just difficult to implement. When I asked about inquiry teaching, I found that all of the teachers were unclear about the use of an inquiry-based approach as planned within a curriculum unit. This may be one reason why inquiry teaching was not being implemented in a real classroom. Moreover, teaching the NOS was not occurring.

Changing my understanding about the NOS and making classroom observations made me interested in studying students' understanding of the NOS in the context of respiration. I wanted to investigate whether students develop their own ideas both in the NOS and respiration during the instructional unit. This is the reason why I choose qualitative research for this study. I hope that the findings from this study will become evidence for science educators to develop curriculum that emphasizes the NOS and the respiration instructional unit will integrate the NOS using the explicit and reflective inquiry-based approach as one sample for guiding science teachers to teach the NOS explicitly.

CHAPTER II

LITERATURE REVIEW

The literature review of this study falls primarily into five main sections: 1) the nature of science (NOS) including the definition of the NOS and research on students' understanding of the NOS; 2) the knowledge of respiration including respiration in the Thai National Science Curriculum Standard, the key concepts of respiration, students' alternative conceptions, and students' alternative conceptions of respiration; 3) the inquiry-based approach including inquiry in science education, pedagogical characteristics of the inquiry-based approach, and the inquiry-based approach in science classroom; and 4) constructivism.

The Nature of Science

Development understanding of the NOS has increasingly become a part of major reform efforts in science education (Driver *et al.*, 1996; Matthews, 1998; Abd-El-Khalick and Lederman, 2000). From an educational perspective, most agree that teaching children to simply recall scientific facts, laws, and theories is not enough. For example, in the United States, the National Science Education Standards (NRC, 1996) and Benchmarks for Science Literacy (AAAS, 1993) recommend that teachers help students not to only acquire understanding of scientific knowledge and develop skills needed to conduct scientific inquiries, but to achieve an understanding of the NOS. Emphasis on the NOS at K -12 levels not only emerges in the United States but also appears in many countries' curriculums such as in England and Wales where it is introduced through the Science National Curriculum (Matthews, 1998; McComas and Olson, 1998), Thailand included explicitly the NOS in the science curriculum standard after education reform (IPST, 2002). As well Hong Kong puts emphasis on the NOS in their curriculum aims and contents after a revision and implementation in 2003 (Tao, 2003).

Throughout this century, and especially in recent years, the goal of science education is scientific literacy in general, with an understanding of the NOS in particular. Scientific literacy has become a necessity for everyone. Everyone needs to use scientific information to make choices in everyday life. Everyone needs to be able to engage intelligently in public discourse and debate about important issues that involve science and technology. Furthermore, everyone deserves to share in the excitement and personal fulfillment that can come from understanding and learning about the natural world (NRC, 1996: 2-3). Therefore, student understanding of the NOS has become an important educational outcome worldwide (Lederman, 1999).

An adequate understanding of the NOS is considered to reach scientific literacy (NRC, 1996; Bybee, 1997) because better people understand the characteristics of scientific knowledge and the way it is constructed, the argument proceeds, the better they will be able to evaluate scientific claims rather than reject or accept them uncritically and apply scientific knowledge to their everyday lives (Hogan, 2000; Bell and Lederman, 2003). Other reasons that support emphasizing the NOS in teaching are understanding the NOS to enhance the learning of science; understanding of science; interest in science; decision making; and instructional delivery (McComas, Clough, and Almazroa ,1998).

1. Defining the Nature of Science

The NOS typically refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge or the development of scientific knowledge (Lederman, 1992; Lederman *et al.*, 2002). However, the specific description of the NOS and the set of propositions about the NOS that students should know upon leaving school is often debated among philosopher of science, historians of science, sociologists of science, scientists, and science educators (Sandoval, 2005).

Eflin, Glennan, and Reisch (1999) claim there are four areas of consensus regarding the NOS among science educators and two areas of argument about the NOS that are related closely to the debates in the philosophy of science. The areas of consensus about the NOS include 1) the main purpose of science is to acquire knowledge of the physical world; 2) there is an underlying order in the world which science seeks to describe in a maximally simple and comprehensive manner; 3) science is dynamic, changing, and tentative; 4) there is no one, single scientific method. The areas of argument about the NOS include 1) the generation of scientific knowledge depends on theoretical commitments and social and historical factors; 2) the truth of scientific theories is determined by features of the world which exist independently of the scientist.

Similar to scientific knowledge, conceptions of the NOS are tentative and dynamic (Akerson, Abd-El-Khalick, and Lederman, 2000; Sandoval, 2005). During the past 100 years, conceptions of the NOS have changed throughout the development of science and the systematic thinking about science and these changes are reflected in the ways the scientific and science education community interact (Lederman, 2006). During the early 1900s, understanding the NOS was equivalent to understanding the scientific method. In the 1960s, the NOS was viewed with an emphasis on enquiry and science process skills: observing, hypothesizing, inferring, interpreting data and designing experiments. In the 1970s, the conceptualizations of the NOS shifted to characterize scientific knowledge as tentative, replicable, probabilistic, humanistic, historic and empirical. By the 1980s, the NOS is incorporated with psychological factors such as the theory-driven nature of observation and the role of human creativity in developing scientific explanation, as well as a social factor that affects the construction and validation of scientific knowledge (Abd-El-Khalick and Lederman, 2000).

On the other hand, there is a general consensus about the desirable understandings of the NOS in international standards documents (McComas and Olson, 1998). Aspects of the NOS are commonly addressed in most science education standards documents. As for the National Science Education Standards (NRC, 1996) and the AAAS Benchmarks for Scientific Literacy (AAAS, 1993), the NOS is identified as three principle subjects including:

1. Scientific world view: scientists share certain basic beliefs and attitudes about what they do and how they view their work. These have to do with the nature of the world and what can be learned about it. This principle includes: a) the world is understandable; b) scientific ideas are subject to change; c) scientific knowledge is durable; and d) science cannot provide complete answers to all questions.

2. Scientific inquiry: the relationship between evidence and logical reasoning involves on one scale, the value of careful observation, and on a larger scale, the role of observations in building a line of reasoning. This principle includes: a) science demands evidence; b) science is a blend of logic and imagination; c) science explains and predicts; d) scientists try to identify and avoid bias; and e) science is not authoritarian.

3. Scientific enterprise: science as an enterprise has individual, social, and institutional dimensions. Scientific activity is one of the main features of the contemporary world and, perhaps more than any other, distinguishes our times from earlier centuries. This principle includes: a) science is a complex social activity; b) science is organized into content disciplines and is conducted in various institutions; c) there is a generally accepted ethical principle in the conduct of science; and d) scientists participate in public affairs both as specialists and as citizens.

The Institute for the Promotion of Teaching Science and Technology (IPST), under the authority of the Thai Ministry of Education, plays a major role in basic science education in Thailand. According to the National Education Act of 1999, IPST established standards of science education and the National Science Curriculum Standards of Thailand. These standards documents explicitly emphasize the NOS in Sub-strand 8: The Nature of Science and Technology as one of the eight cores of basic science that all students should learn. It states that the students should be able to use the scientific process and have a scientific mind in investigations and solving problems, and know that most natural phenomena have definable patterns explainable and verifiable within the limitations of data and instrumentation during periods of investigation, and understand that science, technology and environment are interrelated (IPST, 2002).

In the Standards for Thai science teachers in teaching Science (IPST, 2003a), the NOS is explained in four main aspects:

1. Scientific knowledge comes from human endeavor to use the scientific process in scientific inquiry and to solve problems by observing, investigating, researching and gathering data systematically. Thus, the body of scientific knowledge is increasing all the time.

2. Scientific knowledge should be able to be explained and be testable. It is tentative through debate among scientists based on new evidence or old evidence that is reinterpreted in different ways and with different ideas.

3. Interrelation between science and technology. Scientific knowledge is the important foundation of technology development. Technology is the process of work or process of developing and improving products by using scientific knowledge, cooperating with other disciplines, skills, experiences, imagination, and creativities of humanity. Technology relates to resources, processes, and management systems. Technology must be used to the advantage of society and the environment.

4. Interrelations exist between science and society. Everybody in every part of the world can participate in science. The communication and publication of scientific data for analytical and critical thinking increases scientific knowledge ceaselessly, and affects humanity in every society and every environment. Research and the use of scientific knowledge must be within the limitations of moral principles and ethics which are accepted by society and help maintain a sustainable environment.

McComas *et al.* (1998: 6-7) reviewed eight international science curriculums from several countries including Australia, Canada, England, New Zealand and the United States. They identified 14 consensus statements in terms of understanding the NOS including: 1) scientific knowledge while durable has a tentative character; 2) scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and skepticism; 3) there is no one way to do science (therefore, there is no universal step-by-step scientific method); 4) science is an attempt to explain natural phenomena; 5) laws and theories serve different roles in science; therefore students should note that theories do not always become laws even with additional evidence; 6) people from all cultures contribute to science; 7) new knowledge must be reported clearly and openly; 8) scientists require accurate record keeping, peer review and replicability; 9) observations are theory-laden; 10) scientists are creative; 11) the history of science reveals both an evolutionary and revolutionary character; 12) science is part of social and cultural traditions; 13) science and technology impact each other; and 14) scientific ideas are affected by their social and historical milieu.

As present, the understanding of the NOS by both teachers and students has been the focus of much research. Such research, however, defined the terms of the NOS as having different shades of meaning from study to study (Leach *et al*., 2000). Lederman (1992; 2006) and Lederman *et al.* (2002) advanced a set of seven aspects of the NOS that they argued little disagreement exists among philosophers, historians, and science educators. Lederman used three criteria to determine what aspects of the NOS that are viewed as important and which to include in science curriculum and instruction. These criteria are: 1) is knowledge of the aspect of the nature of science accessible to students (can they learn and understand)? 2) is there general consensus about the aspect of the nature of science? 3) is it useful for all citizens to understand the aspect of the nature of science? (Lederman, 2006: 304).

From these criteria, seven aspects of the NOS are described below:

1. Tentativeness. Scientific knowledge is tentative and subject to change with new observations and with the reinterpretations of existing observations. All other aspects of the NOS provide a rationale for the tentativeness of scientific knowledge.

2. Subjectivity. Science is influenced and driven by presently accepted scientific theories and laws. The development of questions, investigations, and interpretations of data are filtered through the lens of current theory. This is an unavoidable subjectivity that allows science to progress and remain consistent but also contributes to change in science when previous evidence is examined from the

perspective of new knowledge. Personal subjectivity is also unavoidable. Personal values, agendas, and prior experiences dictate what scientists chose to study and how scientists conduct their work.

3. Empirical basis. Scientific knowledge is based on and/or derived from observations of the natural world.

4. Creativity. Scientific knowledge is created from human imaginations and logical reasoning. This creation is based on observations and inferences of the natural world.

5. Sociocultural embeddedness. Science is a human endeavor and is influenced by the society and culture in which it is practiced. The values of the culture determine what and how science is conducted, interpreted, accepted, and utilized.

6. Observation and inference. Science is based on both observation and inference. 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.

7. Theories and laws. Theories and laws are different kinds of scientific knowledge. 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 another, in the hierarchical sense, for they are distinctly and functionally different types of knowledge.

Moss, Abrams, and Robb (2001) propose the model of the NOS, as a set of criteria geared towards secondary education. This model has two main domains namely the nature of scientific enterprise and the nature of scientific knowledge. The characteristics which define the nature of scientific enterprise include:

1. The universe is open to human description, classification and understanding through scientific exploration. However, science is merely one way of coming to know our universe.

2. This scientific exploration attempts to explain and predict phenomena, compare theories, check on previous results, and generate new questions.

3. Logic, imagination, curiosity, and serendipity contribute to scientific exploration.

4. Science is a social activity, both influencing and responding to social needs. Scientists themselves are influenced by cultural and personal factors, such as cultural norms and their own experiences.

5. Questioning, data collection and analysis, drawing of conclusions, and communication are the major phases which characterize the scientific endeavor. Research designs which make use of both experimentation and naturalistic observation are commonly used.

The characteristics which define the nature of scientific knowledge include:

1. Scientific knowledge demands evidence, and it is testable through the scientific enterprise.

2. Scientific knowledge usually cannot provide complete answers to all questions.

3. Scientific knowledge is tentative and developmental.

Moss *et al.* (2001: 773)

Based on 14 consensus statements of the NOS identified by McComas *et al.* (1998) and Toa (2003), seven aspects of the NOS were deemed relevant to revise the science curriculum of Hong Kong and related to the science stories in the instruction. The seven aspects are as follows:

1. Scientific discoveries are for understanding the nature; inventions are for solving a problem and changing people's ways of life.

2. Science and its methods cannot give answers to all questions.

3. Scientists usually work in collaboration and one scientist's work is often followed up by other scientists.

4. Scientists carry out experiments to test ideas, hypotheses and theories.

5. Careful and systematic study is not enough; scientists need to be creative and imaginative.

6. Scientific theories are created by scientists to explain and predict phenomena; they do not necessarily represent reality.

7. Scientific knowledge, while durable, has a tentative character.

(Toa, 2003: 149)

For the epistemology of science, Sandoval (2005:639-641) suggested four broad epistemological themes of the NOS that students should know in order to inquire effectively into scientific problems, to understand their inquiry as science, and to be able to evaluate scientific claims in relation to socioscientific issues in their lives outside of (and beyond) school. The four themes include:

1. Scientific knowledge is constructed. Students should know scientific knowledge is constructed by people and not simply just discovered out in the world. There are consequences to the belief that scientific knowledge is constructed. Firstly,

human creativity plays an important role in the development of scientific knowledge and is the source of theoretical ideas. Secondly, scientific knowledge is socially constructed and includes cooperation, collaboration, and competition. The scientific knowledge is not accepted just because it is true, but because people are persuaded of its value such as its adequacy as an explanation, or its utility or some other standard.

2. Diversity of scientific methods. Related to understanding science and effectively conducting inquiry, students should understand that scientific methods are diverse. According to, the differences among scientific disciplines, there are various methods for exploring different kind of phenomena. For example, controlled experimentation is certainly an important means of generating scientific knowledge, but entire disciplines rely on other methods because controlled experimentation is infeasible for them, including astronomy, paleontology, and others.

3. Forms of scientific knowledge. Students should understand that there are different forms of scientific knowledge, varying in their explanatory or predictive powers and in their relationship to the observable world. Within a sophisticated scientific epistemology, however, these entities vary in both scope and purpose. For instance, laws are typically understood as generalized descriptions of some phenomenon with high predictive value but little explanatory power. Theories, in contrast, are conceptual frameworks that provide relatively high degrees of explanatory power and varying degrees of predictive value. There are other forms of scientific knowledge and its communication that might be considered epistemological entities and with which students should be familiar to fulfill social goals of science education. Besides theories, laws, and hypotheses, models are an important form of scientific knowledge. There are also rhetorical forms, such as explanations, predictions, and arguments that rely on other epistemological forms to advance specific claims.

4. Scientific knowledge varies in certainty. Some scientific claims are more tentative than others. For all practical purposes, the force of gravity is not a tentative idea; whereas string theory is quite tentative. Philosophically, there are many different ways of interpreting the sources of tentativeness: it could be due to our imperfect ability to comprehend the world; we could be inching closer and closer to some

ultimately knowable truth; or we may simply be constructing our reality. An important instructional goal, therefore, is the recognition that current scientific ideas may change as new observations or new, competing ideas come to light. This changing nature of theories reflects the cultural and historical development of scientific theories.

In summary, from international standards documents and researches, the NOS definition is generally accepted as the nature of scientific knowledge and development and justification of such knowledge. For the nature of scientific knowledge, it is both symbolic in nature and also socially acceptable that scientists attempt to explain and interpret this nature based on evidence. Scientific knowledge is constructed in collaborative groups of scientists and based on previous research by many scientists. Human creativity plays an important role in the development of scientific knowledge and is the source of theoretical ideas. Scientific knowledge is uncertain, affected by the interpretive perspectives of knower (scientists), but in which knowledge claims can be evaluated by standards that take account of and transcend individual frameworks. For knowledge acquisition, it means diversities of scientific thinking: scientists use a range of methods and approaches and there is no one scientific method or approach. Moreover, science is a social activity, both influencing and responding to social needs. The values of the culture determine what and how science is conducted, interpreted, accepted, and utilized.

2. Research on Students' Understanding of the NOS

2.1 Eliciting Students' Understanding of the NOS

The NOS has been a subject of extensive research for more than 50 years. During the early states of research related to NOS, researchers had still not distinguished among science attitude, attitude toward science, and students' conceptions of the NOS or scientific knowledge. Over the year, research on students' understanding of the NOS has slowly moved from a quantitative to a qualitative assessment approach (Lederman, 1992).

Traditionally, students' understanding of the NOS has been assessed by standardized paper-and-pencil tests containing multiple-choice questions or the Likert scale items that cover different aspects of the NOS, for example, "Test of Understanding Science [TOUS], Klopfer and Cooley, 1961; the Nature of Science Scale [NOSS], Kimball, 1967–1968; the Science Process Inventory [SPI]; Welch and Pella, 1967–1968; the Nature of Scientific Knowledge Scale [NOSKS]; Rubba and Anderson, 1978; Views on Science–Technology–Society [VOSTS], Aikenhead and Ryan, 1992" (Lederman, 1992; Hogan, 2000). Toward the end of the 1980s, using qualitative methods such as classroom observation and interviews have been more widely used to explore students' understanding of the NOS. Lederman, Wade, and Bell (1998) noted that these standardized instruments usually reflected their developers' views and biases related to the NOS. They suggested that traditional instruments, if used, should be complemented by a qualitative method. This recommendation is consistent with the current shift of educational research towards more qualitative method. The use of interpretive tools such as individual interviews often reflects the researcher's interest in elucidating and clarifying participants' NOS views rather than simply labeling or judging them (Abd-El-Khalick and Lederman, 2000).

However, interviews in early studies of students' understanding of the NOS asked students to respond to direct questions using paper and pencil instruments such as " what is science?", or " Why do you think that scientists do experiments?", or "What is the scientific knowledge?" (Leach *et al.*, 1997; Hogan, 2000). Some researchers have complemented the direct questioning approach by presenting scenarios to elicit students' understanding. For example, the Views of Nature of Science Questionnaire form B was developed by Abd-El-Khalick, Bell, and Lederman (1998): asked the questions "after scientists have developed a theory (e.g. atomic theory), does the theory ever change? If you believe that theories do change, explain why then do we teach scientific theories. Defend your answer with examples" (Lederman *et al.*, 2002).

An alternative approach to research on students' understanding of the NOS was asking students questions in their context of science learning or activity. Some researchers conducted their research in natural classroom settings where they asked students to interpret the meaning of their experiences in science class (e.g.

Hammer, 1994, Roth and Roychoudhury, 1994). An example interview question is "How does working in a group help you to learn physics?" The intermediate approach as it was called by Leach *et al.* (1997) suggested that the researchers can select appropriate contexts for student interest. They designed tasks and after doing them the researchers asked students to elaborate upon their actions and responses to questions in the context of the activity. The advantage of this approach was the context in which student representations were applied was clearer than if a decontextualised question was asked.

2.2 Students' Understanding of the NOS

To elicit students' understanding of the NOS, many researchers use different methods and instruments for assessing students' understanding of the NOS; nevertheless, they have consistently shown that students hold inadequate understanding of the NOS.

In early research, using the TOUS was the most widely used paper-and-pencil assessment of students' conception. Researchers who used the TOUS found similarly inadequate students understanding of the NOS. Similar findings indicated that students lacked sufficient knowledge of a) the role of creativity in science; b) the function of scientific models; c) the roles of theories and their relationship to research; e) the distinction among hypotheses, laws, and theories; f) the relationship between experimentation, models and theories, and absolute truth; g) the fact that science is not concerned with the collection and classification of facts; h) what constitutes a scientific explanation; and i) the interrelationships among and the interdependence of the different branches of science (Lederman, 1992).

More recently, most researches focused on a particular aspect of students' understanding of the NOS. Through the K–12 and college levels, most students held an inadequate understanding of the nature of scientific knowledge. They did not readily acknowledge that scientific knowledge is constructed (Sandoval, 2005). Younger students tended to see scientific knowledge as residing directly in experimental results, gathered from objective observation and existing independently of the knower whereas older students have ideas of scientific knowledge as being definitely right or wrong (Ryan and Aikenhead, 1992; Carey and Smith, 1993: Leach *et al.*, 1997). By high school, there is evidence that some students have developed notions that scientists construct models and theories (Lederman and O'Malley, 1990; Solomon, Scott, and Duveen, 1996).

Students often hold a simplistic, hierarchical view of the relationships among hypotheses, theories, and laws. That is, hypotheses, theories, and laws are related in a linear hierarchy from less to more proof. They understand that hypotheses are guesses or academic guesses, theories are hypotheses supported by evidence or the testing and retesting of hypotheses with the status of a proved theory, and laws have been indisputably proven. Their view is that theories become laws when they are proven, or they viewed those hypotheses, theories, and laws as being developmentally related and having a developmental sequence (Ryan and Aikenhead, 1992; Sandoval and Morrison, 2003). Thus, students believe that laws have a higher status than theories. This view affects their understanding that laws are absolute and do not change (Brickhouse *et al.*, 2002). Students seem to believe that theories are just a stage in the progression toward the truth. Theories change not because scientific knowledge is dynamic or tentative, but because theories are just theories and have yet to attain the status of laws or proven fact (Abd-El-Khalick, 2006).

Leach *et al.* (1997) and Smith and Wenk (2006) found that students view scientific knowledge as an unproblematic knowledge and is known by authorities with a high degree of certainty. They have difficulties in understanding and interpreting different viewpoints expressed by scientists on socially relevant issues within a science dimension. Throughout adolescence, most students seem to believe that scientific knowledge is, or at least can be, certain. Students talk about ideas as either being right or wrong (Sandoval, 2005). Although students understand that scientific knowledge is tentative and able to change over time but they believe that change occurs through a slow process of observation and gathering new evidence as a result of improvements in instrumentation or advances in technology (Moss *et al.*, 2001). They were not concerned about reinterpreting existing data or the role of new ideas to stimulate theory change. It is also related with the inadequate ideas about the role of inference, human inference, imagination, and creativity in generating scientific claims, or constructing scientific models and theories (Tobin and McRobbie, 1997; Khishfe and Abd-El-Khalick, 2002).

In general, students seem to have alternative understandings of the process of doing science and limited understandings of the scientific method. Students understand that scientists use only a single scientific method, or other sets of orderly and logical steps, as tools for their research (McComas, 1998; Bell *et al.*, 2003). For example, Moss *et al*. (2001) found that students understood that an activity was scientific if there was structure, organization, or a certain way of doing it. Moreover, most students ignored the key aspect of science which was generating new questions as a result of conducting research, and they did not understand that science is a human endeavor in which numerous factors may affect how a scientist collects data and interprets their findings. While students realized that scientist made observations and used them as the basis for generating patterns and predictions, they failed to recognize some of the more complex roles of observation in science such as observation can be used to confirm explanations or discount them, observations are not objective, but are guided by the ideas scientists bring to an investigation, and disconfirming observational evidence may lead to theory change (Abell, Martini, and George, 2001).

Sandoval (2003) asserted that most students did not seem to understand the nature of scientific inquiry and that is consistent with current inquiry-based approaches to learning science. 1) Few students saw science as a process of building and testing models and theories; instead, science was seen as a steady accumulation of facts about the world. 2) Many students did not distinguish experimental findings from the ideas. They were designed to test, or saw that relationship simplistically: experiments tell you straightforwardly if you are right or wrong. 3) Students often did not see that experiments are intended to test causal relations. Thus, student ideas about the kinds of products scientists produce hinders their understanding of the scientific processes.

Regarding the relationship between science and society, students failed to realize the role of the scientific community in communicating or debating about competing theories. They tended to see science as individual work, rather than social or collaborative work and as an objective endeavor with scientists detached from their work (Leach *et al.*, 1997; Zeidler *et al.*, 2002). Moreover, they tended to see that science stands alone as a discipline insulated from other aspects of society (Sadler, Chambers, and Zeidler, 2004).

2.3 Enhancing Students' Understanding of the NOS

Khishfe and Abd-El-Khalick (2002) categorized the attempts to enhance students' understanding of the NOS into three categories.

2.3.1 Historical Approach

The first approach, the historical approach, suggests that incorporating the history of science into science teaching can give students a better understanding of the NOS. The National Science Education Standards (NRC, 1996) and Benchmarks for Science Literacy of America (AAAS, 1993) recommend using the history of science in science teaching prominently.

"History provides another avenue to the understanding of how science works . . . it is equally important that students should come to realize that much of the growth of science and technology has resulted from the gradual accumulation of knowledge over many centuries." (AAAS, 1993: 4)

At the secondary school level, the standards state that all students should develop an understanding of science as a human endeavor, should appreciate the nature of scientific knowledge, and have a view of the historical perspectives that have resulted in scientific discovery (NRC, 1996).

However, evidence from research about the effectiveness of the historical approach is at best inconclusive result. According to Khishfe and Abd-El-

Khalick (2002), two large-scale national studies conducted by Klopfer and Cooley (1963) and Welch and Walberg (1972) to assess the influence of History of Science Cases for High Schools (HOSC) and the Harvard Project Physics (HPP) on students' understanding of the NOS produced conflicting results. Abd-El-Khalick and Lederman (2000) investigated the impact of history of science on college students' understanding of the NOS. From the result of questionnaires and interviews, they found that most students exhibited little increase in their understanding of the NOS.

Another research, Irwin (2000) studied the influence of historical approach in atomic theory on ninth grade students' understanding of the creativity of science. Comparing two groups of students, one group of students using a historical perspective and another group of students using only the final contemporary perspective, a pretest and posttest analysis showed that students in the historical group exhibited no better understanding that atomic structure is inferred from empirical results than did the comparison group. Moreover, Irwin found the treatment group showed no deficiency in content knowledge relative to the comparison group.

2.3.2 Implicit Approach

The second approach is presented by Khishfe and Abd-El-Khalick (2002: 553-554) and that is the implicit approach. The implicit approach contends that by doing science, students will come to understand the NOS and advocates the use of hands-on inquiry-oriented activities and/or science process skills instruction—lacking explicit references to the NOS - to enhance student conceptions of the NOS.

Early attempts to improve students' understanding of the NOS focused primarily on the development of curriculum. The Physical Science Study Curriculum (PSSC) and the Biological Sciences Curriculum Study (BSCS) are two notable examples of curricula that adopted the implicit approach. The impact of these curriculums, which tend to address the NOS implicitly through instruction on inquiry and process skills, is mixed (Lederman, 1992).

However, researches have consistently shown that the implicit approach is not effective in helping students develop informed the NOS views. Comparing the influence between the development curriculum, PSSC or BSCS, and traditional curriculum, many researches found that these development curriculums were not more effective than traditional curriculums in enhancing students' understanding of the NOS (Lederman, 1992; Khishfe and Abd-El-Khalick, 2002). Similarly, Moss *et al.* (2001) studied junior and senior high school students who formed partnerships with research scientists as part of the students' environmental coursework. At the end of the experience, students still illustrated gaps in their understanding of the nature of the scientific enterprise. Bell *et al.* (2003) studied high-ability high school students who worked with science mentors while participating in an 8-week apprenticeship program. At the end of the experience, students concluded that laws are tested theories, laws are facts, and that scientists use creativity only when designing an experiment.

The ineffectiveness of the implicit approach in enhancing students' understanding of the NOS could be attributed to an underlying assumption that students would automatically develop better the NOS conceptions as a by-product outcome of engagement in science-based inquiry activities or science process skills instruction (Lederman and Abd-El-Khalick, 1998; Schwartz, *et al.* 2004). In other words, since there is no specific attention paid to the nature of science, it is assumed that student appreciation and understanding will develop as a natural consequence of engaging in the activity (Schwartz *et al.*, 2004).

2.3.3 Explicit and Reflective Approach

The third approach is the explicit and reflective approach. This approach advocates that to improve students' understanding of the NOS, the NOS should be considered as a cognitive learning outcome and should be taught explicitly rather than expected to be naturally development during the regular science activities (Khishfe and Abd-El-Khalick, 2002). This approach refers that students' acquisition of knowledge of some of the aspects of the NOS should be highlighted during their activities. Khishfe and Abd-El-Khalick (2002) explained the important qualifications regarding the conceptualization of an explicit and reflective approach. It cannot be overemphasized that this approach should not be confused with didactic teaching. The explicit and reflective approach does not solely invoke elements from history and the philosophy of science or exclude science-based inquiry activities.

When employing this approach, certain nature of science should be integrally incorporated as a planned instructional outcome of the science lessons (Schwartz and Lederman, 2002; Schwartz *et al.*, 2004). Teacher should explicitly introduce the subjects to certain the NOS aspects and then provided their students opportunities to reflect on these aspects. These opportunities to reflect on the NOS aspects occurred within the context of a science-based activity, science content or historical examples that they are learning (Abd-El-Khalick, 2001; Khishfe and Abd-El-Khalick, 2002). Regarding evidence concerning the effectiveness of reflection, Bell *et al*. (2003) studied high-ability high school students who participated in an 8-week apprenticeship program. The result showed that the only student who exhibited a positive change in the understanding of the NOS was a student who actively reflected on her field experience and tried to make an authentic link between the NOS and her experiences. Similarly, Schwartz *et al.* (2004), studied preservice secondary science teachers enrolled in a science research internship course. They found that participants who wrote journal entries reflecting on their research experiences exhibited enhanced understanding or major changes in their understanding of the NOS by the end of the course.

Most researchers have found explicit and reflective approaches are more effective than implicit approaches in improving teachers' understanding of the NOS (Abd-El-Khalick and Lederman, 2000). For instance, Abd-El-Khalick *et al.* (1998), and Akerson *et al.* (2000), used explicit and reflective activity-based instruction to promote teachers' understanding of the NOS. This approach resulted in teachers holding views more aligned with the NOS as characterized in the reforms.

While most studies about the effectiveness of the explicit and reflective approach conducted employed teachers as the subjects, the evidence garnered suggests that this approach could substantially improve students' understanding of the

NOS. Khishfe and Abd-El-Khalick (2002) investigated the influence of an explicit and reflective inquiry-oriented approach comparing it with an implicit inquiry-oriented instructional approach on sixth graders' understandings of the NOS. The intervention or explicit group was engaged in inquiry activities followed by reflective discussions of the target the NOS aspects. The comparison or implicit group was engaged in the same inquiry activities. An open-ended questionnaire in conjunction with semi-structured interviews was used to assess the change in students' understanding of the NOS, which spanned two and half months. The results showed that asking the questions that elicited connections between activities and the NOS aspects was evidence that students change and develop their understanding of the NOS. This result does not support the intuitively appealing assumption that students would automatically learn about the NOS through engagement in science-based inquiry activities. Developing informed conceptions of the NOS is a cognitive instructional outcome that requires an explicit and reflective instructional approach. Similarly, Khishfe and Lederman (2006) investigated explicit and reflective approach on ninth graders' understanding of the NOS in the global warming unit about 6 weeks and Khishfe (2008) investigated the affects of this approach on seventh graders in the structure and function of living things, the populations and ecosystems unit for about 3 months. Results showed that most students improved in their understanding of the NOS as a result of the intervention.

The Knowledge of Respiration

Respiration is one topic in the study of biology because respiration is a key life process (Sander, 1993). The understanding of respiration is fundamental to a complete comprehension of the way in which living organisms function, for example, the breathing, digestive, circulatory systems and respiration systems of many animals function as they do largely because of the needs of body cells to engage in respiration (Anderson *et al.*, 1990; Sander, 1993). Moreover, the understanding of respiration is a prerequisite for any systematic understanding of ecology. Food webs and food chains begin with photosynthesis and end in respiration. Respiration relates with the flow of energy through an ecosystem (Anderson *et al.*, 1990). In biology education, the respiration topic is taught at the school and university level in a wide range of courses and context.

1. Respiration in the Thai National Science Curriculum Standard

Based on the National Science Curriculum Standard of Thailand in Respiration content standard, Sub-strand1: Living Things and Living Processes, there are two Standards as follows:

Standard Sc 1.1 explains that students should be able to understand the fundamental unit of living things and the relationship between the structures and functions of various systems that work together, to carry out investigative processes, to communicate what is learned and to apply the knowledge for one' own existence and to care for other living things;

Standard Sc 1.2 explains that students should be able to understand the processes of reproduction and inheritance, evolution of living things, biodiversity, technological applications that impact on man and the environment, to carry out investigative processes, to have a scientific mind, to communicate what is learned and to apply the knowledge gained.

The knowledge of respiration is addressed in all of levels of the content standard. Table 2.1 shows the basic science standard in each level of the content standard related to the study of respiration. According to the content standard, students are first introduced to the concepts underlining respiration as early as the first level (grade 1-3). Table 2.2 shows the concepts of respiration and the related concepts in each level. The data comes from the concept map in the teacher manuals curriculum standard and the student textbook from the IPST, the respiration concepts and related concepts are addressed in each grade.

Table 2.1 The Basic Science Standards in Each Level Related to the Study of Respiration

Sub-strand	Level of content standards			
	Level 1 (grade 1 – grade 3)	**Level 2 (grade 4 –grade 6)**	**Level 3 (grade 7 – grade 9)**	**Level 4 (grade 10 – grade 12)**
Sub strand 1: Living thing and living process Standard 1.1: Understand the foundations of living things and the relationships between structures and functions of various life sustaining systems, apply this knowledge to understand and maintain personal health and quality of life.	1. Observe, investigate, compare and contrast living things and non-living things, various structures and functions of plants and animals in locations suitable for living but in different environmental settings.	1. Investigate, search for information, discuss an explain the function of various organ of animals, factors essential for growth, life cycle, reproduction, behavior of animals and apply the knowledge acquired.	1. Investigate, search for information, discuss and explain structures and functions of various systems in living things (Plant, animal and man), interrelationship of functions and apply knowledge acquired.	1. Investigate, search and explain the maintenance of equilibrium in cells, bodies of plants and animals and homeostasis in human and apply knowledge for daily living and further acquisition of additional knowledge.

Table 2.1 (Continued)

Sub-strand	**Level of content standards**			
	Level 1 (grade 1 – grade 3)	**Level 2 (grade 4 –grade 6)**	**Level 3 (grade 7 – grade 9)**	**Level 4 (grade 10 – grade 12)**
Sub strand 1: Living thing and living process Standard 1.1: Understand the foundations of living things and the relationships between structures and functions of various life sustaining systems, apply this knowledge to understand and maintain personal health and quality of life.	2. Observe, pose questions, discuss and explain functions of various organs that function together and use the knowledge to care for health.	2. Explore, search for information, discuss and explain nutritional components in food, the body's need for nutrients which are of correct proportion and commensurate with age. 3. Search for information and explain the coordination of various organs in the human body to maintain normalcy and development from birth to adulthood, also the effects of some substances on the function of various systems and apply the knowledge for appropriate self-conduct.	2. Search for information, discuss and explain addictive drugs, their effects on the function of various systems of the body and purpose ways of preventing and fighting against addictive substances.	

Table 2.1 (Continued)

Standard	Level of content standards			
	Level 1 (grade 1 – grade 3)	**Level 2 (grade 4 –grade 6)**	**Level 3 (grade 7 – grade 9)**	**Level 4 (grade 10 – grade 12)**
Sub strand 1: Living thing and living process Standard 1.2: Understand the processes of reproduction and inheritance, evolution of living things, biodiversity, technological applications that impact on man and the environment, carry out investigative processes, have scientific mind, communicate what is learned and apply the knowledge gained.	1. Investigate the local environment, analyze data, discuss and explain the relationship between cohabiting living things and present the study.	1. Observe, investigate, discuss and explain the relationship between groups of living things in different habitats, write diagrams showing food chains and explain relationship between the environment and life and living things.		

Table 2.2 The Concepts of Respiration and the Related Concepts in Each Level

School Level	Grade	Content
Level 1	Grade 1-3	Living things and the environment - living things and non living things - Structures and functions of plants and animals - Factors essential for sustainability of living things and their extinction - Functions of human organ
Level 2	Grade 4-6	Living things and living process - Structures and functions of plants - Responses to the environment - Photosynthesis - The working of human organ - Life cycle of plant and animal - Nutrients
Level 3	Grade 7	Living unit and Plant life - Structures and functions of cell - Diffusion, osmosis - Photosynthetic process - Transport in plants - Response to stimuli - Biotechnology
	Grade 8	1. Our Body - Different systems in the body - Relationship among different system - Food and nutrients - Effects of some substances on our body 2. Animal life - Structures and functions of different systems
Level 4	Grade 10-12	Maintaining balance in cells, in plants, in animals, and in human body

2. The Key Concepts of Respiration

The key respiration concept is described below (Hopkins, 1999; IPST, 2003b): respiration is the chemical processes by which a carbohydrate (glucose) releases energy, to carbon dioxide and water. The energy released is trapped in the form of ATP for use by all the energy-consuming activities of the cell.

These processes occur inside the living cells of every type of organism- plant and animal. For this reason, it is also called internal respiration or cellular respiration. To avoid confusion with respiration or breathing, it is best to use the term cellular respiration. External respiration stresses that the entry of oxygen and exit of carbon dioxide happen at a different place than where energy is released. There are two types of cellular respiration:

1. Aerobic respiration (requires oxygen) is the normal form of the process in which glucoses are broken down and oxidized to provide energy, in living organisms. The overall equation for the oxidation of glucose is:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

2. Anaerobic respiration or fermentation does not require oxygen releases much less energy per mole of glucose. The respiration processes are divided into three metabolic processes: Glycolysis, the Krebs cycle, and the electron transport chain. Each of these occurs in a specific region of the cell.

1. Glycolysis occurs in the cytosol.

2. The Krebs cycle takes place in the matrix of the mitochondria.

3. Oxidative phosphorylation via the electron transport chain is carried out on the inner mitochondrial membrane.

With the absence of oxygen, anaerobic respiration consists of two metabolic pathways: Glycolysis and fermentation. Both of these occur in the cytosol.

Fermentation is a process in which pyruvate is partially broken down, but there is no Krebs cycle and no production of ATP by an electron transport chain. Fermentations of various kinds produce a number of different compounds. Examples of fermentation products are ethanol, lactic acid, and hydrogen. However, more exotic compounds can be produced by fermentation, such as butyric acid and acetone.

Respiration serves two major functions:

1. To provide energy in the form of ATP and $NADH_2$ needed for maintaining reactions and growth.

2. To provide carbon skeletons for the synthesis of metabolic intermediate substances, both in primary substances (amino acids, protein, nucleic acid, TCA, storage biosynthesis, etc.) and secondary substances (terpenes, phenylpropanoids, isoprenoids, flavanoids).

3. Students' Alternative Conceptions

Over the past three decades, research in science education has indicated that students' conceptions are different from those generally accepted by scientists on a particular subject. These different conceptions generated by students have been called alternative conceptions, naïve conceptions, misconceptions, and misunderstandings (Sander, 1993; Songer and Mintzes, 1994; Alparslan, Tekkaya, and Geban, 2003). The term "alternative conceptions" confers intellectual respect to students' informal ideas which are viewed as explanations constructed by students through their own experiences or assembled from his or her collective interactions with others. An important outcome of the studies on students' alternative conceptions is to reveal possible cause of their problems in science learning (Yip, 2000). Researchers have found that having the wrong prior knowledge is more debilitating to learning than having no prior knowledge at all. It is difficult to change an existing conception than to acquire new information. This knowledge will provide clues for the device of effective teaching strategies that may prevent the development of misunderstandings and lead to conceptual changes (Eckstein and Shemesh, 1993; Anders and Guzzetti, 2005).

Based on the work of Wandersee and Mintzes (1994), reviews of 2,600 published articles, there are eight knowledge claims about alternative conceptions:

1. Students come to formal science instruction with a diverse set of alternative conceptions about natural objects and events.

2. The alternative conceptions that learners bring to formal science instruction cut across age, ability, gender, and cultural boundaries.

3. Alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies.

4. Alternative conceptions often parallel explanations of natural phenomena offered by previous generations of scientists and philosophers.

5. Alternative conceptions have their origins in diverse sets of personal experiences including direct observations and perceptions, peer culture and language, and in teachers' explanations and instructional materials.

6. Teachers often subscribe to the same alternative conceptions as their students.

7. Students' prior knowledge interacts with knowledge presented in formal instruction, resulting in a diverse set of unintended learning outcomes.

8. Instructional approaches that facilitate conceptual change can be effective classroom tools.

Based on researches, Anders and Guzzetti (2005: 84-85) have suggested three different ways that could influence the development of alternative conceptions. First, they can be acquired physically, through an individual's interactions with the environment. For example, a student may observe that grass grows faster in the summer. He or she may try to explain this observation by reasoning that plants grow faster in warmer environments, or that plants eat more minerals in the summer, which makes them grow faster. Naïve theories like these represent a student attempt to make sense and to form personal theories regarding a real-life phenomenon.

Another way alternative conceptions may be acquired is socially, through interactions with peers, family, and the media. For example, the alternative conception that ostriches bury their heads in the sand is reinforced by a magazine advertisement for a life insurance company that uses a photograph of an ostrich burying its head in the sand. The third way that alternative conceptions can be acquired is instructionally, though inaccurate texts or teachers. Textbooks, for example, may be out of date, biased, or simply incorrect. Often the illustrations in textbooks are inaccurate because graphic artists do the artwork and have no background in the topic. Students will be most likely remembering misleading diagrams long after they have forgotten details from the text. In the model of learning in which teachers act as transmitters of knowledge (rather than as co-inquirers or constructors of knowledge), teachers can pass on alternative conceptions to their students if they are unsure of the correct conceptions themselves.

4. Students' Alternative Conceptions of Respiration

Researches into students' understanding the process of respiration indicated that students hold many concepts that are different from biologist concepts.

4.1 The Definition of Respiration or the Purpose of Respiration

The process of respiration, as it is understood by biologists, involves both a sequence of chemical reactions and an energy conversion. In all aerobic organisms, the sequence of chemical reactions combines glucose with oxygen to produce energy, carbon dioxide and water. In this process, chemical potential energy in the glucose is released and converted to heat or to chemical potential energy in another compound, ATP. The study of Anderson *et al.* (1990), when students were asked to define respiration, over 80% of the students gave definitions such as breathing exchange of CO_2 and for O_2, exhaling CO_2 for human, exhaling O_2 for plants, have lungs to breathe with, and air in and air out (p. 767). These results indicated that students provide a common-language definition for respiration, in which the term is used as a synonym for breathing, rather than a biological definition of respiration.

4.2 Respiration in Animals

According to the definition of respiration given by students, they understood that respiration occurs in particular organs in the respiratory system such as lungs and tracheae; they could not explain how animal cells use either food or oxygen; respiration occurs only in the cells of the respiratory organs (Anderson *et al.*, 1990; Sander, 1993). Students did not know how carbon dioxide is formed and did not understand that carbon dioxide can be produced in the lungs, blood or organs. Some students did not mention carbon dioxide as a substance produced during cellular respiration.

In the relationship between digestion and respiration, Songer and Mintzes (1994) found that students understood that the energy for the life processes of animals came from food and digestion. When they asked students to explain in detail how we get energy out of the food we eat, most students understood that food is necessary for respiration. However, they were unable to explain how energy is transformed and conserved during the biological processes. One student said that "the body gets its energy from food just as a car needs gas to run, our body's organs need nutrients and vitamins in food to perform correctly." Researchers claimed that this explanation is correct. However, it focuses on the body and organs rather than on cells and energy transformation.

4.3 Respiration in Plants

Alternative conceptions related with respiration in plants from many researches (Haslam and Treagust, 1987; Sukteeka, 2000; Alparsian *et al.,* 2003; Ozay and Oztas, 2003), for example, that plants respire through stomata on the leaves and they have special pores in which to do gas exchange. The cause of these alternative conceptions might came from students' understanding that plants are vaguely analogous to animals and hold thus they held an alternative conception about the meaning of respiration using very unscientific everyday language.

Other alternative conceptions regarding respiration in include, plants perform respiration only at night because they take in oxygen and give off carbon dioxide during the night or they perform photosynthesis during day. Some students understood that respiration is the reverse process of photosynthesis because products of photosynthesis are reactants of respiration. This result indicated that students perceived respiration and photosynthesis as mutually exclusive processes that do not occur simultaneously in plants (Alparsian *et al*., 2003).

4.4 The Respiration Processes and Products

A study regarding the respiration processes was carried out by Songer and Mintzes (1994). Most of students held a variety of different uses for oxygen. For example, even after instruction on the role of oxygen in the electron transport mechanism, one post instruction student suggested that oxygen feeds the muscles and organs with fresh air to relax them. Another student claimed that oxygen serves as a source of energy for the cells of the body. Some students showed alternative conceptions about how oxygen related with lung function such as the air gets filtered in the lungs and travels to the heart or the oxygen goes to the lungs and is stored in the bronchi. About glucose, some students understood that glucose is the only substrate used in the respiration.

For anaerobic respiration or fermentation, Songer and Mintzes (1994) found that some students understood that CO_2 is used instead of O_2 in fermentation reactions. Moreover, students who participated in their study were not able to recognize yeast as a living organism, and they believed that yeast releases O_2 in the fermentation process. While Sander (1993) reported that students ignored anaerobic respiration, they understood that all organism use oxygen in the respiration reaction.

Yip (2000) studied students' understanding of lactic acid fermentation. Many students held a variety of alternative conceptions about the nature and role of lactic acid fermentation, such as students understood that carbon dioxide is released during lactic acid fermentation; some even said that oxygen was required for the process; anaerobic respiration provides more energy for muscular contraction than aerobic respiration; the muscle stops aerobic respiration during vigorous activity; and there is a shortage of oxygen supply during exercise.

Inquiry-based Approach

1. Inquiry in Science Education

Inquiry has been viewed as an approach that involves a process of exploring the natural or the material world that leads to asking questions and making discoveries in the search of new understanding. Along the way, the inquirer asks questions, generates and proceed with strategies to investigate those questions by generating data, analyzing and interpreting that data, drawing conclusions from them, communicating those conclusions, applying conclusions back to the original question, and perhaps following up on new questions that arise (Cartier and Stewart, 2000; Sandoval, 2005).

In science education, inquiry has been a central term of teaching and learning science in past and present science education reform. The National Science Education Standards of America (NSES) (NRC, 1996: 23) defines inquiry in education as:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in the 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 logical thinking, and consideration of alternative explanations.

According to the NSES, Anderson (2002) asserts that there are three main usages of inquiry namely, scientific inquiry, inquiry learning, and inquiry teaching.

Scientific Inquiry

Scientific inquiry refers to the diverse ways in which scientists conduct themselves in everyday practice, study the natural world and propose explanations based on the evidence derived from their work (NRC, 1996; Anderson, 2002). It also refers to the scientific enterprise through which scientific knowledge is acquired, including the conventions and ethics involved in the development, acceptance, and utility of scientific knowledge (Schwartz, *et al.* 2004: 611).

The following aspects of scientific inquiry are derived from the NSES (NRC, 1996, 2000):

1) Scientific inquiry involves asking and answering a question and comparing the answer with what scientists already know about the world;

2) Data analyses are directed by questions of interest, involve representation of data in meaningful ways, and involve the development of patterns and explanations that are logically consistent;

3) Investigations have multiple purposes and use multiple methods;

4) Scientists formulate and test their explanations by examining evidence, and they suggest alternative explanations;

5) Scientists often work in teams with different individuals contributing different ideas;

6) Creativity is found in all aspects of scientific work;

7) Scientists make the results of their investigations public.

Inquiry Learning

Inquiry is a central component of science learning. There has been a great deal of interest and effort in recent years in reforming science education to engage students in authentic, scientific inquiry (Sandoval and Millwood, 2005). Moreover, this is compatible with the constructivist theory of learning, which emphasizes the idea that knowledge is not transmitted directly from one knower to another, but is actively developed by the students, who are responsible for their own learning (Zion *et al.*, 2004: 729). Inquiry learning refers to a learning process that is driven by students. Students are engaged as a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results (NRC, 1996; Anderson, 2002; IPST, 2002).

According to the NSES, there are five essential features of classroom inquiry: 1) learners are engaged by scientifically oriented questions, 2) learners give priority to evidence, which allows them to develop and evaluate explanations that address the questions, 3) learners formulate explanations from the evidence to address the scientifically oriented questions, 4) learners evaluate their explanations in light of alternative explanations, particularly those that reflect scientific understanding, and 5) learners communicate and justify their explanations (NRC, 2000:25).

> "… These essential features introduce students to many important aspects of science while helping them develop a clearer and deeper knowledge of . . . science concepts and processes." (NRC, 2000: 27)

Inquiry Teaching

From an instructional perspective, inquiry teaching is a way of organizing activities in the classrooms. It means that teachers design instructional environments that involve students and that have inquiry learning as scientific inquiry (Sandoval, 2005). In other words, teachers provide students with activities in which they develop scientific knowledge and an understanding of the nature of scientific knowledge as well as an understanding of how scientists study the natural world (Anderson, 2002).

Inquiry teaching is expected to become more prominent in science teaching due to the fact that the common framework of science learning outcomes encourages the inquiry teaching in teaching science. Abd-El-Khalick *et al.* (2004: 398) explained the concept of inquiry teaching as 'inquiry as means' or 'inquiry in science' that refer to inquiry as an instructional approach intended to help students develop understandings of science content. Science content serves as an end or instructional outcome. The concept of inquiry learning as 'inquiry as ends' or 'inquiry about science' refers to inquiry as an instructional outcome thus students learn to do inquiry in the context of science content and develop epistemological understandings about the NOS and the development of scientific knowledge, as well as relevant inquiry skills (e.g. identifying problem, designing and conducting investigations).

From above, scientific inquiry, inquiry learning, and inquiry teaching are interrelated. Each one is fairly distinct from the others, even though each has various nuances (Anderson, 2002: 2). The engaging students in inquiry teaching and learning helps students develop ideas about how we know what we know in science. Students in science classrooms should be developing abilities necessary to do scientific inquiry (what students be able to do) and knowledge about scientific inquiry (what students should understand), which is one aspect of the NOS (Schwartz *et al.*, 2004).

2. Pedagogical Characteristics of Inquiry-based Approach

The inquiry-based approach is not new pedagogy in science education (Schwartz *et al.*, 2004). Science is a process of inquiring into the nature of the universe. Science teaching should be inquiry-based approach. The limitations of learning science by rote, in the absence of inquiry experiences, are well known. However, there is no precise operational definition of inquiry teaching in regards to a characteristic of a desired form of teaching and as a certain kind of activity in standard documents. Many varied images of inquiry teaching can be expected among its readers (Anderson, 2002).

Some of the characteristics of inquiry teaching as depicted by the NSES (NRC, 2000) include: 1) inquiry as the activities in which students develop knowledge and an understanding of scientific ideas, as well as an understanding of how scientists study the natural world; 2) inquiry as activities that involve students in generating authentic questions from their experiences; 3) inquiry as activities that provide a basis for observation, data collection, reflection, and analysis of firsthand events and phenomena; and 4) inquiry as activities that encourage the critical analysis of secondary sources, including media, books, and journals in a library.

Gibson and Rea-Ramirez (2002) proposed that inquiry teaching begins with teachers who are willing to start with what students already know or think they know and to take the time needed to understand with what they are struggling. On the other hand, inquiry begins when students are puzzled about some event or object. Students are allowed to seek the answer that they do not have the answer about already. This does not mean that students have to discover everything on their own. After that, students design and carry out scientific inquiry. The process involves all the activities that a real scientist uses to find information such as hypothesizing, conjecturing, reading, designing experiment, collaborating with other, etc.

An inquiry process, Harwood (2004) outlines ten interrelated steps in which scientists engage in as often as necessary throughout the scientific inquiry process. He gives the terms of these steps as "an activity model for scientific inquiry": 1) asking question; 2) defining the problem; 3) forming the question; 4) investigating the known; 5) articulating the expectation; 6) carrying out the study; 7) examining the results; 8) reflecting on the findings; 9) communicating with others; and 10) making observations. These steps do not occur in any particular order but at the center of each step is the question asked. Scientists move among the steps in a pattern dictated by their specific needs. Additionally, due to the nature of inquiry some scientific investigations do not involve all these steps. For example, for some complex phenomena such as global warming, students can analyze data from a weather data base that they do not collect empirical data by themselves or do not carry out the hands-on experiments in order to arrive at an explanation for the phenomena. Students should be provided with opportunities to appreciate and understand various forms of scientific inquiry.

Following the NRC (2000), Colburn (2000) and Martin-Hansen (2002), stated that inquiry-based approach can vary from being very structured, “Guided Inquiry”, to very open, “Open Inquiry”. Four types of inquiry-based approach are described below.

Open Inquiry

Open or “full” inquiry can be defined as student-centered activities that require the presence of all five features of inquiry in the NSES (NRC, 2000) to be attained by students. Students formulate their own questions to investigate by using their background knowledge and experiences, and communicate their results with the others. It requires higher-order thinking and students working directly with materials, concepts, equipments, and so forth. This approach most closely mirrors scientists' actual work. In many ways, it is comparable to doing science. The key to inquiry here is students asking the questions that guide their own investigations.

Guided Inquiry

During these types of activities, teachers help students initiate inquiry-oriented activities. Usually, the teachers provide a scientifically-oriented question for investigation and may assist in decided how to proceed with the investigation. When students are involved in guided inquiry, they do not necessarily have to attain all the features of the inquiry on their own. Martin-Hansen (2002) explains that, “Teachers find that this is a time when specific skills needed for future open-inquiry investigations can be taught within context. Guided inquiry is a natural lead-in to open-inquiry”. (p. 35). In some case, students have to learn about more complex phenomena that they cannot be investigated directly in a classroom. The teacher can provide applicable scientific data from a variety of sources for student to construct explanations about phenomena.

Coupled Inquiry or Learning cycle

This approach incorporates two types of inquiry: guided inquiry and open inquiry. Using this approach the teacher begins the activity with an invitation to inquiry along with guided inquiry that leads to open inquiry. Martin-Hansen (2002) described the cycle as follows: "1) an invitation to inquiry, 2) teacher-initiated 'guided inquiry,' 3) student-initiated 'open inquiry,' 4) inquiry resolution, and 5) assessment" After the assessment is complete, another inquiry cycle can begin. This is usually a coupled inquiry or perhaps another open inquiry (p. 35).

Structured Inquiry

Martin-Hansen (2002) stated that structured inquiry is guided inquiry directed by the teacher. Both Colburn (2002) and Martin-Hansen (2002) described this type of inquiry as similar to "cookbook" style activities which provide more direction to students than structured inquiry does. Colburn explained, "The teacher provides students with a hands-on problem to investigate, as well as the procedures, and materials, but does not inform them of expected outcomes. Students are to discover relationships between variables or otherwise generalize from data collected," (p. 42).

3. Inquiry-based Approach in the Science Classroom

As an instructional method, inquiry can occur along a continuum of more to less structure. The aims of development inquiry teaching as a pedagogical approach in science class is to help students: 1) to grasp scientific content, 2) to develop abilities of conducting inquiry (what students should be able to do), 3) to understand the NOS, how knowledge comes from, how scientists acquire such knowledge, how practicing scientists conduct scientific inquiry (Bybee, 2000). Results of several researches on using inquiry- based approaches have shown many positive effects.

Effect on Students' Concept Achievement

At the secondary-school level, Mao, Chang and Barufaldi (1998) compare the effects of inquiry-based teaching and traditional teaching on 9th grade student learning of earth-science concepts, focusing on the topic "The apparent motion of the sun in the sky." The results indicated that the inquiry-based teaching did significantly improve student learning of earth science concepts in comparison to the traditional teaching method, especially at the comprehensive and integrated levels. In qualitative research, Wallace *et al.,* (2003) investigated the impact of an inquiry-based laboratory experience on non-major biology students' conceptual ecologies. They found that students with constructivist learning beliefs tended to add more meaningful conceptual understandings during inquiry labs than students with positivist learning beliefs. All students improved their understanding of experiments in biology.

Effect on Scientific Process Skills and Inquiry Skills

The evidence from researches regarding the impacts of inquiry-based approach showed varied improvement in scientific process skills and inquiry skills in K-12 students (Krajcik *et al,.* 1998; Wu and Hsieh, 2006) to college level students (Basaga, Geban, and Tekkaya, 1994; Suits, 2004). Krajcik *et al.* (1998) described realistically what middle school students do and where they have difficulties in their first encounters with inquiry learning. In this study, students designed and carried out their own investigations during 2 projects that spanned several months. The findings indicated that middle school students were thoughtful in designing investigations and in planning procedures, for instance, they thought about controls, about samples, and about how to organize data collection. However, the cases also revealed areas of weakness, such as failures to focus on the scientific merit of the questions generated and to methods used to systematically collect and analyze data and draw conclusions. Similarly, Wu and Hsieh (2006) found that sixth grade students who participate in inquiry-based learning activities significantly improve their inquiry skills such as identifying causal relationships, describing the reasoning process, and using data as evidence. Meanwhile, they showed slight improvement in evaluating explanations.

Effect on Problem Solving Skills

Roth and Bowen (1993) studied the situated nature of students' problem framing and solving as they engaged in an open-inquiry science classroom. They found that open- inquiry environments allow students to negotiate and frame their own problems to which they seek solutions, being relatively certain that their peers understand the problem in the same way. There are ample opportunities to renegotiate, calibrate, and repair their understandings when students find that they have different definitions of what exactly the problem is. Because they frame the problems, they know what to look for during the solution process. It is quite a different story when the problems are set by the teacher.

Effect on Attitudes Toward Science

Some evidence about the positive effect on attitudes toward science has been shown by Cavallo and Laubach (2001) and Gibson and Chase (2002). Cavallo and Laubach explored tenth grade biology students' attitudinal perceptions of students. Questionnaire and observation data was collected from 119 students in the classrooms of six learning cycle biology teachers. Results indicated that in classrooms where teachers most closely adhered to the ideal learning cycle, students had more positive attitudes than those in classrooms where teachers deviated from the ideal model. In the same way, Gibson and Chase examined the long-term impact of the Summer Science Exploration Program (SSEP), a 2-week inquiry-based science camp, conducted at Hampshire College Amherst, MA from 1992 to 1994. In 1996, 22 participants were selected to participate in follow-up interviews using stratified random sampling procedures. The interviews, the Science Opinion Survey, and the Career Decision-Making Revised Survey suggested that SSEP students maintained a more positive attitude towards science and a higher interest in science careers than students who applied to the program but were not selected.

4. Teaching Practices in Inquiry-based Approach

Although the inquiry-based approach is central to current science education standards and research says inquiry teaching can produce positive results (e.g. AAAS, 1993; IPST, 2001, 2003a; NRC, 1996, 2000). It does not, by itself, tell teachers exactly how to do it (Anderson, 2002: 4). The inquiry-based approach has not been widely adopted by science teachers. The result of researches found that inquiry in school science is different from the inquiry of scientists. Science teachers have difficulties translating guiding principles of reform documents to their own classrooms (e.g., Crawford, 1999; Crawford *et al.*, 2005; Keys and Kennedy, 1999, Wallace and Kang, 2004).

Inquiry-based approach has been described as difficult to implement and limited in its applicability because of constraints including lack of experiment, time and support, safety issues, classroom management, and the need to teach basics (Furtak, 2006). Moreover, efforts to implement inquiry in science classrooms have been confronted by a great number of barriers. For example, researchers have explored the constraints that face secondary science teachers as they attempt to implement inquiry. Logistical constraints such as class size, physical facilities, and time (Loughran, 1994; Roehrig and Luft, 2004; Wallace and Kang, 2004) and lack of administrative support (Brickhouse and Bodner, 1992) are frequently cited as barriers to inquiry-based instruction. Other researchers have claimed that teacher content knowledge, pedagogical knowledge, or knowledge of the nature of science, are major impediments to implementing inquiry (Brickhouse, 1990). For example, Loucks-Horsley *et al.* (2003) claimed that teachers' tendency to use the methods through which they were taught, reliance on textbooks, lectures, and use of cookbook laboratories are challenges to implementing inquiry-based instruction.

Windschitl (2003) found out that inquiry-based activities can be threatening to some teachers who lack experience in conducting scientific research, because inquiry-based activities can produce unexpected outcomes or results, contrary to cookbook kinds of laboratory exercises in which teachers know the outcomes in advance. Hogan and Berkowitz (2000) and Wallace and Kang (2004) found that teacher perceptions of student ability and motivation constrained their dispositions to implement inquiry.

Recent critiques of inquiry teaching in the science classrooms regarding with the distance between students' activities and the ordinary everyday practices of scientists, authentic scientific inquiry. Anderson (2002: 6-7) mentioned the report of Stake and Easley (1978) two decades ago. Of the many classrooms visited in eleven school districts across the country (USA), only three classes were identified where inquiry-based approach was in use. Two major reasons were cited in the case studies for this dearth of inquiry teaching. First, there was a widespread philosophic persuasion in favor of a textbook approach. The textbook was viewed as an authority. Furthermore, teachers were persuaded that learning from a textbook were discipline students needed to master. A second reason was the frustration and difficult problems encountered in implementing inquiry teaching as intended.

Correspond to, Chinn and Malhotra (2002) presented a theoretical framework for analyzing the inquiry tasks in terms of how similar they are authentic science by using the taxonomy of cognitive processes. Six of the fundamental cognitive processes that scientists engage in when they conduct research are 1) generating a research question; 2) designing a study to address the research question; 3) making observations; 4) explaining results; 5) developing theories; and 6) studying others' research. They categorized the inquiry task that found from science textbooks into three types of simple inquiry tasks which they called simple experiments, simple observations, and simple illustrations. From their results, it was found that cognitive processes are employed in authentic science differs from simple inquiry. They argued that inquiry tasks commonly used in schools to be based on an epistemology that differs from epistemology of authentic science. Another feature of the epistemology of authentic science that different is the construction of scientific knowledge through social processes and institutions.

Although students enjoy practical activities, such as lab or field activity, they do not necessarily internalize concepts and principles, and do not necessarily develop positive attitudes to science. Moreover, inquiry teaching should not be confused with merely providing students with a series of hand-on activities. Instead, teachers need to meld inquiry activities with constructivist-oriented discussions to facilitate students building on their current knowledge and revising their understandings (Crawford, 1999).

By considering the combination of factors that influenced teachers in moving towards inquiry-based approach, Crawford (1999) claim that first, teachers' beliefs about science and teaching are an important first step in getting them to think about inquiry-based learning environments. Second, teachers should have opportunities to undertake authentic investigations. Third, teachers are provided models of teaching about scientific inquiry in field placements and/or through videotaped cases. Fourth, teachers are received scaffold in planning long term units that relate to important questions and ink to science content.

Crawford (2000) reported that in an inquiry-based classroom the roles of teacher are not limited to “teacher as facilitator” or “teacher as guide.” Crawford’s study suggested that a teacher’s work in an inquiry-based classroom requires a myriad of teacher roles demanding a high level of expertise. Furtak (2006) examined three teachers and their practice of guided inquiry after participating in training specific to implementing an inquiry-based interdisciplinary program curriculum for middle school students. This study explored the different ways that the three teachers described and managed an activity in a middle school physical science investigation- the Liquids and Vials activity where sinking and floating anomalies were presented. The results of this study indicated that the teachers had difficulty with withholding answers from their students during guided inquiry-oriented activities. The researchers stated that neither curriculum nor the models of guided inquiry teaching provided the teachers how to manage the situation once problems arose. While one teacher managed the problem by treating the investigation as a game, another teacher accepted his students’ ideas without evaluation, and the third spent considerable time rationalizing his teaching strategies to students.

Constructivism

Constructivism primarily is a synthesis of ideas from philosophy, sociology, psychology, and education. In education, constructivism refers to the theories of knowledge and learning that offers explanation of the nature of knowledge, how people construct knowledge and how human beings learn (Brooks and Brooks, 1993). The central idea of the constructivist theory is that knowledge is constructed and learners build new knowledge upon the foundation of previous learning (Hoover, 1996) or understand the world through experiencing things and reflecting on those experiences (Brooks and Brooks, 1993). It holds that knowledge does not have a separate existence from the physical nervous system. It cannot exist in some complete form outside the learner and be internalized, stored, and reproduced at some later time (Wadsworth, 1996).

Constructivism today has an increasingly significant impact on educational reform and is increasingly being adopted as the accepted theory on how children learn (Llewellyn, 2001). The constructivist theory is one theory at the forefront of educational attention today even though there are several theories that explain the learning process. In the National Science Curriculum of Thailand, the constructivist theory is used as a guide in the theoretical framework for science teaching (IPST, 2001). With the rise of cultural psychology, two perspectives of constructivism have become dominant: cognitive constructivism and social constructivism. These are different in emphasis, but they share many common perspectives about teaching and learning.

1. Cognitive Constructivism

Cognitive constructivism is based on the work of Jean Piaget, a Swiss developmental psychologist. He developed the theory based on his views of the psychological development of children. Piaget’s theory provides a framework for understanding how children develop cognitive abilities. There are two major parts: ages of the learners and stages of the component that predicts what children can and cannot understand at different ages. Piaget's theory of cognitive development proposes that humans cannot be given information, which they can immediately understand and use. Instead, humans must construct their own knowledge. They build their knowledge through experience. To learn, Piaget stressed the holistic approach. A child construct understanding through many channels: reading, listening, exploring and experiencing his or her environment (Perret-Clemont, Garugati, and Oates, 2004).

The development of human intellect proceeds through adaptation and organization according to Piaget. Adaptation is a process of assimilation and accommodation. The process of assimilation is the process of external events or phenomena which are interpreted to make sense in accordance with existing internal constructs, while the process of accommodation is the adaptation process of existing internal constructs to correspond to external events or phenomena. Piaget considers that the organization of the mind is accomplished through a series of increasingly complex and integrated ways, of which the simplest one is the scheme such as a mental representation of some action that can be performed on an object. As Piaget identifies knowledge with action, he considers that mental development organizes these schemes in more complex and integrated ways to produce the adult mind (Wadsworth, 1996; Llewellyn, 2001).

Two important main ideas explain constructed knowledge. Firstly, individual learners create or construct their own new understandings through experiencing things and reflecting on those experiences. When they encounter something new, they have to reconcile it with their previous ideas and experience, maybe changing what they believe, or maybe discarding new information as irrelevant. Secondary, learning is active rather than passive. Learners confront their understanding in light of what they encounter in new learning situations. If what learners encounter is inconsistent with their current understanding, their understanding can change to accommodate new experiences. Learners remain active throughout this process: they apply current understandings, note relevant elements in new learning experiences, judge the consistency of prior and emerging knowledge, and based on that judgment; they can modify knowledge (Hoover, 1996; Abdal-Haqq, 1998).

2. Social Constructivism

Lev Vygotsky (1896-1934), a Russian psychologist and philosopher is most often associated with the social constructivist theory (von Glasersfeld, 1995). The basic principle behind social constructivism is that the knowledge is constructed through social interaction, and is the result of social processes (Tobin, 1990). Individual development derives from social interactions within which cultural meanings are shared by a group and eventually internalized by the individual. Individuals construct knowledge in transaction with the environment, and in the process both the individual and the environment are changed. The subject of study is the dialectical relationship between the individual and the social and cultural environment (Cobern, 1993; Abdal-Haqq, 1998).

Another aspect of Vygotsky's theory is the idea that the potential for cognitive development is limited to a certain time span which he calls the "Zone of Proximal

Development" (ZPD). Vygotsky defined ZPD as a region of activities that individuals can navigate with the help of more capable peers, adults, or artifacts. In Vygotsky' view, peer interaction, scaffolding, and modeling are important ways to facilitate individual cognitive growth and knowledge acquisition (Vygotsky, 1978). Therefore, human cognition is considered to include not only individual processes but also social processes. In addition, it is believed that individual and social processes cannot be distinguished and separated. Moreover, social processes are considered to be a priority to individual processes when it comes to high levels of mental functioning.

3. Implications for This Study

In summary, constructivism focuses on knowledge construction, not knowledge duplication. It is a belief that one constructs knowledge from one's experiences, mental structures, and beliefs that are used to interpret objects and events. Constructivism when referred to the learner is a defined a theory of how the learner constructs knowledge from experience, which is unique to each individual**.** Each individual learner uniquely constructs knowledge. Social constructivism focuses on the role that social interaction plays in creating knowledge. Human cognition cannot be thought of as being separate from cultural and social context. Thus, the particular knowledge that is constructed by individuals will be affected by the learner's prior knowledge and experiences and the social context in which learning takes place.

From this perspective of constructivism, students' understanding should be analyzed by considering their activities and action within their classroom and school culture. Throughout this study, I try to explain how students developed understanding both in the NOS and key knowledge of respiration within their social contexts of learning.

CHAPTER III

METHODOLOGY

This chapter describes the methodology used to conduct this study. The first section discusses the methodological perspective in this study. The second section describes the participants and participant selection criteria. It includes a rich description of teachers, students, and context of schools, to provide a context of participants. The third section describes the data collection procedures, specifically interviews, field notes, and concept test. The fourth section describes the data analysis procedure. The final section discusses the issues of trustworthiness of study.

Methodological Perspective

Qualitative research is a broad approach to the study of social phenomena. It is an umbrella concept covering several forms of inquiry that help us understand and explain the meaning of social phenomena. It is pragmatic, interpretive and grounded in the lived experiences of people because qualitative researchers are interested in the complexity of social interactions expressed in daily life and by the meanings that the participants themselves attribute to these interactions. These interests take qualitative researchers into natural setting rather than laboratories (Marshall and Rossman, 2006). In education, qualitative research is viewed as naturalistic because the researcher is visiting the locations where the events under study naturally occur. The data gathered by this method include talking, listening, teaching, and working (Guba, 1978).

Maxwell (2005: 22-24) describes the five intellectual goals for qualitative research as follows:

1. Understanding the meaning, for participants in the study, of the events, situations, experiences, and actions they are involved with or engaged in. The qualitative researchers are interested not only in the physical events and behavior that are taking place, but also in how the participants in their study make sense of these,

and how the understanding of the participants influences their behavior. This focus on meaning is central to what is known as the interpretive approach to social science.

2. Understanding the particular context within which the participants act, and the influence that this context has on their action. Qualitative researchers typically study relatively small numbers of individuals or situations thus they are able to understand how events, actions, and meanings are shaped by the unique circumstances in which these occur.

3. Identifying unanticipated phenomena and influences, and generating new, ground theories about the latter. Qualitative research has an inherent openness and flexibility that allows you to modify your design and focus during the research to understand new discoveries and relationships.

4. Understanding the process by which events and actions take place. Qualitative research seeks to understand how things happen, not only what happens. It is concerned with the process. This does not mean that qualitative research is unconcerned with outcomes, it does emphasize that a major strength of qualitative research is in getting at the processes that led to those outcomes.

5. Developing casual explanations. Qualitative researches tend to ask how x plays a role in causing y and what is the process that connects x to y. This is different from quantitative research that is interested in whether and what extent variances in x causes in y.

This research is guided by qualitative research, based on an interpretive methodology. This methodology aims to understand the meanings people have constructed to be able to make sense of their world and the experiences they have in the world (Behrens and Smith, 1996; Merriam, 1998). It also provides an understanding of the community in terms of the actions and interactions of the participants, from their own perspectives (Tobin, 2000: 487). The interpretive researcher believes that to understand this world of meaning one must interpret it. The inquirer must elucidate the process of meaning construction and clarify what and how meanings are embodied in the language and actions of social actors (Schwandt, 1994:118).

This research purpose is to investigate how an instructional unit that integrates aspects of the NOS using explicit and a reflective inquiry – based approach impacts on students' understanding of the NOS as well as their knowledge of respiration concepts and what ways teachers' teaching practices influence students' understandings of the NOS and respiration concepts. In researcher's view, the students as participants in this research are persons who construct their own knowledge through the teachers' implementation of the unit and interaction with teachers and other students as actions of complex social actors. Thus, this methodology can provide appropriate directions to conduct the research in order to reach the answers to the research questions. This methodology is employed as a framework to find out the meaning of how students construct their understanding of the NOS and knowledge of respiration in specific contexts.

Interpretive research seeks a more holistic view of its subjects. Patton (1990) indicates that in such a holistic view, a description and understanding of a person's social environment are essential for overall understanding of what is observed. When they collect data, they gather not only one perspective and one attribute of the phenomena, but also multiple aspects of the setting under study because interpretive researchers believe that studying only one variable of an individuals' attributes is not enough to understand the meaning people have constructed in a complex and manifested world. They attempt to understand individuals as a whole (Lincoln and Guba, 1985; Bryman, 2001) and use as many kinds of data collection methods as possible, and look for consistency of findings across the different methods. Moreover, the data of multiple aspects provide a comprehensive and complete picture of a particular context. Thus, in this research, a variety of research methods such as, interviews, observations and respiration concept survey can assist in providing a holistic view of what students understand, how they develop their understanding of the NOS and their knowledge of respiration.

Research Method: Case Study

The case study is a common way to do qualitative inquiry. Yin (1994) stated that a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident (p.13). The principal difference between the case study and other research studies is that the focus of attention is on one individual case and not a whole population of cases. In the case study, the focus may not be on generalization but on understanding the particulars of that case in its complexity (Stake, 1995). It is particularly useful when researchers need to understand a unique situation and are interested in gaining insight and interpretation rather than testing a hypothesis. The main aim of the case study is an intensive, holistic description and analysis of a single subject, event, phenomena, or social unit. The case could be a person such as a student, a teacher, a principal, a program or a group such as a class, a school, a community, or a specific policy and so on (Cohen and Manion, 1994; Merriam, 1998).

Merriam (1998: 29-30) describes three major characteristic of the case study as being particularistic, descriptive, and heuristic. Particularistic means that the case study focuses on a particular situation, event, program, or phenomenon. Descriptive means the end product of a case study is a rich, thick description of the phenomenon under study. Thick description is a term from anthropology and means the complete, literal description of the incident or entity being investigated. Heuristic means that case study illuminates the reader's understanding of the phenomenon under study.

The case study does not claim any particular methods for data collection or data analysis. Any and all methods of gathering data, from testing to interview, can be used in a case study, although certain techniques are used more often than others (Merriam, 1998). The case study includes triangulating information from multiple sources of evidence (e.g. observation, interviews, and documents) and collecting rich and detailed contextual data (Yin, 1994).

In this research, the multiple case studies are research method, and it helps the researcher understand the impact of the instructional unit on students in their context.

It also helps researcher understand how students come to an understanding of the NOS and respiration concepts. Case study is used to understand what ways teachers' teaching practices influence students' understandings of the NOS and respiration concepts. Each case of this study consists of a biology teacher and two groups of students at one school. The cases are bounded by time (data collection), place (implementation the respiration instructional unit), and subject (background of teacher and students).

This research carries out the three major characteristics of the case study that were discussed previously. For particularistic, this research focuses on how particular students develop their understanding in a particular context, while engaging in an instructional unit that integrates aspects of the NOS using the explicit and reflective inquiry – based approach. For descriptive, this research attempts to describe contexts and settings. This research obtains information from multiple data sources that explore students' understandings. Multiple data sources are used to provide a holistic explanation regarding the impact of the instructional unit on students' understandings.

According to Merriam (1998: 39), there are three types of case study upon which to base the overall intent of a study: 1) descriptive case study, 2) interpretive case study, and 3) evaluative case study. Descriptive case study is useful for presenting basic information to form a database for future comparison and theory building. Interpretive case study contains rich and thick description which is used to develop conceptual categories. The researcher gathers as much information about the problem as possible with the intent of analyzing, interpreting, or theorizing about the phenomenon. Evaluative case study involves description, explanation, and judgment. In this sense, the case study is evaluative because it provides thick description, is grounded, is holistic and lifelike, simplifies data to be considered by the reader, illuminates meanings, and can communicate tacit knowledge. This research used descriptive and interpretive case study. The data from the case study described students' understanding of the NOS and the respiration concepts while engaging in the respiration instructional unit. Moreover, this data is interpreted from the description to set the patterns of how students develop their knowledge.

Participants and Context of the Study

In this section, I describe the participants including the recruitment process for the participants and descriptions of them.

1. Participant Selection

The participants in this study consisted of two groups, three biology teachers and their students, twenty four students, as primary participants. Using multiple case studies, therefore, one case included one biology teacher and eight students. Three teachers were selected using purposeful sampling (Bogdan and Bicklin, 1998). They were selected using three criteria: a) inadequate understanding of the NOS; b) willingness and volunteer; and c) limited time and expense in conducting the study. These criteria involved their response to questionnaire about their perceptions regarding the NOS and inquiry-based approach. The questionnaire was distributed to biology teachers who taught the respiration topic to level four students in 13 schools of Education Service Area 1, Pranakornsriayutthaya Province during the first of the academic year 2006. From the survey results, ten teachers showed an inadequate understanding of the NOS. However, there were five of ten teachers who indicated that they wanted to develop their teaching for enhancing student understanding the NOS and respiration concepts and volunteered to participate in this study. Because of the limited time for traveling and expenses in conducting the study, three teachers from three schools were chosen. These schools were located not far from each other. This was convenient to collect the data.

Student participants came from the students in class of the teacher participants that were taught the respiration topic. In each class, students were divided into group by using a mix of gender, science process skills and achievements that involved grade point average, grade of biology subject, and teacher evaluation (science process skills). Two groups of students (four students per group) were random selected from one class of each teacher participant to be the student participants in this study. The reason for randomly selecting the student participants was to ensure unbiased selection. Thus, there were 6 groups, twenty four students as student participants.

2. Description of the Participants and Context of the Study

There were three biology teacher participants in this study. There were two female and one male. All teachers taught in a public secondary school in Education Service Area 1, Pranakornsriayutthaya Province, located in the central part of Thailand. For this study, all teachers, students and their school were reported with pseudonyms and symbols because of ethical reason. Table 3.1 shows the pseudonyms and overviews of the teachers' information including school, age, educational background, and teaching experiences of the three biology teachers in the study. Detail of their educational background, teaching experiences, responsibilities, school context and students' information as follows:

Table 3.1 Biology Teacher Information

Teachers	Schools	Age	Academic Background		Teaching experiences (year)	
			Bachelor degree	Master degree	Science	Biology
Pimpan	Tawan	47	Bachelor of Education (Biology)	-	15	15
Sirintip	Wanna	36	Bachelor of Education (Biology)	Master of Education (Science Education)	10	8
Chatchai	Rama	55	Bachelor of Education (Chemistry-Biology)	-	23	15

Pimpan

Pimpan is a 47-year-old, science teacher at Tawan School. She received her Bachelor degree in Education, majoring in biology from Valaya Alongkorn Rajabhat University. She had 15 years experience in teaching science and biology. She taught science and biology 21 hours per week, three classes of grade eight science (9 hours), one class of grade ten basic biology (3 hours) and advanced biology (3 hours), one class of grade eleven advanced biology (3 hours) and one class of grade twelve advanced biology (3 hours). Besides teaching, she was the head of the science department at Tawan School, the financial management officer, and advisor for the eighth grade students.

Pimpan taught the respiration topic in grade 10. There were 31 students, 8 males and 23 females. The student age interval in this study ranged between 16-18 years old. The students' biology grades in the first semester ranged from 1.5 to 4. Two groups of students from this class were randomly selected as primary participants. Each group consisted of four students. Group A had a GPA interval of 2.3-3.93 and a biology grade interval of 2.5-4. Group B had average a GPA interval of 2.5-3.92 and a biology grade interval of 2.5-4. Each student's information is detailed in Table 3.2.

Table 3.2 Grade 10 Student Information for Pimpan's Classroom

Group	Student	Gender	Age	Average GPA	Biology Grade
A	PA1	Female	16	3.93	4
	PA2	Female	17	3.86	4
	PA3	Female	16	2.30	2.5
	PA4	Male	16	2.50	3
B	PB1	Female	17	3.80	4
	PB2	Female	17	3.20	3.5
	PB3	Female	17	3.92	4
	PB4	Male	16	2.50	2.5

Tawan School

Tawan School is categorized a small school with 550 students. It is a suburban school, located in the Nakhornloang district, in Pranakornsriayutthaya Province. In this district, there are two secondary schools the school was a large one. Tawan School was composed of two school buildings and one temporary building. There were two science laboratories that had been adapted from normal classrooms. Science teachers had to reserve to use these rooms. Unfortunately, there was not enough science equipment for the number of students. Some of the equipment was out of order and were not being fixed and the school had no budget to buy new equipment. There was one television for distance learning via satellite in the room. The school had one computer room that had only 15 computers and was also used to teach computer. Students therefore were only able to use this room for short periods of time when the room was free from classes.

Students Context of Tawan School

Most students lived around the school area and were from poor to medium income families with 70% of the parents involved in agriculture. In level 3 (grade 7-9), there were three classes in each grade and there were about 40 students in each class. In level 4 (grade 10-12), there were two classes in each grade including both the science program and general program, with an average of 30 students in each class. After students finished level 3, most of the higher achieving students moved to a larger school in the same district or urban area. Some students moved to vocational college. Thus, most of the students in level 4 were moderate to low achievement students at level 3 and the number of students in the level 4 classrooms were less than in the level 3 classrooms.

Chatchai

Chatchai is 55 years old and he received a Bachelor degree in Education, majoring in chemistry-biology from the Khonkaen University. He is a science teacher at Rama School, in the Tha Ruea District, in Pranakornsriayutthaya Province. He taught science for 32 years and taught biology for 15 years. He taught science and biology for 16 hours per week, two classes of grade eight basic science (6 hours), two classes of grade eight advanced science (4 hours), and two classes of grade eleven biology (6 hours). Besides teaching, he was the advisor of the grade seven students and the school facility manager.

Chatchai taught the respiration topic in grade 11. In the first science program class, there were 37 students, 26 females and 11 males and the student age interval was 16-17. For achievement, the average biology grade interval of students was 1.5 to 4.0 Two groups of students from this class were randomly selected as the primary participants. Each group consisted of four students. Group A had an average GPA interval of 2.70-3.33 and a biology grade interval of 2.0-3.0 Group B had an average GPA interval of 2.40-3.80 and a biology grade interval of 1.5-3.0 Each student's information is detailed in Table 3.3.

Table 3.3 Grade 11 Student Information for Chatchai's Classroom

Group	Student	Gender	Age	Average GPA	Biology Grade
A	CA1	Female	17	3.33	3
	CA2	Female	17	2.86	2.5
	CA3	Female	17	2.82	2
	CA4	Male	17	2.70	2
B	CB1	Female	17	3.0	3
	CB2	Female	17	3.30	3.5
	CB3	Male	17	3.80	2.5
	CB4	Male	17	2.40	1.5

Rama School

Rama School is the largest school in the Tha Ruea District set on 14 acres (36 rai) with a student enrollment of approximately 1,700. The school consisted of five classroom buildings, one multi-purpose building, and three other buildings. Rama School participated in a lab school project thus most students could access learning resources such as the internet and other media. There were six science laboratory rooms, three rooms for science teaching in level 3 (grades 7-9) and three rooms for science teaching in level 4 (grades 10-12), biology, chemistry, and physics. However, in level 4, the science laboratories were adapted from normal classrooms. The biology laboratory was small compared with other the laboratories. The biology lab stored science equipment and had as well a LCD projector, three student computers and one teacher computer in which the internet was accessible. The room also had learning resources in English as well as on topics related to biology such as botany and agriculture.

Students Context of Rama School

Most of the students came from moderate to poor economic status. Sixty percents of parents were agriculturists and twenty percent of parents worked in factories. In level 3 (grade 7-9), there were 10 classes in each grade. Each class had an average 40 students. In level 4 (grade 10-12), there were six classes in each grade, two classes were in the science program, two classes were in the language program, and two classes were in the general program. Each class had an average 33 students. In the science program, students were divided in classes by using student achievement and GPA in level 3. The first science program class students had a GPA of more than 2.5. However, some students who had high achievement scores usually moved to an urban school or got a quota to study in a school that emphasized science.

Sirintip

Sirintip is a 36 year old science and biology teacher at Wanna School in the Wangnoi District Pranakornsriayutthaya Province. She received a Bachelor degree in Education, majoring in biology from Pranakornsriayutthaya Rajabhat University and a Master of Education (science education) from Srinakharinwirot University. She has 10 years experience in teaching science and 8 years experience in biology teaching. She taught science and biology for 21 hours per week, three classes of grade eight science (9 hours), three classes of grade nine science (9 hours), and one class of grade ten biology (3 hours). Other duties included a role as a teacher-counselor and advisor of grade ten students.

Sirintip taught the respiration topic in grade 10. In the grade 10 science program, there were 37 students, 30 females and 7 males. The student age interval was 16-17. The biology grade levels of the students in the first semester were 2-4. Two groups of students from this class were selected as primary participants. Each group consisted of four students. Group A had an average GPA interval of 2.75-3.85 and a biology grade interval of 3-4. Group B had an average GPA interval of 2.60 -3.90 and a biology grade interval of 2.5-4. Each student's information is detailed in Table 3.4.

Table 3.4 Grade 10 Student Information for Sirintip's Classroom

Group	Student	Gender	Age	Average GPA	Biology Grade
A	SA1	Female	16	3.85	4
	SA2	Female	16	3.20	3.5
	SA3	Female	16	2.75	3
	SA4	Male	17	3.21	4
B	SB1	Female	16	3.40	4
	SB2	Female	16	3.90	4
	SB3	Female	16	2.97	3
	SB4	Male	16	2.60	2.5

Wanna School

Wanna School is the biggest school in the Wangnoi District with a student enrollment of 1,100. Most of the students lived in the Wangnoi District while some students lived in the neighboring province of Pathumthanee that was not far from the school. There were three school buildings and two other buildings. Wanna School participated in the lab school project that supported consultants and provided a special budget from the government for learning media. Thus, there were LCD projectors, computers and internet access in certain designated rooms such as science laboratories, the Thai language center room, and the social science center room. There were three science laboratories, a biology, chemistry, and physics lab of which were all adapted from regular classrooms. In each room, besides science equipment, there were two or three computers for students to do word processing and one computer for searching information from the internet and an LCD projector. There were other locations in the school with internet access separate from the designated computer room so researching online was relatively easy for the students to do at school.

Students Context of Wanna School

Most of the students came from moderate to poor families with forty percent of parents involved in agriculture and thirty-five percent working in factories. In level 3 (grades 7-9), there were eight classes in each grade. In level 4 (grades 10-12), there were three classes in each grade; the science program, language program; and general program. There was an average of 34 students in each class of all grades. Most students had a low to moderate level of achievement because most of the high achievement students moved to larger schools in urban areas. Some students moved to vocational colleges or dropped out of school to work in factories or to study in more non formal environments.

Description of the Procedure

This study consisted of two phases which included: a) exploring teachers' understanding of the NOS and inquiry teaching and teachers' teaching of the respiration topic; and b) developing, implementing, and investigating the respiration instructional unit that integrates aspects of the NOS using the explicit and reflective inquiry – based approach.

1. Exploration Phase

In the exploration phase of this study, teachers' teaching in the respiration topic and understanding of the NOS and inquiry-based approach were surveyed through an open-ended questionnaire. The questionnaire was distributed to13 level 4 biology teachers who taught the respiration topic in November 2006. The questionnaire consisted of four parts: 1) teacher demographics; 2) teacher's teaching of respiration; 3) teachers' understanding about the NOS; and 4) teachers' understanding inquiry-based approach. The questionnaires were sent by mail. The researcher included empty envelopes with stamps for the respondents to return the questionnaire. The three teacher participants of this study were selected from the respondents of this questionnaire. After being selected, the three teachers were interviewed to provide more detailed information about their understanding of the NOS, inquiry teaching, and their teaching of the respiration topic. Besides the interview, the researcher asked to observe them while teaching. Pimpan and Sirintip were observed three times each, in May, 2007. Chatchai was observed two times in November, 2007.

2. Development, Implementation, and Investigation Phase

This phase aimed to develop, to implement, and to investigate the impact of the respiration instructional unit that integrated the NOS by using the explicit and reflective inquiry – based approach. The following topics therefore described this phase in detail.

2.1 Developing the Respiration Instructional Unit

The respiration instructional unit was developed to enhance students' understanding the NOS and knowledge of respiration concepts based on integrates the NOS by using explicit and reflective inquiry – based approach. The process required the synthesis of important considerations such as information from analyzed documents such as the National Education Act of 1999, the National Science Curriculum (IPST, 2002), relevant literature, extensive data gathering from surveying teacher understanding of the NOS and inquiry teaching and observing the teachers teaching respiration in their classrooms. The data from surveying the teachers provided the guidance needed to prepare the teachers to implement the respiration instructional unit as well.

After the scope and sequence of the contents and activities in the unit was organized, the unit was validated by experts including three science educators and one scientist. In addition, the unit was piloted within one class of the school of Education Service Area 1, Pranakornsriayutthaya Province that was taught the respiration topic in grade 10, in the first semester of the 2007 academic year, June to August. The researcher asked permission from school administrators and the teachers to implement the unit and interview some students. Later, the lessons were revised.

2.2 Implementing the Respiration Instructional Unit

To implement the respiration instructional unit, three teachers participated in three meetings. The first meeting was constructing the teachers' perceiving about the importance of the integrating the NOS into their teaching, understand the theoretical background in the development of the unit including the NOS and the inquiry-based approach and adapting the respiration instructional unit to correspond with their students and their school's context. During this meeting the researcher presented the teachers with empirical data about inadequate understanding of the NOS and alternative understandings of respiration concepts from literature review. Teachers had opportunities to discuss the NOS in terms of why it is important, how to teach the NOS and inquiry-based approach. Then, the researcher introduced the theoretical background of the respiration instructional unit and led teachers to analyze, to discuss and to revise the unit to best fit with their students and in their school context.

In the second and third meetings, both during and after implementation of the unit, all teachers presented how they taught each unit, what problems they encountered while teaching and how to solve these problems. The members discussed the strengths and weakness of each lesson plan. In second meeting, teachers planned and prepared for any remaining teaching. These discussions also focused on methods of evaluating the impact of the implementation of the unit.

2.3 Investigating the Impact of the Respiration Instructional Unit

At the beginning of the respiration instructional unit student participants completed the respiration concept survey and had follow-up interviews as a pre-test. As well they were interviewed about their understanding of the NOS in general. During implementation six groups of students were interviewed about their activities two times namely after finish; 1) the respiration rate activity and 2) the exploring the gas exchange organ activity. About three months later, at the end of the respiration instructional unit students' participants completed the respiration concept survey as a post- test, follow-up interview, and interview about the NOS. Figure 3.1 shows the implementation of the respiration instructional unit and data collection process of this study.

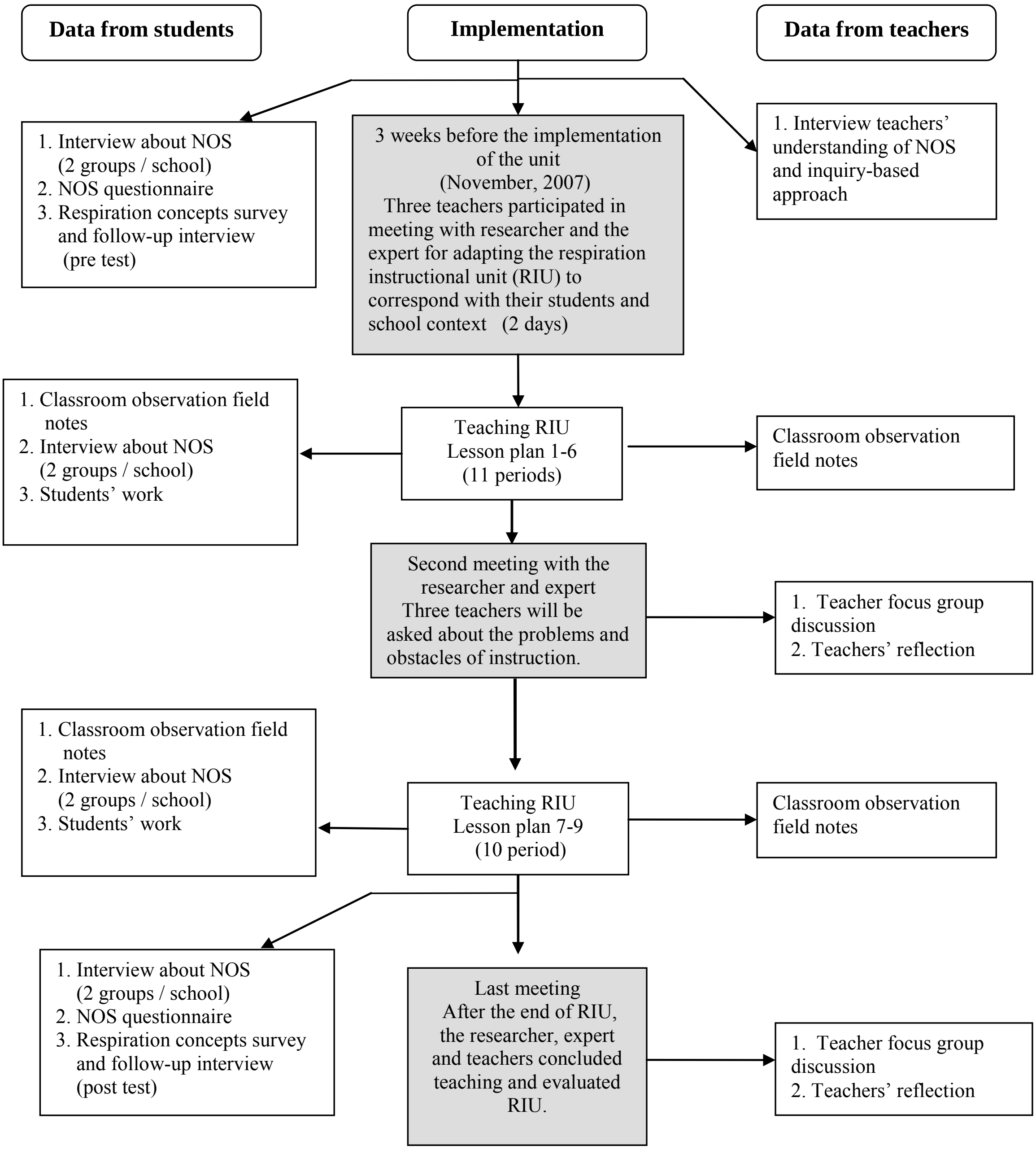

Figure 3.1 Implementation of the Respiration Instructional Unit and Data Collection of This Study.

Data Source

Data sources were chosen on the basis of their congruence with the research purposes and the research questions. The details of data sources were as follows:

1. Interviews

An interview is a purposeful conversation, usually between two people but sometimes involving more, that is directed by one in order to get information from the other (Bogdan and Biklen, 1998: 93). Merriam (1998: 72) indicated that the interview is necessary when we cannot observe behavior, feelings, or how people interpret the world around them. It is also necessary to use the interview when we are interested in past events that are impossible to replicate. Kvale (1996: 105) argued that interviews are particularly suited for studying people's understanding of the meaning of their lived in world, describing their experiences and self-understanding, and clarifying and elaborating their own perspective on their lived in world. According to Merriam and Kvale illuminated the suitability of interviews to investigate understanding. Thus, in this study, the interviews are the main data source for investigating both teachers and student understandings.

Qualitative interviews vary in the degree to which they are structured. There are three main types: structured or standardized, semi-structured and unstructured or informal interviews (Patton, 1990; Merriam, 1998; Corbetta, 2003). A structured interview is sometimes called a standardized interview. The same questions with the same wording and in the same sequence are asked of all respondents. The Nature of questioning route is fixed, given order and very standardized. It would be ideal if the questions could be read out in the same tone of voice so that the respondents would not be influenced by the tone of the interviewer (Gray, 2004: 215). On the other hand, semi-structured interviews are non-standardized and are frequently used in qualitative analysis and are conducted on the basis of a loose structure consisting of open ended questions that define the area to be explored, at least initially, and from which the interviewer or interviewee may diverge in order to pursue an idea in more detail (Merriam, 1998). In this type of interview the order of the questions can be changed depending on the direction of the interview. An interview guide is also used, but additional questions can be asked. The third type of interview, the unstructured interviews or informal interviews are unplanned, non-directed, uncontrolled, unformatted, involve bilateral communications and are flexible. It is more casual than the other interviews method mentioned previously. There is no need to follow a detailed interview guide. Each interview is different. Interviewees are encouraged to speak openly, straightforwardly and give as much detail as possible. The unstructured interview is commonly used in combination with participant observations in the early stages of a case study (Lincoln and Guba, 1985; Merriam, 1998). Bogdan and Biklen (1998) remind us that it is important to focus on the research goal when selecting the specific type of interview for a study. Furthermore, different types of interviews can be employed at different stages of the same study.

This study used semi-structured interviews for both teachers and student interviews. The major aim of these interviews was to gather teachers' understanding and students' understanding. Semi-structured interviews were conducted with each teacher and with each group of students as focus group of interviews that are discussed below. All interviews were recorded, transcribed, and pseudonyms were assigned. The interviews were recorded using an audio-recorder.

1.1 Teacher Interviews about the NOS and the Inquiry-based Approach

Interviewing teachers were employed after they were selected from the respondents of the questionnaire. These interviews were the primary data source about teachers in the exploring phase, while the respondents of the questionnaire from 13 teachers were secondary data source. Three were three main topics discussed in the interviewing: 1) understanding of the NOS; 2) understanding of inquiry-based approach, and 3) their teaching in respiration unit (See Appendix A). The researcher used similar questions from the questionnaire but not in the same sequence depending on how the interview progressed. Teachers were asked to explain in more detail and to give more examples during the interview. The researcher asked for clarification when the teachers mention something that seemed unfamiliar such as "What do you mean?" or "Could you explain that?" The semi-structured interviews were tape recorded to allow the researcher to concentrate on what the teachers were saying and to preserve their exact words for subsequent review, transcription, and reflection (Merriam, 1998). The interviews ranged in length from forty to fifty minutes.

1.2 Student Interview about the NOS

Focus group interviews were used for interviewing student understanding of the NOS. Focus group interviews can be useful in bringing the researcher into the world of the subjects. They were particularly useful in studying adolescents' perspectives on particular issues. When participants reflected together on the same topic, they often stimulate each other to talk about the topics that the researcher can explore later. The groups ranged in size from as small as 4 to as large as 12 and they were selected because they shared certain characteristics relevant to the research questions (Bogdan and Biklen, 1998). Merton, Fiske and Kendall (1990: 137) claimed that the size of the group should not be so large as to be unwieldy or to preclude adequate participation by most members nor should it be so small that it fails to provide substantially greater coverage than that of an interview with one individual.

This method assumed that an individual's attitudes, beliefs, and understandings do not form in a vacuum: people often need to listen to others' opinions and understandings to form their own. Often the questions in a focus group setting are deceptively simple; the trick is to promote the participants' expression of their views through the creation of a supportive environment. The advantages of focus group interviews is that this method is socially orientation and studying participants in an atmosphere that is more natural than artificial experimental circumstances and more relax is better in one to one interview situation (Marshall and Rossman, 2006).

Each student in a group was asked to respond to each interview question. Whenever a student responded to a question or follow-up probe, other students in the group were asked to add to the response and to agree or disagree with that had been said. There were two types of questions for interviewing students' understanding of the NOS: interview questions about the NOS in general and the NOS in activities (See Appendix B). Each group of students was interviewed four times: before, during (two times), and after implementation of the respiration instructional unit. An initial interview and fourth interview used questions as interview questions about the NOS in general. The second and third interview used questions related to student activities to access their understanding of the NOS reflected by their activities. The two activities used for interviewing are described in Table 3.5. The interviews ranged in length from forty to fifty minutes. The data from these interviews was used as evidence to explain student understanding development.

Table 3.5 Topics and Inquiry Activities for Interviewing

Topics	Focus of activity	Description of activity
Respiration rate	- Factors of respiration rate - Experimentation study	After students learned how to measure the respiration rate, the teacher asks the students to think about the factors that impact respiration rate in a brainstorming session. Then, each group chooses one factor to design an experiment. Finally, each group shares their results and conclusion and everyone discusses together.
Gas exchange	- Structure and function of gas exchange organs - Observation study - Observation and inference	The teacher asks students to dissect different animals such as a squid or fish and observe its gas exchange organ structures. One group dissects one kind of animal and then uses their observations to explain the relationship between function of and the structure itself. Each group creates a poster presentation of their animal. After presentation the poster, the students are asked to summarize the general structure of the gas exchange organ that appropriated with exchanging gas.

2. Observation

Observation is a fundamental and highly important method in all qualitative inquiries. It is used to discover complex interactions in natural social settings. Observations entail the systematic noting and recording of events, behaviors, and artifacts (objects) in the social setting chosen for the study. At a minimum, observation involves a researcher watching and listening to actions and events within some context over some period of time, and making a record of what has been witnessed (Patton, 1990; Marshall and Rossman, 2006).

The two main types of observation were participant observation and non-participant observation based on the role of the observer (Patton, 1990; Cohen, Manion, and Morrison, 2000). In participant observation, researchers allow themselves to be immersed in the situation under investigation. This enables them to develop a deeper understanding of the motives and actions of the people they are studying. The researcher is a member of the group, and tries to really understand the insider's views of what is happening in that situation (Patton, 1990). On the other hand, in non-participant observation the researcher stays relatively uninvolved in the social interactions under investigation. In the classrooms in this study, for example, the researcher sat at the back of the classroom and recorded teacher-student discourse by means of a structured set of observational strategies (Cohen *et al.*, 2000).

Recording observation, data obtained from observations can include both oral and visual data (Cohen *et al*., 2000). Techniques employed in observations involve the use of videotape, audiotape, and field notes (Cohen *et al*., 2000: Merriam, 1998). The observational record in this study is frequently referred to as field notes: detailed, nonjudgmental, concrete descriptions of what has been observed. What is written down or mechanically recorded from a period of observation becomes the raw data from which a study's findings are based. Field notes are not scribbles (Marshall and Rossman, 2006). The observer should have explicit note organizing and note management strategies. Even though, formats can vary, a set note usually begins with the time, place, and purpose of the observation. Field notes consist of two kinds of materials. The first is descriptive which provides a word-picture of the setting, people, actions, and conversations as observed. Researchers try to record details of what has occurred in the field as objectively as possible. The other is reflective and this is the part that captures more of the observers' frame of mind, ideas, and concerns (Bogdan and Biklen, 1998)

In this study, the researcher was a non-participant observer, who observed each teacher teaching in both the exploring phase and the implementing phase. In the exploring phase, data from observations were used as secondary sources for exploring teacher understanding of the inquiry-based approach and their teaching practices. Mrs. Pimpan and Mrs. Sirintip were observed three times and Mr. Chatchai was observed two times. During implementation of the unit, from December 2007 to February 2008, the researcher was a non-participant observer, sitting either in the corner or on the side of the classrooms. The researcher observed Mrs. Pimpan a total of 8 times, Mrs. Sirintip 6 times, and Mr. Chatchai 7 times. Observation data was a primary data source and also served to triangulate emerging findings from interviews. During each observation, the researcher looked for evidence within the classroom observation to answer the questions: Does the teacher understand the lesson plan? What part of the lesson plan is enacted, omitted, and/or adapted? How does the teacher use the materials? How does the teacher interact with the students in terms of the nature of science? What ideas about the NOS does the teacher mention or emphasize in the classroom? What is the teacher's behavior that displays inquiry teaching?

The observations were employed in the same processes. The researcher was the non-participant observer, sitting either in the back or on the side of the classroom. At the beginning of the observation, the researcher went into the classroom in order to ensure that the students were familiar with being observed. The teacher introduced the researcher to the students, and explained to the class that they were participating in a research study. Sometimes, with the teacher's permission, the researcher walked around the classroom and observed the students while they were doing laboratory work. The observations were recorded using videotape. By using the videotape recorder, the researcher could collect detailed data of the teaching practices.

Field notes were written during observations and further notes were made as soon as possible after each observation. The format of the field notes consisted of two columns: descriptive and reflective. The empirical data gathered as classroom observation was written as descriptive notes. Reflections, interests, and conclusions made by the researcher were written as reflective notes.

3. Focus Group Discussion in Meeting

There were two times that the focus groups meet and had discussion and each time the group included the three teachers, the researcher, and the science educator. These meetings were set for the teachers to be able to reflect upon their teaching to discuss the implementation of the respiration instructional unit into their classrooms. Each teacher had the opportunity to share ideas about factors that might facilitate or constrain their teaching of the unit. The researcher asked the teachers to think about their practices and their roles in the classroom and the effective of their teaching on the student learning outcomes. These focus group discussions were considered an evaluation of the impact of the implementation the unit.

4. Respiration Concept Survey

The respiration concepts survey was a diagnostic test consisting of seventeen opened-ended questions. This survey was divided into two parts: a) 10 items of a two-tier format and b) 3 open-ended questions to assess the students' conceptions about the meaning and products of respiration, aerobic respiration, anaerobic respiration, respiration in plants, and the relationship between gas exchange and cellular respiration. The first part of each two-tier test item was a true-false content question. The second part of each item contained a set of four or five possible reasons for the answer to the first part. The respiration concept survey can be seen in Appendix C.

Student participants from three classes completed the respiration concept test pre and post they learned the respiration topic. Then they were interviewed after completing the survey. They were asked to recall their thinking at the time they responded to each test item and to explain their ideas. During post interviews, they were also asked to describe how their thinking had changed as a result of instruction. The data from pre-test would be used to create a baseline of students' understanding regarding the respiration and for describing how students develop their understanding.

The respiration concept survey was developed using the following steps: a) the analysis of the learning outcomes of respiration from the IPST Science Curriculum Standards and related document such as biology textbooks and biology teaching manuals; b) the study of related research in respiration concepts and other literature used for defining the content framework with a concept map and a list of propositional knowledge statements; c) one science educator from the Faculty of Education, Kasetsart University and one biology teacher at the Faculty of Science, Kasetsart University reviewed the concept map and the propositional knowledge statements to see if they were accurate and relevant to level 4 students; d) the development of items based on the propositional knowledge statements and adapting questions from the literature. The set of reasons for the two tier formats was constructed which based upon student responses to interviews, open-ended questions and previous research, consisting of identified alternative conceptions and scientifically acceptable answers; e) revision of the survey items after receiving feedback and suggestions from the three experts (two from the Faculty of Education, Kasetsart University and one from the Faculty of Science, Kasetsart University); f) piloting of the survey with grad 10 students who had been taught about respiration to establish the face validity of the survey and to make sure that the survey would be sufficient and appropriate in terms of number of items and time needed for survey completion.

Data Analysis

The purpose of interpretive research, qualitative in general, is to gain a better understanding of human behavior and experience. The most important part of the process was not the data collection but the data analysis, which was where the process of interpretation actually takes place (Patton, 1990). Qualitative data was used for thematic analysis.

1. Thematic Analysis

Thematic analysis is a process for encoding qualitative information. The encoding requires an explicit code. A Theme is a pattern found in the information that at minimum describes and organizes the possible observations and at maximum interprets aspects of the phenomenon (Boyatzis, 1998). Themes or patterns within data can be identified in two primary ways in thematic analysis: an inductive approach (data-driven) and a theoretical approach (theory-driven). An inductive approach means the themes identified are strongly linked to the data themselves (Patton, 1990). In this approach, if the data has been collected specifically for the research, the themes identity may bear little relation to the specific questions that are asked of the participants. They would also not be driven by the researcher's theoretical interest in the area or topic. Inductive analysis is therefore a process of coding the data without trying to fit it into a preexisting coding frame, or the researcher's analytic preconceptions. In this sense, this form of thematic analysis is data-driven. In contrast, a theoretical thematic analysis would tend to be driven by the researcher's theoretical, analytic interest in the area, and is thus more explicitly analyst driven. The researchers begin with his or her theory of what occurs and then formulates the signals, or indicators, of evidence that would support this theory. This form of thematic analysis tends to provide a less rich description of the overall data, and more a detailed analysis of some aspect of the data (Braun and Clarke, 2006). This research employed data-driven thematic analysis.

Steps of the data thematic analysis used in this research are described as the following.

1. Familiarizing data: this step was transcribing the data, reading and re-reading the data, noting down initial ideas. The raw information or data must be in a form that allows easy, repeated review, thus, written material is easier to review repeatedly than audiotape or videotaped material (Boyatzis, 1998). All the data collected is transcribed into the text format. Each of the interviews is transcribed in preparation for analysis. Field notes from the classroom observations and group discussion in meetings are typed using as much detail as possible.

2. Generating initial codes: Coding interesting features of the data in a systematic fashion across the entire data set involves collating data relevant to each code. This step involves the production of initial codes from the data. Codes identify a feature of the data (semantic content or latent) that appears interesting to the analyst, and refers to the most basic segments, or elements, of the raw data or information that can be assessed in a meaningful way regarding the phenomenon (Boyatzis, 1998: 63).

3. Classifying a pattern or searching for themes: This step begins when all data have been initially coded and a related and having a long list of the different codes that identify across the data is set. Essentially, the researcher is starting to analyze codes and consider how different codes may combine to form an overarching theme. The researcher writes the name of each code which a brief description, then organizes them into sub-themes. At the end this step there is now a collection of sub-themes and all extracts of the data have been coded in relation to them.

4. Reviewing themes: Checking if the themes work in relation to the coded extracts and the entire data set. This step begins after devising the set of sub-themes. It involves the refinement of those themes. During this step, it will begin to become evident that some sub-themes are not really themes (if there is not enough data to support them, or the data is too diverse), while others might collapse into each other (two apparently separate themes might form one theme). Other themes might need to be broken down into separate themes.

5. Creating a valid argument for choosing the themes based on the literature review and theoretical framework. This is done by referring back to the literature, and theoretical framework. Once the themes have been collected and the literature has been studied, the researcher is ready to formulate theme statements to develop a story line. When the literature is interwoven with the findings, the story that the researcher constructs is the one that stands with merit. A developed story line helps the reader to comprehend the process, understanding, and motivation of the interviewer.

2. Respiration Concept Survey Analysis

The data from the respiration concept survey and follow-up interviews was analyzed for accessing student understanding of the key concepts of respiration. The method used to analyze the students' responses, through which the conceptual patterns were established, consisted of two steps:

1. Categorization of the conceptions according to the coherence that student answers will vary from survey and interview.

2. Establishment of conceptual patterns from the first step and the use of simple statistical procedures to report the results.

Establishing the Trustworthiness of a Qualitative Research Approach

To establish the quality of qualitative research, Lincoln and Guba (1985) explained that, in place of the traditional ideas of validity and reliability in quantitative research, qualitative researchers substitutes the concept of trustworthiness. The aim of trustworthiness in a qualitative research is to support the argument that the research findings are "worth paying attention to" (Lincoln and Guba, 1985: 290). In any qualitative research, there are four fundamental components that more accurately reflect the assumptions of the qualitative paradigms-credibility, transferability, dependability, and conformability.

1. Credibility

Credibility is compared to the positivist term internal validity which is used to describe the quality of a research study (Lincoln and Guba, 1985). Credibility demonstrates an inquiry process in such a way that the research findings are credible. Lincoln and Guba (1985) and Merriam (1998) suggest several strategies of research inquiry to enhance credibility; a) triangulation by using multiple investigations, multiple sources of data, or multiple methods to confirm the emerging findings; b) prolonged engagement, this refers to the amount of time the researcher is engaged in the research setting and connotes a sufficient amount of time to provide scope and depth to the study; c) member checking, taking data gathering and analyzing processes back to the participant to check that both data gathering and analyzing processes by confirming that the results are plausible; d) persistent observation by identifying issues or elements that are most relevant to the problems; e) peer examination, asking colleagues to comment on the finding as they emerge; f) participatory or collaborative modes of research involving participants in all phases of the research from conceptualizing the study to writing up the findings; and g) researcher bias, clarifying the researcher's assumptions, worldviews, and theoretical orientations at the outset of the study.

2. Transferability

External validity in quantitative research refers to the degree to which the findings of one study can be generalized to other studies. However, within qualitative research study, the term transferability is more appropriate than generalization because there is a weakness of generalizing qualitative findings to other populations, settings, or situations (Marshall and Rossman, 1995). Transferability depends on the degree of similarity between the context of research being studied and contexts of another research. To enhance the possibility of the results of qualitative study generalization, the qualitative research should provide a clear, detailed, and in-depth description so that others can decide the extent to which findings from one piece of research could be transferred and applicable to another situation. In case study research, multiple case studies and cross-case analysis are used to enhance transferability. These two strategies can give a greater variation across the cases. They can generate categories, themes, typologies, or an integrated theoretical framework that can conceptualize and cover all the cases (Merriam, 1998).

3. Dependability

Interpretive researchers introduce the term dependability or consistency as a substitute for the traditional term, reliability (Cohen *et al.*, 2000; Lincoln and Guba, 1985). Reliability refers to the extent to which research findings can be replicated (Merriam, 1998). It is difficult to repeat the inquiry process under similar conditions and yield very similar findings in qualitative research. Because the social context being studied may have changed over time, qualitative research can not generally display reliability in the same way as quantitative research does. Dependability deals with the question of whether the research findings are consistent with the data collected (Lincoln and Guba, 1985). It is also concerned with a large set of factors that are associated with observed changes. To increase dependability, the researcher should describe and explain the assumptions and theory behind the study, how data was collected in detail, how categories were derived, and how decisions were made throughout the inquiry (Merriam, 1998). These processes and products of data collection and analysis should be examined and reviewed by auditors to give the researcher feedback on their points of view of the accuracy (Lincoln and Guba, 1985).

4. Confirmability

Confirmability is similar to the positivist notion of objectivity, which exists when a result of a study and reality are isomorphic; an appropriate methodology is employed; and, a process of inquiry is value-free (Lincoln and Guba, 1985). What is seen as objectivity emphasizes a characteristic of a researcher, while confirmability has moved to be concerned with the data itself (Lincoln and Guba, 1985; Marshall and Rossman, 1995). Confirmability pursues data assurance, interpretations, and outcomes of research in that they are not from the subjectivity among different researchers (Guba and Lincoln, 1989). One of the principal techniques for establishing the confirmability of findings is the audit trail (Lincoln and Guba, 1985). Thus, strategies for enhancing confirmability is asking other researchers or experts to check or audit the data collection, interpretation and analysis procedures and findings and make judgments about the potential for bias or distortion.

5. Trustworthiness in This Study

In this study, trustworthiness was enhanced through the several strategies: prolong engagement, triangulation, peer debriefing, member checking, tick description, and a statement of the researcher’s biases. All are detailed below.

Prolong engagement meant spending sufficient time in the field to learn the context or understand the culture, social setting, or phenomenon of interest, to build rapport and trust with participants, and to minimize distortions. In this study, the researcher was engaged in the setting over a period of several months (May, 2007, November, 2007 through February, 2008). Before collecting data, the researcher had opportunities to talk with each teacher, visit school and procure documents related to the school and students which gave the researcher the opportunity of become more familiar with the research site and meet the student participants. Conversations before and after the interviews showed that the rapport between the researcher and participants was enhanced from those visits. The participants were eager to talk and share their ideas trustfully.

Credibility of this study was further enhanced through triangulation, the use of multiple data sources such as interviews, non-participant observations and group discussion to confirm emerging theory and to explain findings. Data from multiple sources will be analyzed in relation to each other and this served to triangulate the data and to help enhance the credibility of the findings and assertions made. Specifically, student participants were interviewed to gain their understanding regarding the development about the NOS by using two types of questions. Additionally, observation field notes and students worksheets were collected and used to ascertain responses gained through the interviews.

Peer debriefing, as described by Lincoln and Guba (1985), refers to maintaining an external check on the research process by communicating with and utilizing peers to assist the researcher in clearing his or her mind of "emotions and feelings that may be clouding good judgment or preventing emergence of sensible next steps" (p. 308). Peer debriefing assists the researcher in following methodological procedures, in avoiding bias contamination, and in working through interpretations. This is done using a leveled colleague (not with a junior or senior peer) who is outside the context of the study and who has a general understanding of the nature of the study and with whom researcher can review perceptions, insights, and analyses. This research relied on the advisor and committee for peer debriefing.

The member checking process refers to the research participants reviewing a summary of the data analysis procedure and a summary of the final results of the inquiry. Member checking could be accomplished through several methods: summarizing interview content and understandings and asking the participants to verify or correct information, allowing the participants to provide further information, and allowing the participants to challenge interpretations; summarizing understandings from one participant and checking or testing those understandings with another participant; and providing a report of the categories and emerging theory to participants and asking for their written commentaries (Lincoln and Guba, 1985). According to these methods, during interviews, the researcher summarizes points and asks participants to correct them or to share additional ideas that were not covered earlier during the interview. Some information, including biographical sections and teaching and learning perceptions of the teacher description was e-mailed and mailed to teachers for their review and editing.

Thick description, as a credibility technique, assists others in their understanding of the findings in the study and in their assessment of the transferability of the findings to other situations (Lincoln and Guba, 1985; Merriam, 1998). Thick description typically refers to the scope and depth of the description of site and sample selection, of research setting and participants, and of data collection and analysis procedures. Merriam (1998) suggests that transferability (generalizability or external validity) was related to what the reader wants to learn. The researcher thickly describes these aspects of the research procedures to provide the reader with a context for comparison or to decide on the applicability of the research findings to other situations and other populations.

Research biases are important in qualitative research because the researcher is the research instrument. The researcher is the key person in obtaining data from respondents. It is also the researcher who is instrumental in translating and interpreting the data generated from the respondents into meaningful information. Understanding researcher biases could help the reader to have more faith in the research findings and conclusions. As for researcher's biases, a statement of these biases was presented in Chapter 1.

CHAPTER IV

RESPIRATION INSTRUCTIONAL CONTEXTS

In the chapter four, the respiration instructional contexts were described. The respiration instructional unit was developed to enhancing students' understanding of the knowledge of respiration and the NOS in level 4, grade 10-12, in advanced biology, based on the National Science Curriculum of Thailand. The four guiding principles of the unit include students' understanding of the respiration, integration of the NOS using the explicit and reflective approach, inquiry-based approach, and social constructivism as conceptual framework for instructional development as described. Then the expected learning outcomes, content, and activities of each lesson are illustrated.

Four Guiding Principles of the Respiration Instructional Unit

1. The Instruction Students' Understanding the Respiration

From literature review about student understanding the respiration discussed in chapter 2, it was found that students hold alternative conceptions for many respiration concepts, for examples, the meaning of respiration, the purpose of respiration, the role of oxygen in aerobic respiration, and plant respiration. These alternative concepts may come from experiences in real life and the classroom. Moreover, it indicated that the respiration topic was difficult for both students to learn and teacher to teach. Thus, the respiration curriculum is designed to help students to correct their misconceptions through a varieties of inquiry activities and having them continually reflecting upon their understanding. Materials and activities such as videos, computer animations for explaining the cellular respiration process as well as using role play to explain Krebs' cycle are used to support students learning and understanding of the abstract concepts of respiration.

Students were engaged in creating their own model for explaining some the concepts of respiration such as the process of Glycolysis and human breathing and then the students discussed and assessed their model in terms of their explanation. In addition, students had opportunities to connect the respiration concepts into daily live by discussion their activities. These methods were used for assessing student understanding of the concepts and for revising alternative conceptions that occurred.

2. Integrating the NOS by Using Explicit and Reflective Approach

Students understand that the NOS is central to achieving scientific literacy, an important goal of science education reform in many countries including Thailand. Based upon the goals of science education, the development of students' understanding of the NOS is the aim of designing the respiration instructional unit. The NOS should not be separated from teaching science content and should not be taught by implicit approach. Developing the understanding of the NOS does not come naturally (Abd-El-Khalick and Lederman, 2000). Thus, an understanding of the NOS should be considered a cognitive learning outcome and should be taught explicitly rather than expecting it to development naturally during regular science activities (Khishfe and Abd-El-Khalick, 2002).

For the respiration instructional unit, the NOS is integrated into respiration instruction explicitly. The integration of the NOS is based on the National Science Curriculum (IPST, 2002) and involves respiration knowledge. The NOS aspects in the respiration instructional unit are comprised of: a) scientific knowledge is constructed based on evidence, human imagination and observations and inferences of the natural world; b) scientific knowledge is tentative and subject to change; c) diversity of scientific method; e) science is a social activity.

The NOS understanding is intentionally targeted and planned as learning outcome as well as the understanding of the respiration concepts. The explicit instruction of the NOS aspects incorporates elements from inquiry activities and/ or the history of respiration knowledge development. In an explicit and reflective approach, students are provided opportunities to analyze certain the NOS aspects in relation to the inquiry activities in which they are engaged, and reflect upon these activities from within a framework comprising these NOS aspects.

3. Inquiry-based Approach

The inquiry-based approach in the respiration curriculum is based on five essential features of classroom inquiry of the NRC (2000) namely learners make observations, pose questions, and examine books and other sources of information to see what is already known. Based on their observations, learners plan investigations, review what is already known in light of experimental evidence, and use tools to gather, analyze, and interpret data. Finally, learners propose answers, explanations and predictions, and communicate the results. Students in inquiry-based settings are more actively involved in their own discovery and subsequently have more responsibility for their learning. Teachers using inquiry-based instruction play more of a facilitator role than teachers in traditional settings.

For the respiration curriculum, students are engaged in three types of inquiry namely structured, guided, and open inquiry. Even though, open inquiry is authentic scientific inquiry, it is not feasible for all inquiries in the instruction to be open inquiry because teachers and students are new to this approach. The inquiry activities of the respiration instructional unit begin with structured inquiries and transition to more open inquiry activities. Teachers and students may need practice to get comfortable with learning experiences that require less guidance and fewer teacher interventions.

4. Constructivism

Constructivism is a learning theory inherent in the development of the respiration instructional unit which included cognitive constructivism and social constructivism (discussed in chapter 2). The importance of the constructivist theory is knowledge construction which states that knowledge cannot be transferred intact from the head of a teacher to the heads of students. Constructivist theory believes that one constructs knowledge from one's experiences, mental structures, and beliefs that are used to interpret objects and events. The mind is instrumental and essential in interpreting events, objects, and perspectives on a base that is personal and individualistic. Thus, learning is an internal process and is influenced by the learner's personality, prior knowledge and the social context in which the learning takes place. In this theory, the emphasis is placed on the student rather than the teacher. Teachers are seen as facilitators or coaches who assist students to construct their own conceptualizations and solutions to problems. The teachers become facilitators or coaches who guide or assist students to construct their own conceptualizations and solutions to problems. Teachers provide bridging or scaffolding, help extend the student's zone of proximal development (Brooks and Brooks, 1993).

Prior knowledge of the students is important for learning from constructivist perspectives. When teachers are familiar with a students' prior knowledge they can provide learning experiences to build on these existing understandings. The processes of eliciting and activating students' prior knowledge is the initial activity in each lesson of the respiration instructional unit including asking students what they know, brainstorming, pretest, and concept mapping. According to constructivist perspectives, students should be given opportunities to construct knowledge through their own experiences. They cannot be told by the teacher. There is more emphasis on learning in a meaningful context.

From social constructivist perspectives, students learn through working collaboratively on activities in a small group of four or five students, which give students the opportunity to interact with their peers that help to extend the student's zone of proximal development. They are responsible for investigating and presenting their findings to the class. More generally, collaborative learning should be seen as a process of peer interaction that is mediated and structured by the teacher.

The Respiration Instructional Unit

1. Description

The respiration curriculum is allotted 7 weeks, 3 hours per week for a total of 21 hours, in level 4 (grades 10-12) for advanced biology. According to, the goals of education, it is preparing citizens to live in a science and technology society as science literate person. The outcome of the respiration curriculum is the development of student understanding of the NOS and the knowledge of respiration concepts. This instructional unit includes a unit on cellular respiration with the allotted time of 14 hours and gas exchange with the allotted time of 7 hours. These topics and with the allotted time of the NOS that have been integrated in this unit are emphasized in the National Science Curriculum of Thailand as part of three science sub-strands:

Sub-strand1: Living Things and Living Processes; Standard Sc 1.1: explains that students should be able to understand the foundations of living things the relationship between structure and functions of various systems that work together, carry out investigative processes, communicate what is learned and apply the knowledge for one's own existence and to care for other living things.

Sub- strand 2: Life and Environment; Standard Sc 2.2: Understand the importance of natural resources, the utilization of resources at local, national and international levels, and the application of knowledge in sustainable management of natural resources in the local environment.

Sub- strand 8: Nature of Science and Technology; Standard Sc 8.1: Understand the NOS and nature of technology and appreciate the interaction between science, technology and society.

The approach of the respiration curriculum is the explicit and reflective inquiry-based approach that is effectiveness from a review of the literature. The respiration instructional unit consists of three parts. The first part is a teacher manual including the principles, learning outcomes, instructional direction, and advice. In addition, the teachers' manual is designed to help teachers understand the pedagogical approach, the explicit-reflective inquiry-based approach that is required to make this an effective instructional unit. The second part is the lesson plans that cover respiration and the NOS. Each lesson plan consists of objectives (knowledge, attitude, and processes), content, activities, materials, assessments methods, and time allotments. The last part is the student worksheets.

2. Expected Learning Outcomes

2.1 Cellular Respiration Unit

Students should be able to:

1. Explain the meaning of cellular respiration and the knowledge of cellular respiration regarding the key components and cellular respiration purposes.

2. Make comparison between respiration and combustion.

3. Differentiate between cellular respiration and breathing.

4. Distinguish aerobic respiration and anaerobic respiration with regards to the amounts of energy released, the environment, and the organisms.

5. Explain the evidence that leads to a conclusion of the cellular respiration equation.

6. Investigate the factors that effect to the rate of cellular respiration.

7. Apply the knowledge of respiration to explain the results of using drugs or medicine or chemical substances that affect the rate of respiration.

8. Understand how scientific knowledge is developed and acquired.

9. Understand range of scientific methods to develop scientific knowledge.

10. Understand how the knowledge of respiration had changed over time.

2.2 Gas Exchange Unit

1. Understand gas exchange in animals, plants, and microorganisms.

2. Analyze the general requirements for a respiratory surface and list the variety of respiratory organs that have adapted to meet them.

3. Comprehend the different modes of exchanging gases with the external environment, for moving gases throughout the internal environment and for excretion of body wastes.

4. Understand the mechanism of how we breathe in oxygen and breathe out carbon dioxide.

5. Differentiate between breathing and gas exchange.

6. Analyze the relationship between the factors affecting physical respiration (e.g. breathing, lung capacity, the number of stomata) and getting energy at the cellular level.

7. Understand how scientific knowledge is developed and acquired.

8. Understand the range of scientific method to develop the scientific knowledge.

9. Understand how the knowledge of respiration has changed over time.

3. List of Respiration Concepts

3.1 Definition of Cellular Respiration

Cellular respiration is the chemical process by which organic compounds release energy, carbon dioxide and water. The energy released is trapped in the form of ATP for use by all the energy-consuming activities of the cell.

3.2 The Cellular Respiration Concepts

Aerobic Respiration

Aerobic respiration is the normal form of a process in which glucoses are broken down and oxidized to provide energy which requires oxygen in living organisms. The cellular respiration processes are divided into three metabolic processes: glycolysis, the Krebs cycle, and the electron transport chain.

- The site of aerobic respiration processes: Glycolysis occurs in the cytosol. The Krebs cycle takes place in the matrix of the mitochondria. Oxidative phosphorylation via the electron transport chain is carried out on the inner mitochondrial membrane.

- Glycolysis is a metabolic pathway that is found in all living organisms and does not require oxygen. The process converts one molecule of glucose into two molecules of pyruvate, and makes energy in the form of two net molecules of ATP.

- The Krebs cycle is a cyclical series of steps in which pyruvate is oxidized through the mediation of several organic acids. When oxygen is present, acetyl-CoA enters the citric acid cycle inside the mitochondrial matrix, and gets oxidized to CO_2 while at the same time reducing NAD to $NADH_2$. Two waste products, H_2O and CO_2 are created during this cycle.

- Electron transport chain is the process in which ATP synthesizes from oxidation-reduction reactions and such synthesis is called oxidative phosphorylation.

Anaerobic Respiration

- Anaerobic respiration or fermentation does not require oxygen but releases much less energy per mole of glucose.

- Anaerobic respiration consists of two metabolic pathways: Glycolysis and fermentation. Both of these occur in the cytosol.

- Two fermentation pathways are found in Eukaryotic organisms: alcoholic fermentation and lactic acid fermentation.

- Alcoholic fermentation is the conversion of sugar into carbon dioxide and ethyl alcohol. This process is done by yeast and some kinds of bacteria. Alcoholic fermentation begins after glucose enters the cell. The glucose is broken down into pyruvic acid which is the glycolysis process. This pyruvic acid is then converted to CO_2, ethanol, and energy for the cell.

- Lactic acid fermentation is done by some fungi, some bacteria and sometimes by our muscles. In the process of lactic acid fermentation, after the glycolysis process, the pyruvic acid molecules are turned into two molecules of lactate, which combines with hydrogen ions to form lactic acid.

3.3 The Purposes of the Cellular Respiration concept

Respiration serves two major purposes:

1. To provide energy in the form of ATP and NADH needed for maintaining reactions and growth.

2. To provide a carbon skeleton for the synthesis of metabolic intermediates, both in primary (amino acids, protein, nucleic acid, storage, etc.) and secondary (terpenes, phenylpropanoids, isoprenoids, flavanoids).

3.4 Rate of Cellular Respiration Concept

The rate of any reaction can be determined by measuring the rate at which the substrates disappear or the products appear. Thus, the rate of respiration can be determined by measuring the amount of the product produced over time, CO_2.

3.5 Gas Exchange Concepts

Definition of Gas Exchange

Gas exchange is the exchange of oxygen and carbon dioxide across a respiratory surface by diffusion. It takes place at a respiratory surface - a boundary between the external environment and the interior of the body. For unicellular organisms the respiratory surface is simply the cell membrane, but for large organisms it usually is carried out in respiratory systems.

Gas Exchange in Animals

The respiratory surfaces of terrestrial and aquatic animals are moist to maintain the cell membranes and thus gases must first dissolve in water. Most reptiles and all birds and mammals rely entirely on lungs for gas exchange. Ventilation is much more complex in birds than in mammals. Besides lungs, birds have eight or nine air sacs that do not function directly in gas exchange, but act as bellows that keep air flowing through the lungs. The system in birds completely exchanges the air in the lungs with every breath. Therefore, the maximum lung oxygen concentrations are higher in birds than in mammals.

Gas Exchange in Plants

Plants have no specialized organs for gas exchange. There are many ways that each living cell in the plants performs gas exchange. For example, the exchange of oxygen and carbon dioxide in the leaf occurs through pores called stomata. Most of the living cells in a plant have at least part of their surface exposed to air. The loose packing of parenchyma cells in leaves, stems, and roots provide an interconnecting system of air spaces.

The Respiratory System in Humans

A respiratory system was a group of organs working together to bring about the exchange of oxygen and carbon dioxide with the environment.

- Mechanism of breathing: ventilation is the mechanics of breathing in and out. Inhaling, muscles in the chest wall contract, lifting the ribs and pulling them outward. The diaphragm at this time moves downward enlarging the chest cavity. Reduced air pressure in the lungs causes air to enter the lungs. Exhaling reverses theses steps.

- Lungs: the primary function of the lungs involves the transfer of oxygen from inhaled air into the blood and the transfer of carbon dioxide from the blood into the exhaled air.

4. The Nature of Science Concepts

1. Scientific knowledge is based on empirical evidence and/or derived from observations of the natural world.

2. Human imagination and logical reasoning contribute to create scientific knowledge based on observations and inferences of the natural world.

3. Scientific knowledge is socially constructed, and thus includes cooperation, collaboration, and competition.

4. Scientific knowledge is tentative and subject to change.

5. Scientific methods are diverse. The diversity in methods stems from the differences among scientific disciplines, as they explore different kinds of phenomena.

6. Science is social activity, both influencing and responding to social need. The values of the culture determine what and how science is conducted, interpreted, accepted, and utilized.

5. Outline of the Respiration Instructional Unit

The respiration instructional unit includes two sub-units: the cellular respiration unit and the gas exchange unit.

5.1 The Cellular Respiration Unit

In this unit, students learn the meaning of respiration that scientists use and understand when they talk about it. They learn about how organisms produce the energy that they get from food or nutrients at the cellular level. They learn the roles of oxygen, how the cellular metabolic processes change glucose into carbon dioxide and energy, and the form of that energy. They learn the biochemistry of both aerobic respiration and anaerobic respiration.

Most importantly, development students develop a more sophisticated understanding the NOS in the context of respiration. They learn how the body of knowledge about respiration is developed, including the evidence that supports the evolution of scientist's knowledge of respiration through historical documents, discussion, models and experiments. The distinction between observation and inferences is highlighted in the Black box activity before they learn the cellular metabolic processes. They discuss about the meaning of experiments, the diversities of scientific methods, and science as a social activity after they learn the history of respiration and conduct experiment regarding the factors that effect respiration rate.

The cellular respiration unit is comprised of four lesson plans:

- Lesson plan 1: History of the development of respiration knowledge
- Lesson plan 2: Aerobic respiration
- Lesson plan 3: Anaerobic respiration
- Lesson plan 4: Respiration rate

5.2 The Gas Exchange Unit

In this unit, students learn about gas exchange in animals, plants, and micro organisms. They learn the mechanisms of how we breathe in oxygen and breathe out carbon dioxide. They learn how this process relates to getting energy at the cellular level. Each organism has different mechanisms to acquire oxygen and get rid of carbon dioxide. They have the chance to relate structure and function. In other words, they learn how a part of the body is structured in relation to how it functions. The NOS is emphasized in developing their understanding about the dissection studies, the distinction between observation and inferences, and that science is a social activity.

The Gas exchange unit is comprised of three lesson plans:

- Lesson plan 1: Structure and function of gas exchange organ
- Lesson plan 2: Lungs and the mechanism of breathing
- Lesson plan 3: Relationship between external and internal respiration and other systems

The overview of each lesson includes objectives, focus of the lesson plan in the respiration concepts and the NOS. Table 4.1 shows the overview of the lesson plans in the cellular respiration unit and table 4.2 shows the overview of the lesson plans in the gas exchange unit.

Table 4.1 Framework of the Cellular Respiration Instructional Unit

Lesson plans (time)	Objectives	Focus of lesson plans		Description of activities
		Respiration concepts	**NOS**	
History of respiration knowledge development (2 hours)	1. Explain the meaning of cellular respiration 2. Compare between respiration and combustion. 3. Differentiate between cellular respiration and breathing. 4. Explain the evidence that lead to conclusion of cellular respiration equation. 5. Examine scientists work and create knowledge from evidence and adjust knowledge from scientist society.	- Meaning of respiration	- Scientific knowledge base on empirical evidence - Scientific knowledge is socially constructed - Scientific knowledge is tentative	**Activity 1:** beginning of respiration - Students share ideas about the meaning of respiration, the processes, and the place that respiration occurs. - Students read the beginning of the explanation regarding the purpose of respiration from the Galenic Doctrine of the 16th century. - Students discuss about the definition of respiration. **Activity 2:** combustion and respiration - Each group investigated how scientists know about the gas component of carbon dioxide in the air we breathe. - Each group watches the VDC demonstration about the oxygen. - Students discuss about the different meaning among combustion, respiration and breathing, and how scientists inquiries about respiration from studying the history of the knowledge of respiration including the history of discovery oxygen and carbon dioxide and the relationship between respiration and combustion. - Write the cellular respiration equation and add details about where each come from what process and/ or the evidence that shows each component exists.

Table 4.1 (Continued)

Lesson plans	Objectives	Focus of lesson plans		Description of activities
		Respiration concepts	**NOS**	
Aerobic respiration (6 hours)	1. Explain the knowledge of cellular respiration regarding the key components and the cellular respiration purposes. 2. Describe the structure of an ATP molecule and locate, within the structure, high-energy bonds. 3. Trace and understand the steps of glycolysis, the conversion of glucose to pyruvic acid, the sequence in the Krebs cycle. 4. Trace how each step of cellular respiration leads into oxidative phosphorylation. 5. Describe the process of the electron transport chains	- Aerobic respiration - ATP - Glycolysis - Krebs cycle - Electron transport chain - oxidative phosphorylation - substrate phosphorylation	- Scientific knowledge is based on empirical evidence - Human imaginations and logical reasoning contribute to create scientific knowledge based on observations and inferences of the natural world. - Scientific knowledge is socially constructed - Scientific knowledge is tentative - Scientific methods are diverse - Science is a social activity	**Activity 1**: Mystery box - Teacher assigns each group to figure out what is inside the mystery box and then give the reasons for their answer. - Students discuss the differences between observation and inferences. - Teacher relates this activity with the evidence that shows the existence of oxygen and carbon dioxide that lead to the difference between observation and inference and how scientists study the chemical processes. **Activity 2**: Overview of cellular respiration - Students observe yeast respiration in a flask that is covered with a balloon and predict how the size of the balloon will change over time. - Review with students about the cell and mitochondria - Discuss the differences and similarities between mitochondria from different tissues, the number of mitochondria and relate this to their tissue function. - Students learn the overview of aerobic respiration processes related to the place that each step occurs and the products of each step.

Table 4.1 (Continued)

Lesson plans	Objectives	Focus of lesson plans		Description of activities
		Respiration concepts	**NOS**	
Aerobic respiration (6 hours)	6. Understand the role of oxygen in the electron transport chains. 7. Explain how the energy gradient across the inter-mitochondrial membrane is created, and why this gradient is important. 8. Understand how scientists study the chemical process. 9. Relate experience to understand that scientists attempt to explain and interpret nature based on evidence. 10. Understand how scientific knowledge is acquired and changed			**Activity 3:** Glycolysis - Students share ideas about the relationship between respiration oxygen and blood energy after reading the article about blood doping of athletes. - Have students play the Glycolysis activity - Students learn and discuss how scientists' inquiry of glycolysis including the discovery of intermediate compound and enzymes was developed by different scientists. - Students learn the glycolysis by discussing the chemical processes with teachers. - Have students make a poster showing the steps in Glycolysis and discuss about their poster in terms of the correct concepts of Glycolysis. **Activity 4:** Krebs cycle - Reviews the products and the site of glycolysis. - Students read the article to learn the development the Krebs cycle and discuss about scientific knowledge construction. - Students trace the step of Krebs cycle by a role play activity. - Students discuss about the relationship between glycolysis and Krebs cycle, the appropriate mitochondrial structure.

Table 4.1 (Continued)

Lesson plans	Objectives	Focus of lesson plans		Description of activities
		Respiration concepts	**NOS**	
Aerobic respiration (6 hours)				**Activity 5**: Electron transport chain and Oxidative phosporylation - Review the Krebs cycle in terms of where the intermediate energy carriers NADH and$FADH_2$ are given off. - Teacher explains electron transport by using diagrams, animation and asks the questions - Have students answer the questions in topic: the energy of carbohydrates - Ask students about the other energy resources: proteins and fats. Teacher discusss with students about the pathway of protein and fats to enter cellular respiration. - Have students make posters of the process of cellular respiration.

Table 4.1 (Continued)

Lesson plans	Objectives	Focus of lesson plans		Description of activities
		Respiration concepts	**NOS**	
Anaerobic respiration (3 hours)	1. Explain the steps of anaerobic respiration both alcoholic fermentation and lactic acid fermentation 2. Investigate and observe aerobic and anaerobic respiration of yeast in an enclosed fluid environment. 3. Distinguish aerobic respiration and anaerobic respiration in terms of the relative amounts of energy released. 4. Describe the importance of anaerobic fermentation in ensuring the continued production of ATP as long as it is required and glucose is available.	- Anaerobic respiration meaning - Lactic fermentation - Alcoholic fermentation	- Diversity of scientific methods - Scientific knowledge based on empirical evidence	**Activity 1**: Alcoholic fermentation - Students share idea about food fermentation in real life such as in bread, beer, and yogurts. - Have students discuss about the scientific method - Have students investigate and observe respiration of yeast in a flask that is covered with a balloon in two environments, with oxygen and without oxygen. - Students discuss with teacher about alcoholic fermentation in detail - Have students compare their work and scientists' work and discuss the scientific method and the importance of evidence in science. **Activity 2**: Lactic acid fermentation - Teacher shows pictures of teeth decay. Have students read the article, sugar and tooth decay. Ask questions that relate to lactic acid fermentation. - Students write the steps of lactic fermentation. - Teacher asks and discusses how to make yogurt using lactic fermentation. Teacher asks students to explain lactic fermentation in yogurt.

Table 4.1 (Continued)

Lesson plans	Objectives	Focus of lesson plans		Description of activities
		Respiration concepts	NOS	
Anaerobic respiration (3 hours)	5. Apply the knowledge of cellular respiration to explain the result of using drug or medicine or chemical substance that effect to respiration. 6. Understand range of scientific method to develop the scientific knowledge.			**Activity 3**: Results of chemical to cellular respiration - Review the cellular respiration - Assign each group to answer the question about the results of chemical respiration in real life that affects the cellular respiration and present their answer to the class for discussion.
The rate of respiration (3 hours)	1. Plan an experiment to measure the rate of respiration 2. Experiment with the factors that affect the rate of respiration. 3. Understand the meaning of experimentation 4. Relate experiences to understand that scientists attempt to explain and interpret nature based on evidence.	The rate of respiration Factors that affect the rate of respiration	- Scientific knowledge is based upon empirical evidence - Human imagination and logical reasoning contribute to developing scientific knowledge based on observations and inferences of the natural world. - Scientific knowledge is socially constructed. - Diversity of scientific method - Experimentation	**Activity 1**: Measure the rate of respiration - Student share ideas about measuring of the rate of any reaction and how to measure the rate of cellular respiration - Have students investigate the measuring the rate of yeast respiration by counting bubble. - Students share ideas about the factors that affect to the rate of respiration and then choose one factor for planning an experiment in which to study that factor. - Students discuss the meaning of experiment, diversity of scientific method, and how scientists work differently from their work.

Table 4.2 Framework of the Gas Exchange Unit

Lesson plans (time)	Objectives	Focus of lesson plans		Description of activities
		Respiration concepts	NOS	
Structure and function of gas exchange organ (3 hours)	1. Describe the general requirements for a respiratory surface and list the varieties of respiratory organs that have adapted to meet them. 2. Present data publicly, cooperating as a team, and evaluating alternative explanations. 3. Understand range of scientific method in developing the scientific knowledge. 4. Understand how to develop scientific knowledge	- Gas exchange meaning - The general requirements for a respiratory surface - Gas exchange in animals - Gas exchange in plants	- Diversity of scientific method: dissection - observation and inference - Scientific knowledge is socially constructed.	**Activity 1**: Gas exchange organs - Students share ideas as to how each organism takes in oxygen and diffusion. - Each group chooses an animal that they are interested in dissecting such as a fish, squid, prawn and crab. - Each group shows the organs for they think are in gas exchange and describe their reasons for their choice then make a poster to present to the class. - Students summarize the general characteristics of an organ that is effective for gas exchange. - Students discuss how plants exchange gas. - Have students relate their experiences to how scientist working, and compare and contrast a dissection and experimentation and between observation and inference.

Table 4.2 (Continued)

Lesson plan (time)	Objectives	Focus of lesson plan		Description of activities
		Respiration concepts	NOS	
Lungs and mechanism of breathing (2 hours)	1. Observe the trachea, bronchi, bronchioles, and alveoli of animal lungs and how the lung inflates by blowing air down a trachea with plastic tubing. 3. Measure lung capacity and explore factors that affect the amount of air the lungs can hold. 4. Explain how lungs work, the structure and surface, and relate it to other organs in respiratory system. 5. Make a model to explain the mechanism of breathing. 6. Understand the range of scientific method used to develop scientific knowledge. 7. Understand how to develop scientific knowledge	- Structure and function of lungs - Breathing: meaning and mechanism - Lung capacity	- Diversity of scientific method - Scientific knowledge is based on empirical evidence. - Human imagination and logical reasoning contribute to create scientific knowledge based on observations and inferences of the natural world.	**Activity 1:** the human lung - Students share ideas about the respiratory system, gas exchange, and structure and function of lungs. - Each group chooses the factor that they think relates to lung capacity such as sex, weight, age. All of students write their name, weight, age and height on a board and measure the capacity of their lungs and then each group plots on a graph from data gathering. - Students observe pig lungs including trachea, bronchi, bronchioles, and alveoli and how the lungs inflate by blowing air down the trachea with plastic tubing. - Students calculate the surface area of different sizes of papers to relate with the relationship between surface and the number of alveoli. - Have students relate their experiences with using evidence to support their ideas and scientific knowledge. - Remind students to think about diversity of scientific method and share ideas about their work as experimentation or not, give reasons to support their ideas.

Table 4.2 (Continued)

Lesson plan (time)	Objectives	Focus of lesson plan		Description of activities
		Respiration concepts	NOS	
Lungs and mechanism of breathing (2 hours)				**Activity 2**: Mechanism of breathing: Lungs and diaphragm - Students share ideas about the differentiation between breathing and gas exchange, and how we breathe. - Have students make a model of a lung and then teacher explains the mechanism of breathing using the student model and diagrams. - Have students create their lung model to explain what happens when lungs are diseased or abnormal - Have students describe in detail the relationship among lungs, gas exchange and cellular respiration regarding the path of oxygen from the atmosphere into the lungs, through the body, and back out to the atmosphere. - Have students relate their experiences with those of scientist working and the importance of human imagination, creation and logical reasoning as it contribute to create scientific work.

Table 4.2 (Continued)

Lesson plan (time)	Objectives	Focus of lesson plan		Description of activities
		Respiration concepts	**NOS**	
Relationship between external and internal respiration and other systems (2 hours)	1. Review the primary processes involved in cellular respiration in the context of physical exercise. 2. Explain how gas exchange supplies oxygen for cellular respiration and disposes of carbon dioxide. 3. Determine their respiratory rate and explore the factors that affect breathing rate. 4. Present data publicly, cooperating as a team, and evaluating alternative explanations. 5. be aware of the importance of cooperation, collaboration, and competition in scientific work.	- Relationship between external respiration and cellular respiration	- Scientific knowledge base on empirical evidence - Scientific knowledge is socially constructed	**Activity 1:** Exercise and respiration - Providing students an opportunity to think about the cellular respiration and write everything that they understand. - Each group solves problems focused on various inhibitors of respiration. - After each group completes their questions, have students compare answers, and then present their answers with evidence that supports their answer. - Have students relate their experiences, using evidence to support their ideas with scientific knowledge based on evidence. - Students compare their work with scientists work in terms of cooperation, collaboration, and competition.

CHAPTER V

CURRICULUM IMPLEMENTATION

This chapter discusses the implementation of a respiration curriculum to level 4 students in three classes from three schools. This chapter is divided into two sections. The first section describes three cases in a separate sub-section. Each case includes a general teacher's background, a description of teacher understanding about the NOS and inquiry teaching, teaching of respiration before implementation, the implementation of the respiration instructional unit that includes the students' understanding of the NOS and key concepts of respiration knowledge and a description of teachers' teaching practices. The second section presents the cross-case analysis.

Case Study One: Pimpan and Students

1. General Teacher' s Background

Pimpan is a forty-seven year old, biology teacher at Tawan School. She completed a Bachelor degree of Education, majoring in Biology from Valaya Alongkorn Rajabhat University, former named Petchburi Vitthaya Longkorn Teacher College, in 1985. In 1986, she began teaching at an elementary school in the Northeast for four years. In 1990, she shifted to teaching science and biology at one secondary school in the central part of Thailand for eight years and then moved to the school where she is currently teaching. At the time of this study, she had 16 years experience in teaching science and biology. She is married and has two sons.

Pimpan decided to be a teacher because she loved to teach students, to talk and to work with them. Pimpan thought that the aims of science teaching were for students' achievement in science content and scientific process skills. She said that "I hope that my teaching will make students get science knowledge and scientific skills. They should have scientific knowledge for passing examinations to study at a university level. Most importantly, they can use scientific process skills in real life. It is very useful for them." (Pimpan interview, October, 2007)

For teaching science, Pimpan gave the meaning of teaching as transferring science content knowledge to students and training students in scientific process skills. However, she said that her teaching methods were lecture, homework, and worksheets with some hands-on activities. She accepted that her teaching style was not effective and wanted to improve her teaching and to learn how to teach science effectively. During five years, she had the opportunity to attend professional development programs on teaching and learning as follows: 1) developing school science curriculum for three times, 2) authentic evaluation, and 3) enhancing biology content knowledge. She said that the professional development program on biology content knowledge was useful for her and helped her teach confidently.

2. Teacher' s Understanding of the NOS and the Inquiry-based Approach and Her Practices before the implementation of the unit

In this section, two topics of Pimpan's understanding are presented as the understanding of the NOS and the inquiry-based approach. These understandings are the results of an interview before the implementation of the respiration instructional unit.

2.1 Understanding of the NOS

Pimpan's understanding of the NOS is presented in six aspects of the NOS: scientific knowledge based on empirical evidence, scientific knowledge as socially constructed, science as social activity, the role of creativity and imagination, the tentative nature of science, and the diversity of scientific method. Pimpan's understanding of the NOS in each aspect is placed in the categories adapted from Lederman *et al*. (2002) and Khishfe and Lederman (2006) as shown in Appendix A. The categories are naïve, informed, and mixed understanding. The mixed understanding means the responses as incomplete explanations of informed understanding or some explanation was naïve understanding. For example, one participant explains that all scientific knowledge can change because of new data or evidence. However, the same participants do not explain that scientific knowledge is changed from reinterpretations of existing data or he/she responds that the knowledge of cellular respiration cannot change.

As a result, Pimpan held informed understanding of two aspects of the NOS as scientific knowledge based on empirical evidence and science as social activity. Other aspects that Pimpan held mixed understanding about were scientific knowledge as socially constructed, the role of creativity and imagination, the tentative nature of science, and the diversity of the scientific method. The details of each aspect are as follows:

2.1.1 Scientific Knowledge Based on Empirical Evidence

For the evidence in science, Pimpan held the informed understanding about the evidence in science. She defined the meaning of science in terms of the products as scientific knowledge. She explained that "science is a body of knowledge that scientists study or discover… (Science is) understanding the nature around us. It is the scientific knowledge of Physics, Biology, and Chemistry." When asked to explain more about the scientific knowledge, she said that "the scientific knowledge is a set of ideas, a series of knowledge, or the answer to questions that scientists explained about natural phenomena." She exhibited understanding about the important of the evidence. She understood that evidence is necessary for knowledge claims to be scientific knowledge. Scientists have to show the evidence that supported their explanations. This evidence comes from their investigations.

"A scientific knowledge is affirmed to be true when it is supported by data or information from scientists' working such as research observation or experimentation. It will be trustworthy."

2.1.2 Science as Social Activity

The second aspect of the NOS that Pimpan held informed understanding was science as social activity. Pimpan was asked how science related to society. She stated that science is an important factor for a developing society. Scientific knowledge is useful for developing technology. The development of scientific knowledge is based on social problem, needs and demands. She described global warming as a social problem.

"Now, global warming is the most interesting thing around the world, so we receive information from many researches about global warming for resolving or decreasing this problem."

When asked Pimpan where ideas or topics for scientific investigation came from, she stated that:

"It comes from many parts, first the interest or curiosity of scientists, and then they had to be concerned with the society's needs because if it is demanded by society, it will be easy to receive money for research, it is an important thing also."

She explained the attention as personal factor that impacted scientists' work that they are happy in their interested work more than uninterested work and that work will be success. She did not refer other personal factors such as bias, norm or experiences that were important influence to science.

2.1.3 Scientific Knowledge as Socially Constructed

When asked to describe the construction of scientific knowledge, Pimpan held mixed understanding about scientific knowledge as socially constructed. She understood that scientific knowledge is developed from many scientists in different fields and a scientist's work is built up on previous scientists' work.

Scientists may work individually or work with the others like a team research. That team is comprised of many scientists who are experts in one field or different fields such as biology, chemistry and work together on one topic.

"Scientific knowledge comes from scientists' working, researching, experimentation, and uses scientific method and then scientists promulgate. It is useful for the others to work further. It is useful not only in the same field. Sometimes biologists not only use the knowledge of biology, but also the knowledge of chemistry." She said.

However, Pimpan did not explain about the background of scientists influencing the interpretation of data. She seemed to understand that all scientists end with the same conclusion from the same data.

2.1.4 The Role of Creativity and Imagination

Concerning the role of creativity and imagination in science, Pimpan held mixed understanding. She understood that creativity and imagination are necessary for scientists' work including all steps of the experimental procedures and the creation of new things. However, she had no idea about the use of the creativity and imagination in the development of theories or model for explaining the natural phenomena.

"When they (scientists) do any experiments or any studies, they have to use their creativity and imagination to plan, design, and summarize the experiment and show their results. Absolutely, new devices or new technologies come from imagination. I believe that creative thinking is important for every work."

2.1.5 The Tentative Nature of Science

Even though, Pimpan understood that the scientific knowledge is based on the evidence, she did not indicate about the inferences and creativity in developing scientific knowledge. Thus, when she was asked about the tentativeness of scientific knowledge, she understood that scientific knowledge can be changed in terms of adding details or new knowledge more than the abolishment of existing knowledge. The details or new knowledge comes from the development of technologies and the investigations of many scientists.

"It (scientific knowledge) can be changed because there are always new technologies and new data. Many scientists do research so they can come up with new knowledge."

For the tentativeness of the respiration knowledge, Pimpan thought that it can be changed like another scientific knowledge. She still stated that the existing knowledge of the chemical processes of respiration is not abolished because each chemical process is a real phenomenon that is discovered by scientists. However, she did not give any examples of changes in respiration knowledge because she had no idea about the history of respiration.

"It (the knowledge of cellular respiration) was the fact that occurs in the cell, it was real…and scientists found this. Carbohydrates released energy by passing Glycolysis …it is a chemical process. In the future scientists may explain in more detail about the chemical processes of each step or find new chemical substances to add detail."

The result from the interview indicated that she had no idea about changing based on prior evidence and did not understand the role of creativity and imagination in the development of scientific knowledge. Thus, she was categorized in mixed understanding of the role if creativity and imagination.

2.1.6 Diversity of Scientific Method

For the meaning of the scientific method, Pimpan explained that the scientific method is a tool of scientists to study something to explain how it occurred or why it occurred and to answer questions. She understood that the scientific method is a series of four steps.

"(The Scientific method) starts with (1) make an observation and set the question, then (2) set hypotheses, (3) plan to test their hypotheses, design and do the experiment and (4) finally make a conclusion and discussion."

She understood that using the scientific method for developing knowledge causes science to be different from other disciplines. It is the way that all scientists use to study the world.

For the diversity of the scientific method, Pimpan understood that all scientific knowledge is proven by the evidence gathered from the experiments and observations. The experiments are the third step of the scientific method for testing hypotheses. When she was asked about the meaning of an experiment, she explained the meaning of an experiment in terms of controlled experiments to test hypotheses. She said that:

"It (the experiment) is the method for testing hypotheses that consists of a dependent variable and independent variable, compares to the control group and the experiment group, and for finding cause and effect."

Moreover, she had an unclear understanding of the difference among the observation, survey, and other types of experiments. She said that observation and surveying are the initial steps or one part of an experimental study, and sometimes she used the term "the experiments" instead of the observations and other types of experiments. For example, she explained her teaching about the gas exchange of gases in animals that "they (students) did experimentation on by observing gills of fish and pig lungs."

2.2 Understanding of the Inquiry-based Approach

Pimpan's understanding about the inquiry-based approach in the context of science teaching was comprised of three domains. The first domain, the inquiry-based approach required the students to behave like scientists. She noted that the investigation as experiments, surveys, and observations are essential parts of the inquiry-based approach that distinguishes inquiry teaching from lecture. In the inquiry-based approach, students should develop their own questions, hypotheses, experiments, answers and analyses. They could communicate their findings, like a real scientist. She had no idea that the level of inquiry-based approach varied from structure to open. Thus, she felt that the inquiry-based approach was difficult to do in her classroom. She was not successful in teaching science using the inquiry-based approach.

"To me, I thought that my teaching was not correct inquiry teaching. They (Pimpan's students) could not do (the experiments) without me. I still told students about the experimental directions or assigned the variables." she said.

The second domain, the inquiry teaching was appropriate for students who had the high level of achievements. By the term of achievement, Pimpan meant that an ability in science processes skills and content knowledge. She thought that the success of inquiry teaching depended on students' achievements because students could do laboratory experiment by themselves. Moreover, students' achievement related with their responsibility to inquiry learning and saving time to teach.

"Students who have the ability in science process skills are responsible to their work. The teacher did not talk or review that much. (Because)They can. If students are low in their abilities, a teacher must explain more and needs more time." she said.

She claimed that the role of the teacher in the inquiry-based approach should be as a facilitator. However, this role depended on the students' achievement. In general, the roles of teachers were designing instruction, providing materials, implementing classroom management as following the plan and motivating the students to keep their doing continuously. In inquiry teaching, teacher is the facilitator for high to moderate the levels of student achievement while the teacher was a guide or teller for students in low levels of achievement. She accepted that she often was a teller.

"The teacher's role, I think, depends upon the students. For good students, with high ability, I think, a teacher just says a little or only supports. They can go through more independently. However, if students are unable to set hypotheses or design experiments, teaching cannot be continuous. I will speak to them or guide them. Normally, I have to give lab directions for them."

The final domain, the inquiry-based approach required the 5E model of inquiry planning. At the beginning of the interview, Pimpan said about inquiry teaching that it was teaching to follow the 5E model of inquiry including engagement, exploration, explanation, elaboration, and evaluation. She thought that the teacher had to design a lesson plan into 5 steps that "stimulated students or motivated them (engagement), had students search or do hands-on (exploration), summarization and presentation (explanation) related with their life (elaboration) and finally evaluation." She thought that the 5 E model of inquiry was not easy to use for every topic.

"I thought that it is easy for content that has an obvious experiment, but some content do have not an obvious experiment. I did not know how to write using the exploration step. I did not know what the student should do."

Pimpan thought that a teacher had to train for designing 5E models because it was difficult, and she claimed that "just only reading from the teacher's manual (of IPST), did not make her understand and write a lesson plan as correctly using inquiry teaching. I did not learn how to do. It needs writing skills also."

2.3 Teaching Practices in Respiration

In this section, data from the interview and classroom observation field notes were analyzed to explain how Pimpan typically taught respiration that related to the understanding of the NOS and the inquiry-based approach before the implementation of the respiration instructional unit.

According to the interview about teaching the respiration topic, Pimpan taught this topic in grade 10 in the second semester. She taught this topic after finishing the digestive system. There were two main topics, namely cellular respiration and gas exchange. The sub-topic, the time and a brief summary of teaching were shown in table 5.1. She stated that in cellular respiration, her teaching was by lecture with the diagram based upon students' textbooks and teachers' manuals of the IPST. However, she did not completely implement the inquiry as stated in the teachers' manual of the IPST. She chose the lecture for teaching an aerobic respiration because she could not create a lesson plan based on the 5E model of the inquiry-based approach. In anaerobic respiration, she stated that she taught like the 5E model because she had students do the experiments and search the information. She provided students experiments about yeast respiration in conditions without oxygen. For gas exchange organs, students were assigned to search information about gas exchange in living organisms and to make a presentation to the class. She demonstrated the dissection of a pig lung for teaching the structure of lungs and the mechanism of breathing and lectured about lung capacity, the mechanism of breathing, and the rate of respiration.

From classroom observation, mostly Pimpan led her students doing activities following her step by step, and she always summarized the knowledge or gave the correct answers for students. In the anaerobic experiment, she explained the direction and everything that she wanted the students to do. After the students completed the experiment, she randomly chose some groups of students to show and compare their results with others. However, she told and wrote the completed summarization on the chalkboard. She did the same in teaching gas exchange. After students presented about the exchange of gases in the organs of living organism, she explained the structure and the function of the gas exchange organs and wrote the summarized table about gas exchange organs for students. She emphasized that students should remember the products of cellular respiration in each step, but she did not emphasize how each step was connected to each other. Moreover, she did not connect the process of cellular respiration with the other processes such as gas exchange, the respiratory system, and digestive systems in humans for students' holistic understanding of respiration.

Pimpan accepted that she had a moderate understanding about cellular respiration. She could not explain the chemical process in depth. Thus, her speech or explanations were the same as in the textbook. She felt that this topic was difficult for teaching and finding science materials that helped students understand the concept better. She could not develop other materials besides using diagrams and pictures in the textbook. During classroom observation, it was noticed that her role was a teller. She always stood or sat in front of the room and kept on explaining and reading the textbook.

For teaching the NOS in biology and respiration in particularly, she perceived that teaching the NOS was important as well as teaching scientific concepts. Teaching the NOS should be integrated in all science teachings. However, she explained the way to teach the NOS as an implicit approach that:

"Students should learn the NOS from their experiments. Students do these by themselves. They will learn both the knowledge and the scientific processes."

Table 5.1 Summary of Pimpan's Teaching of Respiration before Implementation the Respiration Instructional Unit

Topics	Sub-topics	Time	Activities	Materials
Cellular respiration	Aerobic respiration	6	- Teacher lectured the process of aerobic respiration. - Students did the test.	1. Glycolysis diagrams. 2. Diagrams in students' text book
	Anaerobic respiration	2	- Students investigated the anaerobic respiration in yeasts. - Teacher lectured the process of anaerobic respiration. - Students did the test.	1. Material of yeast activity 2. Diagrams in students' text book
Gas exchange	Gas exchange in living organism	2	- Students searching information and presentation about gas exchange in living organism.	1. The picture of gill, trachea 2. The pictures in students' text book
	The structure of lung and mechanism of breathing	4	- Teacher demonstrated the dissection of pig lung. - Teacher lectured the lung capacity, mechanism of breathing.	1. The pig lung 2. Diagrams in students' text book
	The rate of respiration	2	- teacher lectured the rate of respiration	1. Diagrams in students' text book
	Total	16		

3. The Implementation of the Respiration Instructional Unit

3.1 Teaching Context

Pimpan started to implement the respiration instructional unit on the first week of December, 2007 and finished on the last week of January, 2008. During that time, there was one week for midterm examinations and sports activities. She spent the time to implement for a total of 23 hours which was more than the time planned. The implementation of the respiration instructional unit by Pimpan is described in terms of the teacher's teaching practices and parallels with the impact on the students' understanding of the NOS and the key concepts of respiration. Before the description of the impact of the respiration instructional unit, teaching context and teacher preparation are explained.

At the time of the study, the number of students in Pimpan class was 31 students, 8 males and 23 females. Pimpan taught biology at science laboratory room that was located on the third floor of a school building. This room was large (15 m x 10 m) and airy and there were two doors across fifteen windows. At the front of the room was the wall-mounted horizontal chalkboard in the center; next to the chalkboard, on both sides, were bulletin boards displaying colorful posters of science news and information. There were two hanging televisions on two sides in front of the classroom. There was one lab counter with a sink in front of the room and the room had continuous lab counters with four sinks and cabinets beneath on the same side of window. Three open cabinets for collecting students' portfolios, works and some models were located next to the door. In the middle of the room was eight groups of students, one table and individual student chair. At the back of the classroom, there were three big metal cabinets to store science equipment and supplies, one wood cabinet showcase to store microscopes. Figure 5.1 show the classroom setting.

The observations took 20 class periods, each period lasting 55 minutes. The students in this class were the better students in grade 10 in the school. However, Pimpan claimed that her students had moderate to low achievement on content and ability in using science process skills. According to Pimpan's criterion, the students were divided into groups by mixed achievement levels including GPA, grade of biology subject, level of science process skill ability, and gender. Two groups of students were selected randomly to be participants in this study for assessing their understanding of the NOS and the key concepts of respiration knowledge.

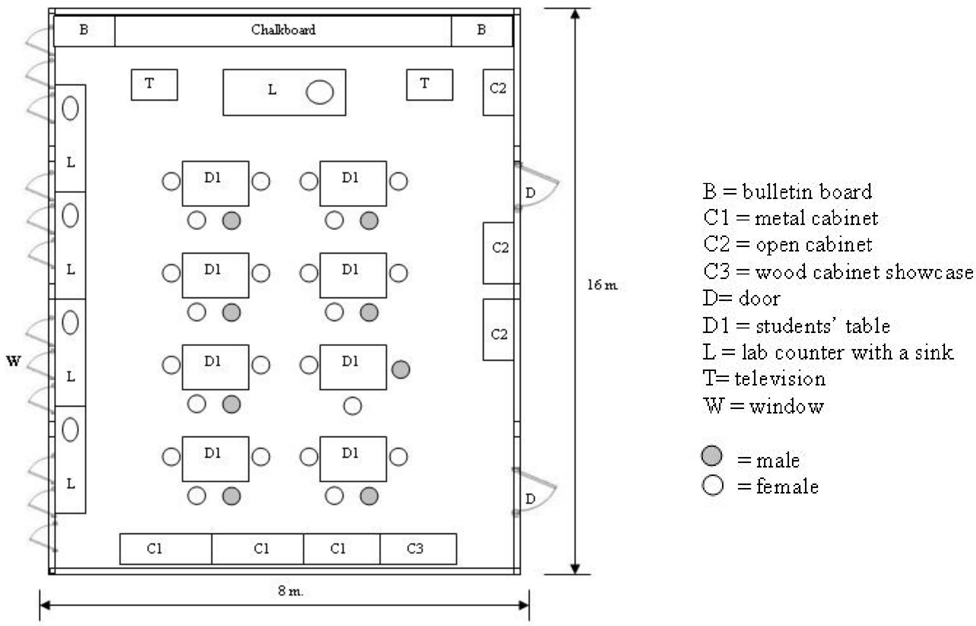

Figure 5.1 Pimpan's Classroom Setting

3.2 Teacher Preparation

Pimpan always read the lesson plan before teaching each lesson, and often asked the researcher to clarify about the objectives of both the NOS and the concepts of respiration and the steps of the lesson plan. Pimpan always worried about the implementation of the respiration instructional unit because of her teaching styles, her content knowledge and her students' abilities.

"I do not know that I can be successful using this teaching method. I am not familiar with asking students in help for constructing the knowledge. Mostly, I used lecture and explanation. My students have moderate and low both in achievement and abilities. I am not sure whether they can do or act completely.” (Pimpan, discussion in the first workshop)

She always put the lesson plan on the lab counter in front of the room and read it when she forgot the steps or the questions to probe student ideas. By the end of the class, she always asked the researcher about her teaching and the correctness of her explanations.

3.3 Students’ Understanding of the NOS and the Key Concepts of Respiration

In this section, the impact of the implementation of the respiration instructional unit on students’ understanding is described into two topics namely the NOS understanding and the understanding of the key concepts of respiration.

3.3.1 Development of Understanding of the NOS

Students’ understanding of the NOS was divided into six aspects of the NOS including scientific knowledge based on evidence, the role of creativity and imagination, the tentative nature of science, scientific knowledge as socially constructed, diversity of scientific method, and science as a social activity. The result of the four times of focus group interviews, classroom observations, and students’ work samples were used to describe students’ understanding of the NOS in each aspect. Students were primarily placed in three categories: naïve, informed, and mixed understanding as mentioned above. Table 5.2 summarized the students’ understanding, with a one in each aspect of the NOS from pre and post interviews. The symbols were used to represent each student. For example, PA1 means Pimpan’s student from group A, student No.1 and PB2 means Pimpan student from group B, student No.2.

Table 5.2 Development of Pimpan Students' Understanding of the Six Aspects of the NOS from Pre and Post Implementation

Students	**Evidence**		**Creativity and imagination**		**Tentativeness**		**Socially constructed**		**Diversity of method**		**Social activity**	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
PA1	M	I	M	I	M	I	N	I	N	I	M	M
PA2	M	I	M	I	M	I	N	I	N	I	M	M
PA3	N	M	M	M	M	M	N	M	N	I	M	M
PA4	N	M	M	M	M	M	N	M	N	M	M	M
PB1	M	I	M	I	M	I	N	I	N	I	M	I
PB2	N	I	M	M	M	M	N	I	N	M	M	M
PB3	N	I	M	M	M	M	N	I	N	I	M	M
PB4	N	I	M	M	M	M	N	I	N	I	M	M

I = Informed understanding

N = Naive understanding

M = Mixed understanding

A. Scientific Knowledge Based on Evidence

For the first interviews before implementing the unit, three students showed a mixed understanding about the evidence. They indicated that scientific knowledge was the explanation of the natural world and was supported by the evidence from observation or experimentation. They understood that scientific knowledge came from direct observation. There were five students that showed a naïve understanding. They understood that scientific knowledge was the facts that scientists discovered from natural phenomena.

PA3: "Scientific knowledge is the facts because it is around us. It is real happening. Scientists discover it."
Researcher: "How scientists discover?"
PA3: "from the observation around us and find it."
(First interview)

They did not claim that evidence supported the scientific knowledge or the data, and it came from scientific inquiry or scientists' working. They only understood that scientific knowledge was proven as truth by performing experiments many times.

During the implementation, the results from the second and third interviews showed that students who held a naïve understanding had changed their ideas about evidence in scientific knowledge. All students understood that their conclusions in each activity came from the inference of the evidence from experiments and observation. The trustworthiness of a conclusion depends upon the evidence from experiment and observation. However, in the last interview, six students showed informed understanding about the evidence in science that how scientific knowledge was constructed and inference based on evidence. Two students showed mixed understanding in the aspect that scientific knowledge was based on evidence, but were not aware of the inference.

B. The Role of Creativity and Imagination

When students were asked to respond to the question, "Do you think scientists use their creativity and imagination during their work?" in the first interview, all students showed mixed understanding about the role of creativity and imagination. They agreed that scientists used their creativity and imagination. However, when students were asked to indicate the stages that scientists used their creativity and imagination, they responded that scientists used creativity and imagination to create new instruments or new technologies. Five students indicated that creativity and imagination were used during investigation. Three of them stated that scientists used creativity and imagination to design the experiment. Two of them indicated that scientists used creativity and imagination to formulate their hypotheses and design their experiments. None of the students indicated that the role of creativity and imagination were essential for explanations or the interpretation of data.

During their activities, students were asked about the use of creativity and imagination in their investigations. In activity 1, the factors of the rate of respiration, all students thought that they used creativity and imagination to formulate their hypotheses, to design their experiment, and to present their data. This result differed from the result of activity 2: dissection of the gas exchange organs of animals. All students explained that they used creativity and imagination to present their results. They thought that this activity was an observational study. The steps of the dissection came from their teacher and they were general steps. They did not formulate hypotheses or design the experiment.

However, three students stated that they used creativity and imagination for their conclusion about the general structure of gas exchange organs after collecting their data.

"When we conclude, we have to think, and image how each organ works, how it is appropriate to diffusion." (PB1, third interview)

After implementation of the unit, three students showed informed understanding about the role of creativity and imagination in the generation of scientific knowledge. Five students showed mixed understanding. They did change their ideas about the role of creativity and imagination from the first interview.

C. The Tentative Nature of Science

Before the implementation of the unit, all of students exhibited mixed understanding about the tentative Nature of Science. They understood that scientific knowledge will change in the future because of new technologies, new data, and more research. They did not claim about reinterpretation of existing of data. Scientific knowledge could be changed in terms of adding something new or the details could be abandoned. The reason for abandonment is such that knowledge is found wrong or has errors.

When asked about their scientific knowledge learned in school and found in textbooks, six students had a naïve understanding that such knowledge had been proven to be true so it would not be changed.

"It (the knowledge in textbook) has been proven to be true and was chosen for us to learn. It will not be changed, if it is changed, it may just be more added detail." (PB3, first interview)

"Law and theory in a textbook cannot change to be a new one because there are many experiments that found the same result repeatedly"

(PA4, first interview)

Five students held mixed understanding about the tentativeness until the last interview. Three students exhibited informed understanding since the second interview about their activities until the last interview. They understood that scientific knowledge could be changed all the time. They explained the way to change from the first interview that scientific knowledge could be abandoned if new data or new ideas to explain the existing data were found.

"The knowledge, it changes as same as the time. Today we think like this, but in the future we may think differently even though it is almost the same phenomena." (PB1, the last interview)

D. Scientific Knowledge as Socially Constructed

As a result from the first interview, all students held naïve understanding that scientific knowledge is built up directly from experiments or observation. They did not claim that scientific knowledge was socially constructed. Even though they understood that new knowledge developed from existing knowledge or the result of other experiments, they did not claim that groups of people could work together and share ideas. They understood that scientists worked as individuals. One student gave the reason for this idea as "I did not know that groups of scientists discovered any scientific knowledge. I believed that scientists' experiments were based on prior knowledge from others, but when they study, they work by themselves, individually."

During the activities and after implementing the unit, all students developed their idea about the construction of scientific knowledge. Six students held informed understanding and two students held mixed understanding. For informed understanding, the six students could relate their activities with scientific work in terms of cooperation in their group and discussion about their results. For mixed understanding, the students believed that scientific knowledge was socially constructed. However, they believed that discussion and sharing of results or knowledge was more about correcting mistakes than adding to an already existing or to the construction of more knowledge. Moreover, they could not explicitly show examples or relate their activities to the knowledge of respiration.

E. Diversity of Scientific Method

For the first interview, all the students held naïve understanding that all scientific knowledge came from scientists using an orderly step procedure found in the scientific method. They seemed to believe in a single scientific method.

"It (scientific knowledge) comes from the scientific method that scientists use. Then scientific method is a way for answering the scientists' questions. It begins with observing natural phenomena, setting the question and hypotheses, designing the experiment, doing the experiment, and then making a conclusion." (PA1, first interview)

They understood that all scientists had to do the experiment as scientific work. When asked to clearly explain the term "the experiment", they stated that experiments were involved with finding the answer to the question arrived at from curiosity, searching information, doing by his/herself. No one noted that experiments involved controlling or manipulating aspects of the investigated phenomena.

When students were asked about their work in the second and the third interview, three students had changed their ideas about the scientific method and the meaning of an experiment and showed informed understanding about the diversity of the scientific method since the third interview until the last interview. They could give the examples of scientific knowledge that was not constructed from only using the experiment.

"Krebs cycle, we learned about history of development (the knowledge of Krebs cycle). Krebs created the cycle by using data from the others. It (the knowledge of Krebs cycle) was not from only direct experimentation. It became scientific knowledge." (PA1, third interview)

Three students clearly understood that a dissection study was one of the scientific methods and different from the experimental study in the third interview and had an informed understanding about the diversity of the scientific method in the last interview. “I know it (dissection) was not the experiment because we did not test anything, it did not involve a dependent variable and an independent variable.” (PB4, third interview) There were two students who still held a mixed understanding that scientific method is an orderly step procedure but scientists have to do experiment or observation as scientific work.

F. Science as Social Activity

This aspect was the understanding of the interaction between science and society. All students held mixed understanding that science was important for the development of society. However, they did not explain the influences of societal factors on science.

“Science impacts on a developmental society. It gives us conveniences.” (PB3, first interview)

After the implementation of the unit, there was only one student who developed an informed understanding that the societal factors had influence on science issues. The others still held a mixed understanding of this aspect.

3.3.2 Development of Understanding of the Key Concepts of Respiration

Eight students responded to the respiration concept survey two times, pre and post implementation, and then they were interviewed after completing the survey. They were asked to recall their thinking at the time they responded to each test item and explain their ideas. In this study, there were four main topics of respiration knowledge in the respiration concept survey and interview namely the definition of respiration, aerobic respiration, anaerobic respiration, and the relationship between cellular respiration and gas exchange. The key concepts of the respiration knowledge were the four main topics that biologists currently consider to be acceptable concepts and were shown in figure 5.2- 5.5 respectively. The result of the pre surveying was used as a baseline for explaining the development of students' understanding about the key concepts of respiration. During post interviews, they were also asked to describe how their thinking had changed as a result of the instruction.

For the definition of respiration, there are four concepts that relate to what biologists currently consider to be an acceptable definition of respiration (Sander, 1993), as shown in figure 5.2. As for the results before implementation, all students held alternative conceptions of the four concepts. All students did not explain the meaning of respiration at the cell level and the chemical process. Six students (PA1, PA2, PA3, PB1, PB3, and PB4) defined the meaning of respiration as gas exchange between oxygen and carbon dioxide and two students (PA4 and PB2) understood that respiration is breathing in and out. None of eight students claimed that the purpose of respiration is to provide energy for metabolism. All students held alternative conceptions about the energy for metabolism and that it comes from the digestion of food in animals, and it comes from photosynthesis in plants.

According to meaning of respiration as gas exchange or breathing in and out, all students held alternative conceptions that in animals, respiration takes place in the respiratory organs such as the lungs and gills, while in plants respiration takes place in leaves or roots. Thus, they held alternative conceptions that plants will die when they are flooded because they are deficient of oxygen and they cannot perform respiration which is the exchange of oxygen and carbon dioxide. Six students understood that respiration occurs just only in plants and animals, it does not occur in microorganisms because they do not have an organ for respiration. Although two students believed that all living things, including microorganisms perform respiration, because the respiration or gas exchange in their understanding is the process that helps keep living things alive.

All students understood that plants perform respiration at night and perform photosynthesis during the day. As for the reason, five students understood that the oxygen which comes from the photosynthesis process is used in the respiration process while three students understood that the respiration process is an opposite reaction to photosynthesis. The respiration process changes oxygen to carbon dioxide and the photosynthesis changes carbon dioxide to oxygen.

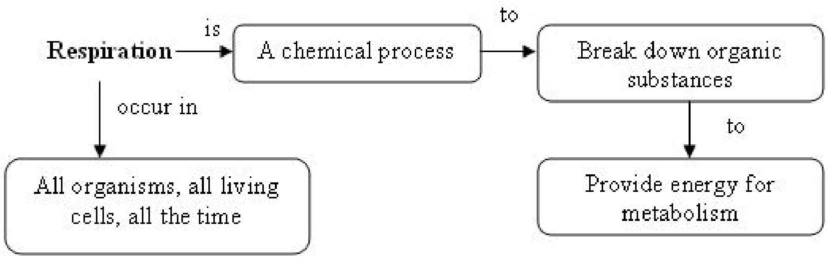

Figure 5.2 Four Concepts Related with the Definition of Respiration

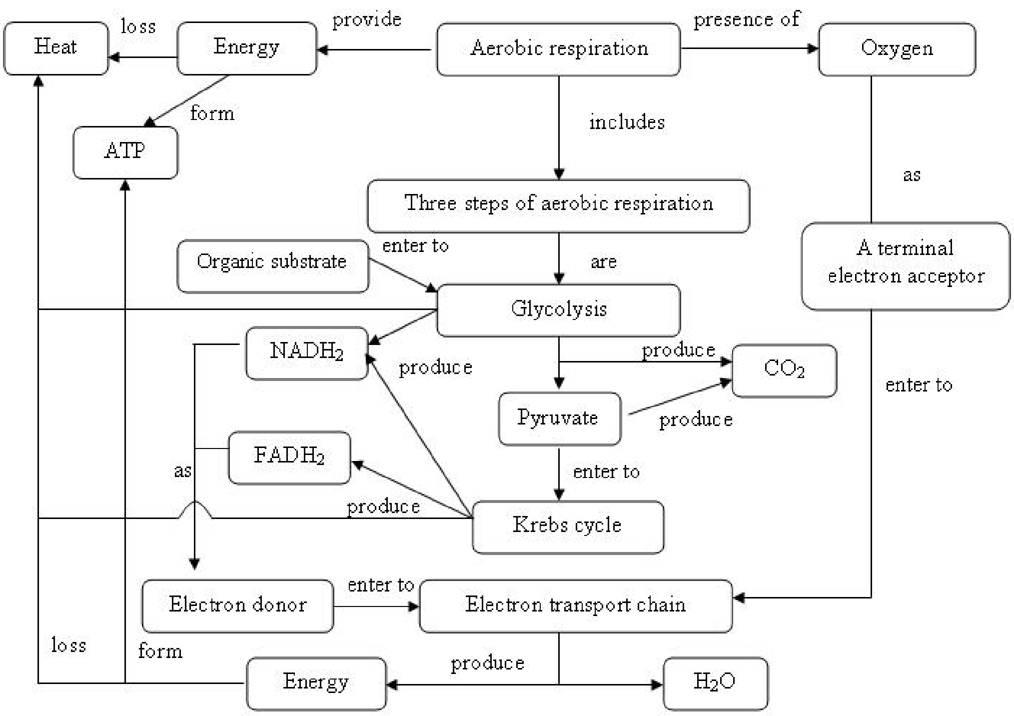

Figure 5.3 Concept Map of an Aerobic Respiration

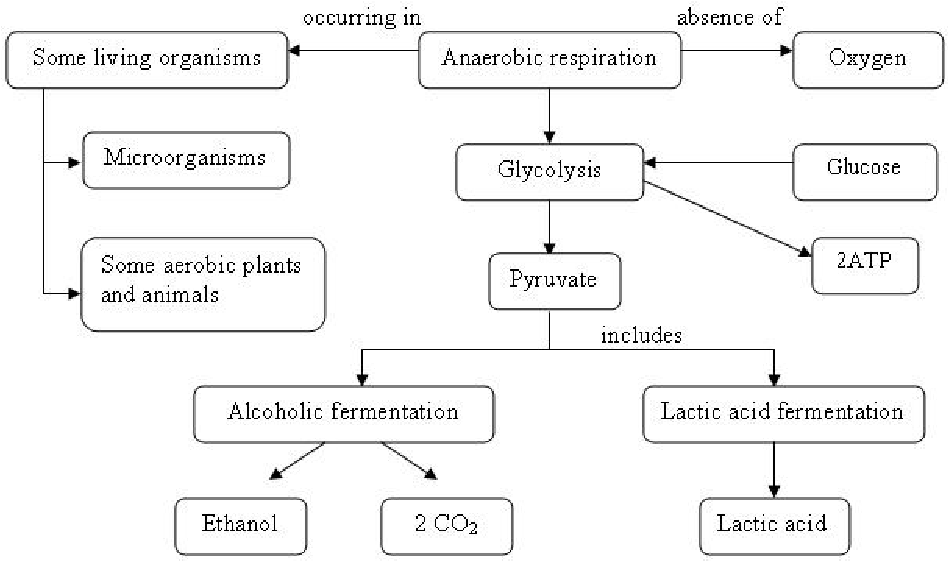

Figure 5.4 Concept Map of Anaerobic Respiration

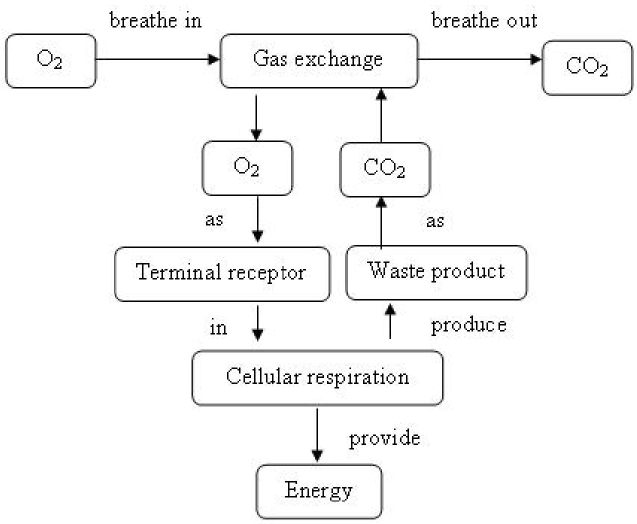

Figure 5.5 Concept Map of the Relationship between Cellular Respiration and Gas Exchange

To understand aerobic and anaerobic respiration, all students did not have ideas about the chemical processes of both. All students held alternative conceptions that all living organisms need to use oxygen from respiration to be alive. It was indicated that they ignored anaerobic respiration. Moreover, they did not clearly understand about the role of oxygen, the process of using oxygen, and why it makes us alive.

According to their understanding of the respiration that is described above, when students were asked to explain the relationship between breathing and cellular respiration when we exercise and after finishing exercising why do we need to breathe deeply in and out. Three students, PA1, PA2, and PB2 explained that we want to take in more oxygen and to take out carbon dioxide more than normal to produce more energy for exercise. They were categorized as an alternative conceptual pattern 1 of the relationship between cellular respiration and gas exchange as shown in figure 5.6. While five students did not indicate the energy idea, they only explained that we perform the exchange between oxygen and carbon dioxide more than normal when we exercise.

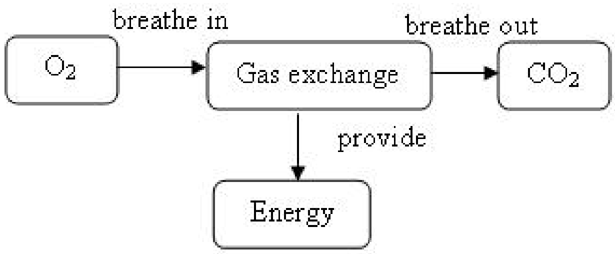

Figure 5.6 Alternative Conceptual Pattern 1 of the Relationship between Cellular Respiration and Gas Exchange

After implementing the unit, the results from the respiration concept survey and interview showed that all students explicitly developed in the four main topics of the knowledge of respiration. For the development of three main topics, namely aerobic respiration, anaerobic respiration, and the relationship between gas exchange and cellular respiration, eight students were categorized in the conceptual pattern according to the coherence of the students' responses in the concept survey and interview. The conceptual development of eight students is described as follows.

Based on the four concepts that relate to the definition of respiration, three students (PA1, PA2, and PB1) held a correct conception of the four concepts that respiration is a chemical process occurring all the time to break down energy-rich compounds to provide energy for metabolism. All students held a correct conception that respiration is the chemical process of producing energy in a cell. All living organisms perform respiration all the time because they need to use the energy from respiration to be alive. However, five students (PA3, PA4, PB2, PB3, and PB4) held alternative conceptions that in plants, cellular respiration occurs in only the cells of gas exchange organs such as the cells of leaves and roots. They failed to understand that respiration occurs in all living cell an in addition, three of them (PA3, PA4, PB4) held alternative conception that only glucose is break down in cellular respiration to provide energy.

As for the concepts of aerobic respiration, PA4, PB2, and PB4 were categorized in the alternative conceptual pattern 1 of aerobic respiration as shown in figure 5.7. They understood that aerobic respiration is the process that provides energy in the form of ATP when oxygen is present. Although, they identified the substrates of aerobic respiration, oxygen and glucose, its products as ATP and CO_2, and three series steps of aerobic respiration, they did not understand about the relationship among theses steps in terms of products to produce CO_2, ATP, and electron donation and reception. Moreover, they ignored the fact that heat is one product of aerobic respiration.

PA2, PA3, and PB1 were categorized in alternative conceptual pattern 2 of aerobic respiration as shown in figure 5.8. They remembered that energy is lost as heat, but did not explained how the heat is produced. They understood that $NADH_2$, CO_2, and ATP are produced during the process of Glycolysis and the Krebs cycle. However, they did not explain that $NADH_2$ are transferred to the electron transport chain for producing ATP. Moreover, they ignore the role of $FADH_2$ and oxygen during the respiration process.

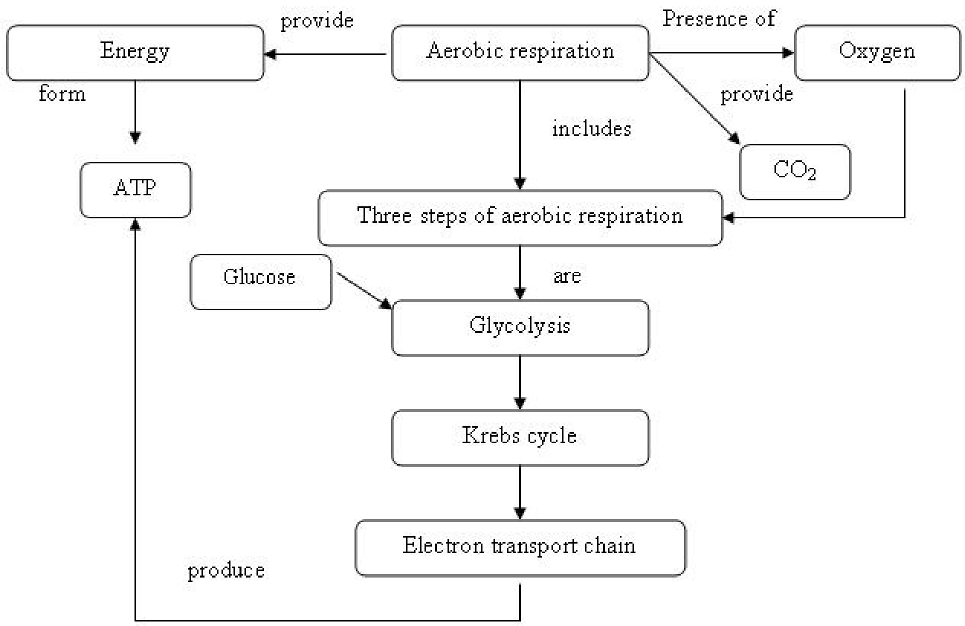

Figure 5.7 Alternative Conceptual Pattern 1 of Aerobic Respiration

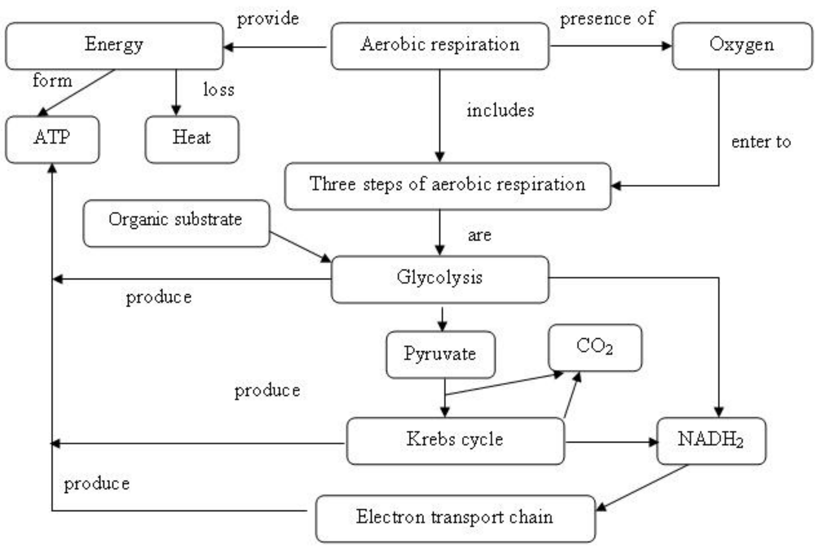

Figure 5.8 Alternative Conceptual Pattern 2 of Aerobic Respiration

PA1 and PB3 were categorized in alternative conceptual pattern 3 of aerobic respiration as shown in figure 5.9. They added more understanding that $NADH_2$, $FADH_2$, and oxygen are entered into the electron transport chain for producing ATP. They understood about the role of the electron carriers, $NADH_2$,

$FADH_2$ is producing ATP. However, they did not explain about the transferring of electrons from $NADH_2$, $FADH_2$ to oxygen molecules to form water molecules (H_2O).

None of eight students were categorized in the correct conception level (Figure 5.3). All students ignored that water is one by product of respiration which relates the role of oxygen as a terminal electron acceptor. They did not explain where heat comes from during the breakdown of organic substances.

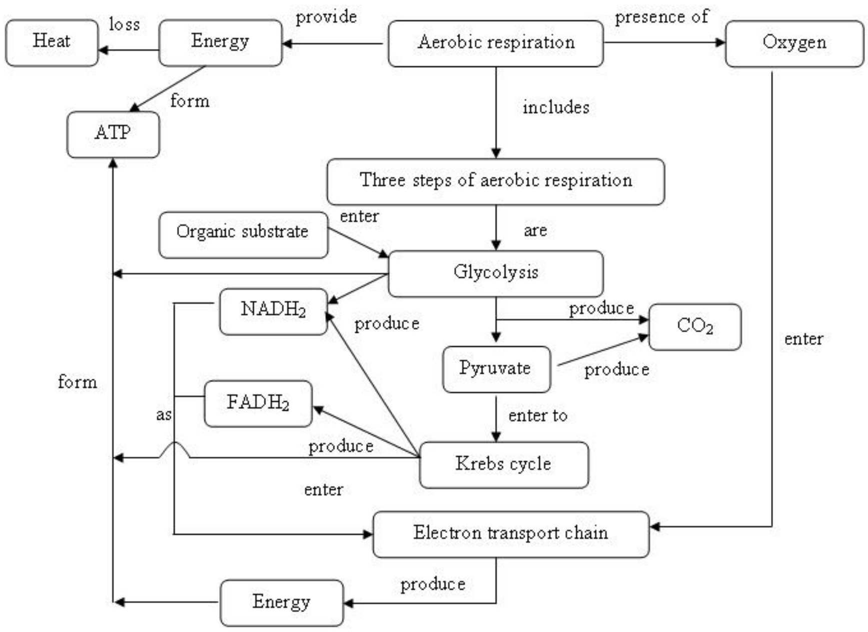

Figure 5.9 Alternative Conceptual Pattern 3 of Aerobic Respiration

As for the knowledge of an anaerobic respiration, none of the students held correct conceptions about anaerobic respiration. All students ignored the fact that plants can perform anaerobic respiration. There were two alternative conceptual patterns from these students. Three students, PA4, PB2, and PB4 were categorized in pattern 1 as shown in figure 5.10 while five students, PA1, PA2, PA3 PB1, and PB3 were categorized in pattern 2 as shown in figure 5.11.

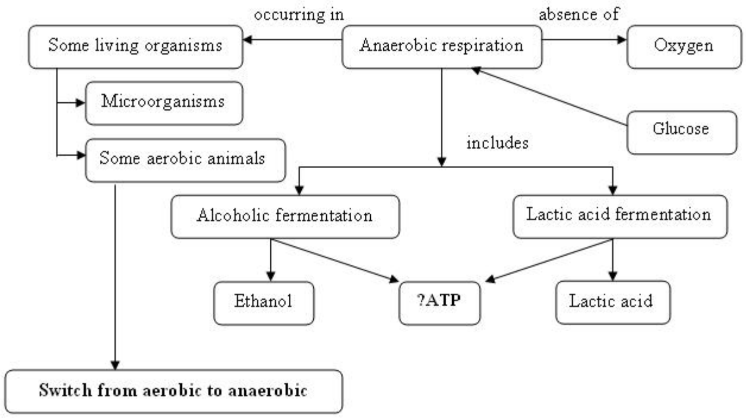

Figure 5.10 Alternative Conceptual Pattern 1 of Anaerobic Respiration

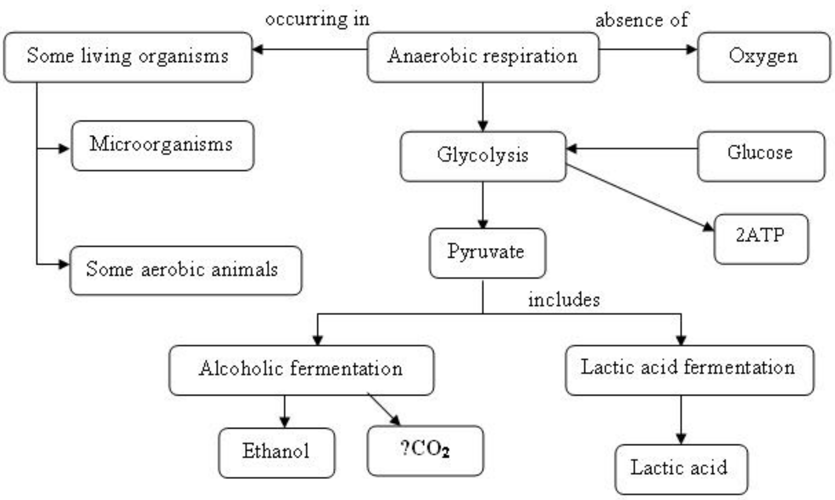

Figure 5.11 Alternative Conceptual Pattern 2 of Anaerobic Respiration

In pattern 1, students understood that some microorganisms perform anaerobic respiration and also some cells of aerobic animals such as muscle cell can perform anaerobic respiration for short periods of time. Nevertheless, they ignored anaerobic respiration in plants. They understood that muscle cells can switch from aerobic respiration to anaerobic respiration when the amount of oxygen is not enough. Moreover, they did not explain how ATP comes from and ignored the CO_2 which is a product of alcoholic fermentation.

In pattern 2, students ignored the fact that anaerobic respiration occurred in plants for short periods of time such as plants in a flood. They explained that two ATP are produced from Glycolysis before pyrutic acid is broken down in alcoholic fermentation and lactic fermentation. However, they did not identify that plants or animals perform Glycolysis even if oxygen levels are not enough to produce ATP. Moreover, they held a correct conception that our muscle cells can produce energy from both processes, aerobic and anaerobic respiration together when oxygen is not enough. Although they identified that CO_2 is produced from alcoholic fermentation. They could not compare the amount of CO_2 between aerobic and anaerobic respiration.

For the last topic, the relationship between cellular respiration and gas exchange, all students held alternative conceptions in this topic. Two students, PA4 and PB2 were categorized in the alternative conceptual pattern 2 as shown in figure 5.12. They indicated that oxygen from the environment enters the cells from gas exchange to produce energy. However, they ignored the fact that CO_2 which is the waste product from cellular respiration, affects the rate of breathing in and out in humans.

Six students, PA1, PA2, PA3, PB1, PB3, and PB4, were categorized in the alternative conceptual pattern 3 as shown in figure 5.13. They could connect between the gas exchange and cellular respiration processes in terms of oxygen, carbon dioxide, and producing energy. They could explain the pathway of oxygen from the environment to the cell and the steps of the cellular respiration processes that produce carbon dioxide that we breathe out. However, they did not clearly understand about the role of oxygen in the electron transport chain and the role of the electron carrier to produce ATP and H_2O.

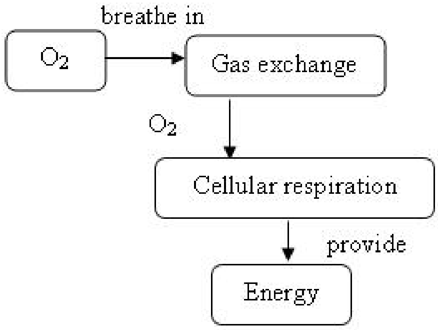

Figure 5.12 Alternative Conceptual Pattern 2 of the Relationship between Cellular Respiration and Gas Exchange

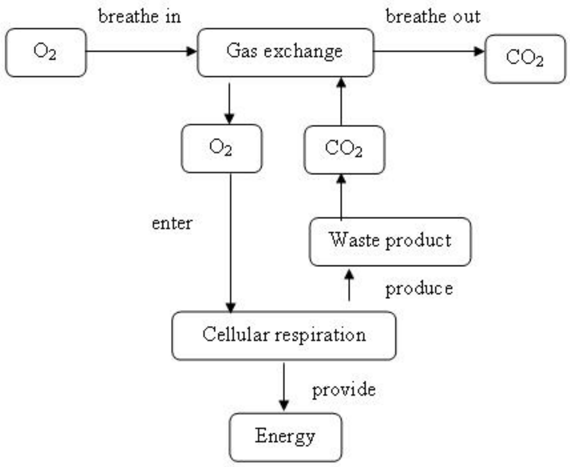

Figure 5.13 Alternative Conceptual Pattern 3 of the Relationship between Cellular Respiration and Gas Exchange

3.4 Teaching Practices and Students' Understanding of Knowledge of Respiration and the NOS

Classroom observation field notes, focus group discussion, and students' interviews about their learning and understandings were analyzed for describing the relationship between teacher practices and students' understanding both the NOS and the knowledge of respiration.

3.4.1 Teaching Practices Related with Students' Understanding the Knowledge of Respiration

There are two themes of relationship between Pimpan's teaching practices and the students' understanding of the knowledge of respiration. Each theme is described as follows:

Theme 1: Shifting authority of knowledge from teacher to other sources enhances students' construction of their knowledge.

Before implementing the unit, Pimpan's role was the lecturer and rarely provided students opportunities to construct their own knowledge from activities or other sources. Although, Pimpan claimed that she was not confident in her content knowledge and explanation of the chemical processes of respiration, she was the authority of knowledge and students were only the receivers of the knowledge from her lectures and explanations with diagrams.

As for Pimpan's implementation of the unit, the authority of knowledge changed from teacher to other sources. Students learned from hands-on activities, materials, and investigations. Then, Pimpan discussed with the students using their experiences with the activities and materials instead of her lectures. Although some times she concluded the lesson for students. From classroom observation field notes, her students paid attention in their activities and materials and had more responsibility for their learning.

An example of her changing role in the Glycolysis activity of the lesson of the aerobic respiration, showed when Pimpan assigned students to watch a VCD that showed in animation the chemical process of Glycolysis. After that each group drew a diagram of the process of Glycolysis and then discussed it with Pimpan. They further discussed the details of the chemical process by using the students' diagrams and questions from the students' worksheets. During the discussion, Pimpan played the VCD to help guide students when editing their diagrams. She assigned each group to create a poster showing the steps of Glycolysis that would reflect their understanding. She commented that using the VCD and having students make the poster the following; "I think that it was useful for students. They are interested in watching the VCD. Some students asked me to copy it for watching again. It is better than I explained, and also I learned from it as well." (Second focus group discussion)

All the students stated that they gained more understanding from the VCD as well. For example, one student said; "I like to watch a VCD because it moves and it is exciting. I learned from that". (PA2, Interview) Moreover, they claimed that the questions and worksheets from Pimpan helped them to think carefully when they watched the VCD.

Theme 2: Fragment of knowledge and telling the correct concepts are related to students' rote learning.

From the data from the classroom observation field notes, Pimpan reviewed and asked questions before students learned in each lesson. After finishing a lesson, she asked students questions as a way of probing their understanding. However, she usually used "what" question more than "how and why" questions. Moreover, she lacked discussing about the relationship among the four topics of respiration namely the definition of respiration, aerobic respiration, anaerobic respiration, and the relationship between gas exchange and cellular respiration and interrelated concepts in one topic.

For example, in the activity: result of chemical to cellular respiration, she reviewed students by asking the meaning of respiration in biology. Some students said that it is "the process of producing energy" or "brings oxygen to combine with nutrients and produced energy." She told them the meaning of respiration is "it is the chemical process in the cell for producing the energy" she failed to emphasize to the students that respiration occurs in all cells of all living things and the concept of energy and the chemical process. After that, students wrote a concept map of aerobic respiration and discussed it so students could correct their understanding before they answered questions about the results of the chemical process to cellular respiration. After students showed their concept map, she often asked questions like “what are substrates?” and “what are the products of the three steps of aerobic respiration more than questions like “where each product comes from?” or “what is the relationship between substrates and products?” Moreover, she did not ask students about the links between the three steps of aerobic respiration such as the linkage between Glycolysis and the Krebs cycle is pyretic acid and $NADH_2$ is the linkage between Glycolysis and electron transport and between the Krebs cycle and electron transport.

Corresponding to the results of the students’ understanding of the knowledge of respiration, all students of Pimpan understood that the meaning of respiration in biology as the chemical process used for producing energy from nutrients. Most of the students had alternative conceptions about the chemical process and energy. They ignored the fact that respiration occurs in all cells of all living things. Nevertheless, most students stated that reviewing before learning the next topic was useful to recall those concepts and tried to understand correctly.

3.4.2 Teaching Practices Related with Students’ Understanding of the NOS

Three themes of the relationship between Pimpan’s teaching practices and students’ understanding about the NOS are described as follows:

Theme 1: Providing the explicit examples of the NOS aspect increase students’ understanding of NOS.

During the implementation of the unit, Pimpan rarely provided opportunities for students to discuss and reflect their understanding about the NOS. However, there were two aspects of the NOS as the diversity of the scientific method and scientific knowledge as socially constructed that she emphasized in teaching and pointed out examples from the students’ activities.

As for the diversity of the scientific method, in the dissection of a gas exchange organ, Pimpan began with a short review about and the meaning of the scientific method and the experiment. Then, she asked students to compare between the observational study and the experimental study by using the experiment of yeast fermentation and the dissection of a gas exchange organ. Correspond with students' understanding about the diversity of scientific method. Six students changed their understanding from naïve understanding or mixed understanding to informed understanding in the third interview after they finished the dissection activity. They had an informed understanding that dissection is one way of inquiring scientific knowledge and informed understanding about the meaning of the experiment in terms of the variables and manipulation.

As for scientific knowledge as socially constructed, Pimpan compared the scientists work with student activities such as working in groups, brainstorming for answers for questions and conclusions. For example: in the first period of teaching, Pimpan divided the students into eight groups and said: "Working together, helps each other. You learn science better if you work like scientists." During the students' presentations of their results and conclusions about the dissection of a gas exchange organ, she said that: "by asking questions and making a conclusion together you should are practicing to be like scientists."

Theme 2: Separate the NOS from the content related with student' holding mixed understanding of the NOS.

Pimpan rarely linked the concepts of the NOS from activities into the respiration context or reflected the NOS aspects in the knowledge of respiration. For example, in lesson 2: aerobic respiration, this lesson began with the Mystery box activity. Students were encouraged to discuss the difference between observation and inferences and relate this activity with the evidence that show that oxygen and carbon dioxide exist and to think how scientists study the chemical processes of cellular respiration. As Pimpan taught in this lesson, after the students finished the Mystery box activity, she explained the difference between observation and inferences more and discussed them with the students. Then, she started teaching the next activity. Through her teaching, she did not link the concept of the inferences when students make a conclusion, and she provided the statement of conclusion. Correspondingly most of the students failed to understand that scientific knowledge is constructed from the interpretation of data and evidence. They understood that the conclusion and scientific knowledge come directly from the data. Everyone meet the same conclusion with the same data.

As for teaching the history of respiration, Pimpan did not allow students to discuss and reflect their understanding after studying the history of respiration. She only randomly selected some groups to answer the questions and then provided the correct answers and told the statements of the NOS aspects without explicit examples from the history of respiration. The corresponded with students understanding of the NOS, few students claimed about the history of science as an example for supporting their understanding of the NOS. Moreover, some students held a mixed understanding about the NOS, but a naïve understanding in its context of respiration. For example, they held a mixed understanding that all scientific knowledge can change both abolishment and the addition of details, but the respiration knowledge that they learn cannot be abolished because it had been proven to be the truth already.

Theme 3: Teacher providing the conclusions obstructed students' understanding of the role of creative and imagination after collecting data.

For students' inquiry, Pimpan did not reflect her understanding about the inquiry-based approach that students should act like scientists. She always taught using structured inquiry. She provided students with the question for investigation, the procedures and materials. She only allowed students the role of collecting the data and making conclusions. She reflected upon her teaching in this activity and stated that she did not have confidence in her students that they could design a correct experiment. It saved time by designing the experiment herself and took more time for hands-on activity and collecting the data. However, she often gave the statement of the conclusion for students after the students presented their conclusion.

For example, in lesson 4: the rate of respiration. She began to review and probe students' prior knowledge about yeast, the respiration process and the scientific method. She reviewed the meaning of the experiments and the variables of the experiments. However, she did not engage students to ask questions related to the investigation. She let students think about the factors that impacted on the rate of respiration. However, she chose the two factors for the investigation. Then, she told the procedures and led the students through them step by step. After students collected the data, she asked each group to write the results on the chalkboard and then the students summarized the results. However, she did not discuss the results or conclusions of the students. She gave the explanation for the conclusion of the experiment.

These teaching practices influenced the students' understanding of the role of creativity and imagination in the second and the third interview. All students stated that they did not use creativity and imagination for formulating hypotheses and designing the investigation and conclusion. In the last interview, although all students understood that scientists used their creativity and imagination during investigations, most students did not claim that scientists use their creativity and imagination after collecting data for making a conclusion.

Case Study Two: Chatchai and students

1. General of Teachers' Background

Chatchai is fifty-five years old and received his Bachelor of Education degree, majoring in Chemistry-Biology, from the Khon Kaen University and has taught science at different grades for 32 years. Currently, he has been teaching for 15 years at the Rama School in level 3 (grades 7-9) and biology in level 4 (grade 10-12). Chatchai was proud to be a science teacher and wanted to be a science teacher since high school because he liked science and mathematics and had good grades in both subjects. Additionally, his uncle was a good teacher, so he wanted to be a good teacher too.

According to Chatchai, the aims of science teaching were to maximize students' achievements and responsibility for their own learning. He perceived that scientific knowledge and scientific processes were important knowledge for students to possess in real life. For teaching and learning in science, Chatchai seemed to believe that knowledge was an entity that one can retain or remember and learning was a cumulative process, rather than a constructivist process. Students it was believed entered the classroom with a lack of knowledge, and his aim was increase their amount of knowledge. He felt that teaching science in the present was more difficult and different in the past particularly after the education reform which occurred in Thailand in which there were many changes such as the organization of the science content, the teaching approaches, the aims of science teaching, and the technology used for instruction.

"I seemed to be running after something. Many things were changed such as from a teacher centered approach to a student centered one. In the past, we (teachers) talked and ordered the students to do the experiments. Now, it was not a good way of teaching." (First focus group discussion)

Chatchai accepted that he was not good in using technology in his teaching such as the computer and internet. This was his weakness in teaching science. He was not able to develop new materials or innovations for helping students to learn science. During a five year period, he attended a professional development program three times that focused on teaching and learning science, the development of the science curriculum, authentic assessment procedures and student-centered instruction.

2. Teacher's Understanding of the NOS and the Inquiry-based Approach and Her Practices before the Implementation of the Unit

In this section, a description of Chatchai understands regarding the NOS and the inquiry-based approach will be presented. The data was collected from an interview before Chatchai's implementation of the respiration instructional unit.

2.1 Understanding of the NOS

The result of Chatchai's understanding of the NOS before his implementing the respiration instructional unit was divided into the understanding of the related scientific knowledge based on empirical evidence, scientific knowledge as socially constructed, science as social activity, the role of creativity and imagination, the tentative nature of science, and the diversity of the scientific method. The results of the interview and the questionnaire are used to generate three categories of understanding, naïve, mixed, and informed understanding.

As the result, Chatchai held an informed understanding in three aspects of the NOS namely scientific knowledge based on empirical evidence, scientific knowledge as socially constructed and diversity of the scientific method. There were three aspects of the NOS that he held a mixed understanding were the role of creativity and imagination, the tentative nature of science, and science as social activity. The descriptions of Chatchai's understanding in each aspect are presented below.

2.1.1 Scientific Knowledge Based on Empirical Evidence

With regard to the nature of scientific knowledge, Chatchai understood that the characteristic of scientific knowledge is logical, reasonable and reliable knowledge. Thus, the evidence is of most importance to scientific knowledge. Moreover, having the evidence makes science different from the other knowledge claims or beliefs. He stated:

"Scientific knowledge is confirmed by the experiments or observations of many scientists. I believe that it is not science if it is without confirmation by the evidence such as graphs or pictures. It just becomes a belief that is not testified as truth or reliability. Nobody accepted it as science. "

Additionally, Chatchai understood that the data from the experiments are the evidence for supporting the explanation or hypothesis. The confidence of scientific knowledge depends on the trustworthiness of the data. The scientists can explain their experiments and others can repeat them.

2.1.2 Scientific Knowledge as Socially Constructed

To construct scientific knowledge, Chatchai exhibited informed understanding that scientific knowledge is accepted by the scientific community. He claimed that the trustworthiness of scientific knowledge depended upon the trustworthiness of the data collected by others. He explained that trustworthy data meant data that "scientists should share and have to show to other scientists where their results came from so other scientists can make a decision as to whether the results will be accepted or not by the scientific community. The method of gathering the data must be easily repeated and the same data gotten as a result so it can be checked to be correct."

When Chatchai was asked about how scientists' work, Chatchai noted that scientific works are carried out by both individuals and in groups. Moreover, scientific knowledge is not clearly separated into three fields namely biology, chemistry, or physics as most scientific knowledge is shared by all three. For example, the knowledge of respiration is derived from the knowledge in biology and chemistry. Thus, groups of scientists can include scientists from many different fields of science.

2.1.3 Diversity of Scientific Method

Chatchai viewed science as the study of scientists by using the scientific method to explain the environment or the natural phenomena in terms of biological and physical science. The existence of a scientific method is unique for science and presents the objectivity of science. To understand the scientific method, Chatchai understood that a scientific method is a set of orderly steps, in particular the sequence of observation, question, hypothesis, experimentation and construction of knowledge. However, the scientific method is flexible, not rigid. He said that "Although, it is based upon sequences. I believe that in real situations, scientists may follow or fall back on those sequences."

As for the diversity of scientific method, Chatchai held an informed understanding that scientific knowledge is derived from a variety of scientific method such as experiment, observation, surveying and dissection. However, he did not clearly separate these methods.

"The experiment involves testing something, I think. The observation and survey are similar to observing and writing the data or something. For a survey, I think, you must observe. Dissection is the study of and observation about the organs of living things."

2.1.4 The Role of Creativity and Imagination

As for the role of creativity and imagination in science, Chatchai understood that it is related to scientists' work in terms of inventing something new and in some stages of the scientific process.

"Creativity and imagination play a large role in creating new technologies or inventions. Additionally, scientists use imagination for thinking why these (the phenomenon) occur. It seems that scientists use their imagination for formulating the hypothesis. I think that the creativity and imagination is used for designing the experimental procedures or used for presenting the results."

Nonetheless, Chatchai did not indicate that scientists use their creativity and imagination for making the conclusions or for the invention of explanations, models or theories. He understood that the scientific processes require logical and objective thinking more than creativity and imagination.

2.1.5 The Tentative Nature of Science

Regarding the tentative nature of science, Chatchai commented that scientific knowledge can be changed because of scientists' work, the new data or better data that is the result of new technologies. When asked how scientific knowledge can be changed, he understood that scientific knowledge can be abandoned and modified over the time. He referred to the history of photosynthesis:

"I think about the history of the photosynthesis. At the beginning, Helmont believed that water is the only the source of the extra mass of plants. Water is the source of plants' life. After that, there were many scientists who studied the process of photosynthesis. Now we know that it is not related to only the water but also light, CO_2, and chlorophyll. We now know the chemical processes in detail."

As for the reason why the scientific knowledge is abandoned, Chatchai noticed that at that time, such knowledge is either uncertain or wrong because of the limit of data, technology and investigation. However, he did not identify that the scientific knowledge is uncertain because of the reinterpretation of exiting data or observations or new competing ideas.

2.1.6 Science as Social Activity

As the relationship between science and social activity, Chatchai held a mixed understanding in this aspect. He did not separate science and technology when discussing the relationship between science and society. Also, he understood that science is importance for the development of society as a modern society. Science meets the social needs and demands of society such as convenience, or in areas of the medical profession.

However, Chatchai did not voice any concerns about the negative impacts of science or technology upon society. He understood that the scientific knowledge is accepted or judge by other scientists. He viewed scientists as objective persons. He separated the scientists from their cultures, biases, or backgrounds. Also, he believed that scientists had a responsibility to inform the public of any new knowledge correctly.

2.2 Understanding of the Inquiry-based Approach

Chatchai's understanding of the inquiry-based approach included three domains. The first prominent domain was that students learn by doing. When Chatchai was asked, "What does the inquiry-based approach mean to you?" he described the general meaning of inquiry and inferred to the process of inquiry-based approach as:

"Inquiry is searching or studying something that creates curiosity. I think that inquiry-based approach is teaching in which students must search or do activities or do whatever to get information or knowledge. Students must do it by themselves."

He described learning by doing as including the searching and presenting of information about content knowledge and applying what has been learned to real life, and experiments. According to Chatchai, searching and presenting the information was one part of the learning by doing inquiry-based approach. He claimed the following about the meaning and process of searching and presenting the information that:

"It (searching) is a way to find information or answers from many resources such as the library, the internet or asking someone. I asked students to search and present what they learned either during or after they have learned it and either make a report or present the information in the class."

As the issue or topic for students to search, he said that it may be the content that they will learn next or information related to the application of the knowledge or details of information beyond their textbook. Moreover, he explained the importance of searching and presenting information that this is useful for other students and saves the time to teach. They could share their information.

Another part of learning by doing in science involves the experiment. He thought that an experiment was a method of inquiry that was particular to the subject of science. For his description of an experiment, he used the term experiment to mean observation, surveying and true experimentation. For example, he described how students make inquiries about an ecosystem as "I assigned students to do an experiment by surveying the plants in the school area." However, the purpose of having the students do the experiment was a better retention of knowledge, and not just answering questions or construction knowledge. He viewed the experiment the same as a practical activity.

The second domain, the inquiry-based approach required structure and direction. When asked Chatchai thinking about the teachers' role of inquiry-based approach, he responded that the teacher has to prepare the materials and the topics for the students to search information about, set the activities to study. In a classroom, the teacher has to explain, manage and control the students and follow the lesson plan. The teacher's role in an experiment activity, he thought that teacher provides the necessary directions for the students to achieve success when performing experiments and to save time in order to have more time to do the experiments.

According to Chatchai, the level of best type of inquiry process was a structured inquiry. As for the processes of the investigation, he claimed that the questions for the students' investigations or experiments came from the textbook or from the teacher. Furthermore, he told the students the hypothesis and the procedure for students. He explained why he had to tell the students the experiment steps by:

"In the past, I provided the students with the opportunity to design their own experiments but some students were unable to do so correctly or did not do anything at all. It took up far too much time. I worried. So, giving them the procedure should be good, and it saved time."

The third domain, the inquiry-based approach focused upon the students as active learners with some responsibility for their own learning. As already described, Chatchai understood that the inquiry-based approach involved students doing something by being active. Thus, when asked about the students' role, he explained that students should be enthusiastic and pay more attention and have more responsibility towards their task because they must do it by themselves. He expressed concern about the role of students if the inquiry-based approach is to be effective. He said that:

"If students had less responsibility or did not pay attention to their task, teaching would not be successful. Sometimes students did not do anything or I told them to bring something for an experiment, and they did not bring it. Then I taught by lecturing them."

2.3 Teaching in Respiration

In this section, Chatchai's typical method of teaching respiration and his instructional practices as they related to his understanding of the inquiry-based approach and the NOS are described here. Because Chatchai's participation in this study happened after one participant dropped out the researcher did not observe his teaching on the respiration topic. Therefore, the data from the interview was analyzed using his description of his typical method of teaching respiration and two classroom observations during which he taught the topic of digestion. We analyzed his instructional practices as they related to the understanding of the inquiry-based approach and the NOS.

Chatchai taught the topic of respiration in grade 11, second semester. His instructional sequence was based on the teachers' manual of the IPST. Table 5.3 shows a brief summary of the instructional sequence used by Chatchai. The respiration unit was comprised of two main topics namely cellular respiration and the exchange of gases. There were two sub-topics in cellular respiration namely aerobic respiration and anaerobic respiration. There were two sub-topics in the exchange of gas organs namely the gas exchange organs of Protists and animals, and the structure and functions of gas exchange organs in humans. He claimed that he used the inquiry-based approach in the sub-topics namely anaerobic respiration and the gas exchange organs of Protists and animals. For the other topics, he did not create any activities for the students to do. He taught using a lecture with diagrams and pictures.

In aerobic respiration, he taught using the lecture with diagrams and the picture from the IPST textbook and some diagrams and pictures from other sources such as the biology textbook and the internet. In anaerobic respiration, he said that he taught using inquiry by having students do the experiment about yeast fermentation. He described the process of student experimentation regarding yeast fermentation as structured inquiry. He assigned students to do the activity in groups and gave them the directions of how to do the experiment. Students collected data and wrote their results on the worksheets. After that, the teacher and students made the conclusions together. He assigned students to search for information about fermentation in real life and then they could either present their findings in class or write a report depending upon the amount of class time he wanted to use. However, he said that he still lectured and summarized the knowledge for the students about the chemical processes of anaerobic respiration.

In the gas exchange topic, he assigned students to search for information and present the exchange of gas in Protists and animals in the class and then he explained in detail the process and summarized the function and structure of the gas exchanged organs for the students. For the structure and function of the gas exchange organs in humans, he claimed that during the last three years; he taught this topic by using the demonstration that involved the dissection of a pig lung. However, he often taught the same topic using a lecture methodology a power point presentation to show structures and diagrams. The way to teach the knowledge of respiration Chatchai reflected back on his understanding of the inquiry-based approach is that students learn by doing something like searching, experimenting, and presenting. Although he accepted that the NOS should be integrated into the teaching of all content, however, he did not emphasize the NOS both in the objective and the activities of the lesson.

The classroom observations took place in two hours of the teaching of digestion of living organisms and two hours of teaching the digestion of lipids. Chatchai said that he used inquiry teaching for these topics. The data from classroom observations mirrored Chatchai's understanding about the inquiry-based approach in that students participated in activities such as searching and experimentation. He motivated students to do inquiry by asking them question. However, students rarely had opportunities to acquire the knowledge or construct the knowledge themselves. He often gave them the correct answers and briefly summarized more than discussed with the students or let the students find the answers from the activity. For example, in teaching the digestion of living organisms, he wanted students to read the information about the digestion of each living organism and then summarize it. He introduced the students to the topic by asking students.

Chatchai: What are the digestive organs of animals?
Students: Stomach and intestine.
Chatchai: How about the digestion of microorganism, amoeba, paramecium? Do you know?
Students: Quiet.

Chatchai: For microorganism, they do not have a specific organ because they are usually single-celled but for higher leveled, multi-cellular organisms they have special organs for digestion such as the stomach or intestines. You will learn about these organs in the next activity.

For the student investigations, Chatchai's role was a director of the activity and the students the performers of the activity. He explained the directions of the experiment, the objectives of the investigation to the students, but he let the students collect the data and make conclusions regarding any results they determined. However, he did correct their writing of the observation and conclusion. He never really provided the students with an opportunity to add to their already learned knowledge as such there was no scaffolding happening. After each group of students read, answered the questions pertaining to the topic and summarized the information regarding digestion in living organisms, he then randomly chose a group to answer questions not hearing from all groups in turn and then he, himself made a power point presentation describing in detail digestion in living organisms.

Table 5.3 Summary of Chatchai's Teaching of Respiration before Implementation the Respiration Instructional Unit

Topics	Sub-topics	Time	Activities	Materials
Cellular respiration	Aerobic respiration	8	- Teacher lectured on the process of aerobic respiration. - Students answered the questions and were tested	1. Diagrams in student text book and internet.
	Anaerobic respiration	3	- Students investigated anaerobic respiration in yeast. - Teacher lectured on the process of anaerobic respiration. - Students searched for information and presented about fermentation occurring in real life situations.	1. Material for yeast activity 2. Diagrams in student text book
Gas exchange	Gas exchange of Protists and animals	3	- Students searched the information and presented about gas exchange in Protists and animals. - Teacher lectured in detail	1. Pictures of gills and a trachea 2. The pictures in student text book
	The structure and functions of gas exchange organ of human	8	- Teacher lectured on structure and function of gas exchange organs of humans.	1. Diagrams in student text book 2. PowerPoint presentation
	Total	22		

3. The Implementation of the Respiration Instructional Unit

3.1 Teaching Context

Chatchai began the implementation of the respiration instructional unit in the first week of December, 2007 and finished in the last week of January, 2008. During that time, there was one week for the New Year holiday and one week for midterm examinations and sport activities. As a result the implementation time was 22 hours, much more that the time he had planned. Below is a description of the impacts of the respiration instructional unit, teaching context and teacher preparation.

In Chatchai's classroom, there were 37 students, 26 females and 11 males. He commented that the students had moderate to high GPA and were successful in general in school. However, they had a moderate achievement in content and their ability to use the science process skills as compared with students of other schools in Ayutthaya province. According to Chatchai's criterion, students were divided into groups by mixed achievement levels including their; GPA, grade in biology, level of science process skill ability, and gender. Two groups of students were selected randomly to be participants in this study for assessing their understanding of the NOS and the key concepts of in the knowledge of respiration. The observation periods in Chatchai's class included 16 class periods, 55 minutes each.

Chatchai taught biology in the biology lab that was located on the first floor of the school building. The size of the room was 8×10 m. This room had originally been a study room and had been renovated into a science. There was one lab counter and one sink in the front of the room for teacher and students and on the right side of the front lab counter was a computer desktop for the teacher. The front of the room had a wall-mounted horizontal whiteboard and on each side of it next two bulletin boards displaying models of the kidney structure and colorful posters of science information. There was one hanging projector monitor in the front of the classroom and one wood cabinet for showing student prizes and awards. There were windows on two sides of the room. Two computers for students were located at the right side of the room. One refrigerator and lamina air-flow cabinet were located at the left side of the room. In the middle of the room there were tables for nine groups of 4-5 students to sit on individual chairs. This room had just one door at the right back of the room and next to it on its side there were six wood cabinets to store microscopes, chemical substances, science equipment and supplies. Figure 5.14 showed the Chatchai's classroom.

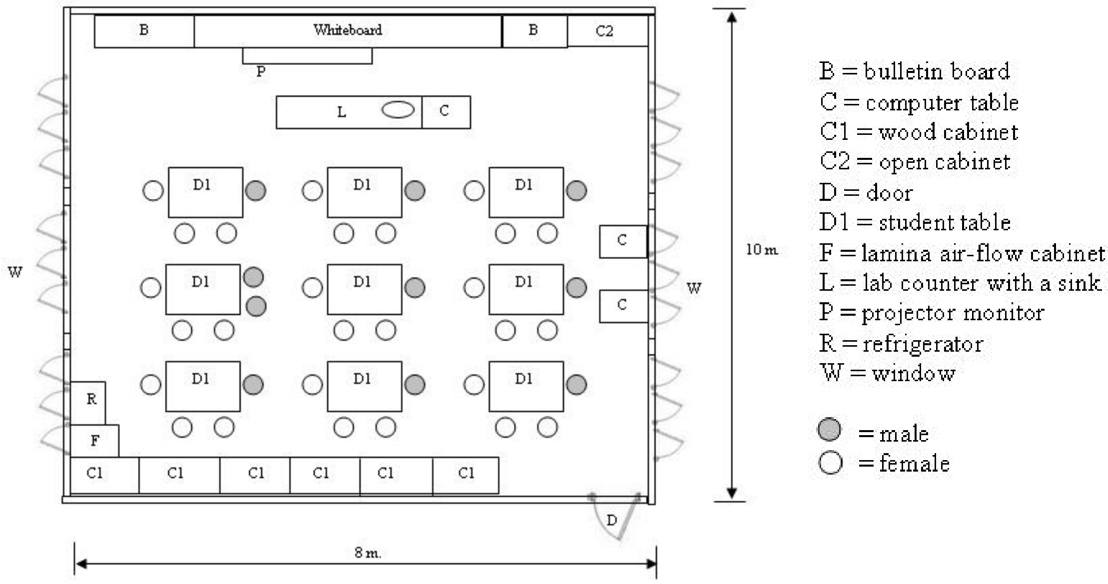

Figure 5.14 Chatchai's Classroom Setting

3.2 Teacher Preparation

In the first period of the implementation, Chatchai spoke briefly with the researcher about the objectives and the activities. In his initial teaching of the implementation package, Chatchai was quite nervous and it showed in his teaching. He read the lesson plan and followed it step by step. After finished the lesson, he said he was worried about being able to internalize the steps of the lesson and therefore had to read the lesson plan and check it often and because he had to do this he was not prepared enough to discuss the history of respiration with the students. After that experience, he prepared more and checked his understanding about the objectives, the sequences of teaching, and the questions with the researcher before continuing to teach. Moreover, because he was worried about his teaching style Chatchai often gave or explained the concepts for the students rather than having them find the answers by themselves. He often said, “I worried that they will not get the knowledge and “it is hard for me to wait for students to answer or ask questions until they understand the concepts.” However, he did try hard to wait for students to answer questions and discuss their answers with before just telling them the right answers.

3.3 Students’ Understanding of the NOS and the Key Concepts of Respiration

In this section, the impact of the implementation of the respiration instructional unit on students’ understanding is described into two topics namely the NOS and the key concepts of respiration.

3.3.1 Development of Understanding of the NOS

The students were primarily placed in three categories: naïve, informed, and mixed understanding on the six aspects of the NOS namely scientific knowledge based on evidence, the role of creativity and imagination, the tentative nature of science, scientific knowledge as socially constructed, diversity of scientific method, and science as social activity. Table 5.4 summarizes student understanding, with a one in each aspect of the NOS from pre and post interview. The symbols were used to represent each student. For example, CA1 meant student No.1 from group A of Chatchai’s classroom, and CB2 meant student No.2 from group B of Chatchai classroom.

Table 5.4 Development of Chatchai Students' Understanding of the Six Aspects of the NOS from Pre and Post Implementation

Students	**Evidence**		**Creativity and imagination**		**Tentativeness**		**Socially constructed**		**Diversity of method**		**Social activity**	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
CA1	M	I	M	I	M	I	N	I	N	I	M	I
CA2	M	I	M	I	M	I	N	I	N	I	M	I
CA3	M	I	M	M	M	M	M	M	N	I	M	M
CA4	M	I	M	M	M	M	M	M	N	M	M	M
CB1	M	I	M	I	M	I	N	I	N	I	M	I
CB2	M	I	M	I	M	I	N	I	N	I	M	M
CB3	N	M	M	I	M	M	N	M	N	M	M	M
CB4	N	M	M	M	M	M	N	M	N	I	M	M

I = informed understanding

N = naive understanding

M = mixed understanding

A. Scientific Knowledge Based on Evidence

For the first interview, six students exhibited a mixed understanding about the nature of evidence in science. They defined science as the knowledge that explains and predicts natural phenomena. They understood that scientific knowledge requires the evidence. However, they held a naïve understanding that such knowledge has been proven and can be repeated by someone to show the same results or data as evidence that the knowledge is correct and is indeed scientific knowledge. Moreover, they noted that the evidence which supporting scientific knowledge come directly from an experiments or observations. Two students showed a naïve understanding that science is all around us and that scientists made discoveries and they could reasonably explain their scientific discoveries. They did not indicate that there needed to be data or evidence to support scientific knowledge.

During the implementation, when asked students about their conclusions and the scientific knowledge in their investigations in terms of the evidence, two students changed their naïve understanding to show an appreciation for the importance of evidence to support their conclusions in their investigations. However, they indicated that their conclusion came directly from the investigation that excluded any inferences, and they held this mixed understanding until the last interview. As for six students who held mixed understandings, they showed positive change between the second and third interviews. They noted that their conclusion came from an interpretation of the data and the trustworthiness of the conclusion depended upon the data gathered by doing the experiment and making observations. In the last interview, they held an informed understanding about the evidence in scientific knowledge, and they were able to give specific examples and questions that related evidence to science.

CA1: "The history of Krebs cycle came from Krebs who collected data from experiments. I remembered the table that showed the names of scientists and the enzymes or chemical substances that were found, but I could not remember who found them. I knew that it was evidence for Krebs. He did not just think or dream about it". (Last interview)

CB2: "When we explain something, we have to show the evidence. For example, how yeast performs respiration or what is the factor of the rate of respiration. We have to show the data or graph from the experiment and be able to explain them". (Last interview)

B. The Role of Creativity and Imagination

In understanding the role of creativity and imagination before the implementation, all students showed mixed understanding of the role of creativity and imagination. They noted that the scientists use their creativity and imagination for the invention of new things such as new technologies, materials, or new experiments and for some stages of a scientific investigation namely in the formulation of a hypothesis and when planning and designing the investigation. Six students disagreed that scientists used creativity and imagination for making a conclusion from the data or to construct the knowledge because they understood that scientific knowledge is based on the evidence without imagination. Moreover, all students did not explain the role of creativity and imagination in creating the explanations, models, or theories.

As for the interview about the role of creativity and imagination in student investigation, in the experiment about the factors of the rate of yeast respiration, three students thought that they used creativity to formulate their hypothesis, to design their experiment, and to present their data. Five students indicated that they used creativity during their experiment including in their interpretation of the data. This result differed from the result of the interview about the dissection of the gas exchange organs in animals. In general all students still understood that they used creativity and imagination during activity. However, three students thought that their creativity and imagination were only used to present their data. Five students thought that they used their creativity for concluding the general structure that was appropriate to gas exchange and the presentation of their results. All students understood that they did not create or design the dissection procedure. One student gave the reason that:

CA3: "We used a general method. We used the scalpel and carefully observed. We did not create any new procedures". (Third interview)

The results from the last interview showed that three students still held mixed understanding that creativity and imagination are used in some stages of scientific investigation excluding the interpretation of the data, and there are used for the invention of new things such as technologies or materials excluding the explanation or models. Five students changed from a mixed understanding to informed understanding. They understood that the creativity and imagination are used in all stages of scientific investigation including the formulation of a hypothesis, the design of the investigation and interpretation of the resulting data. Two of them could show examples of using creativity and imagination for construction the knowledge of the Krebs cycle and Glycolysis. Moreover, all of them indicated that scientists use their creativity and imagination for inventing the models. For example,

CB2: "Creative thinking was used for creating a model similar to our lung model but they (scientists) can create the perfect model and good work more than us." (Last interview)

C. The Tentative Nature of Science

For the first interview, all students exhibited mixed understandings regarding the tentative nature of science. They understood that scientific knowledge can change. There were two reasons that they used to explain why scientific knowledge can change, time and the discovery of something new like data, information, technology, research methods, and discoveries. Nevertheless, none of them mentioned the reinterpretation of existing of data or gave the examples of scientific knowledge that had been changed. Although they did describe two kinds of changes: knowledge is added in detail; knowledge is replaced or abandoned. They most closely understood that knowledge is added in detail more than knowledge is abolished, especially the scientific knowledge that they learned in school and found in textbooks. Most of them gave the reason that because such knowledge had been proven and accepted as truth and right for long time. For example, one student gave the reason that:

CB3: "It (scientific knowledge in student textbook) is truth for long a time. Such knowledge that we learn is certain. We can repeat the experiments for proving and get the same results." (First interview)

As for the second interview in the experiment about the factors of the rate of yeast respiration, four students believed that different persons will come to the same conclusion when confront with the same data. Therefore, their conclusions can be changed only if they find that they do something wrong or they got new data. Although, they understood that some knowledge that relates with the rate of yeast respiration such as the rate of any reactions can be determined by measuring the rate at which the substrates disappear or the products appear and the chemical equation of cellular respiration can change. However, such knowledge cannot be abandoned because it is basic knowledge that has been proven and accepted as truth for a long time. They still held these understandings when asked about the dissection of gas exchange organs in animals in the third interview. They claimed that the knowledge of the general structure of gas exchange organs cannot be abandoned because it is fact and facts cannot change. For example, one student said:

CB4: "A gill still is a gill and has the similar structure, and it is used for gas exchange. It cannot be changed. Fish and prawns will forever use gills for gas exchange organs unless someone finds a new different organs or finds a new species. The number of the kind of gas exchange organs may then be changed" (Third interview)

On the other hand, four students believed that probably different conclusions came from the same data because of different thinking and inferences. As for the knowledge that related with to both investigations, they believed that such knowledge may be changed by adding details or abolishment because of new data, new evidence, and reinterpretation. For example, one student said that “may be in the future, scientists will nave new knowledge or more information. Scientists will then think about the past, the new knowledge and rethink things.” (CB1, Second interview)

After the implementation of the unit, four students held mixed understanding that scientific knowledge can be changed in terms of adding more rather than abolishment because of new data or new discovery. Although two of them could give an example of how knowledge learned in the past about respiration was discarded they thought this change occurred because the new data proved it wrong rather than a reinterpretation of the existing data causing the change. For example, one student said: “in the past from history, we believed that we breathe because we want the air to cool the heat of our heart. Now, we know that it was wrong.” (CB3, last interview)

There are four students who exhibited an informed understanding that scientific knowledge can be changed in terms of the addition of more detail, replacement or abandonment of details because such knowledge was constructed from an interpretation of the data. For example, one student said about the history of respiration that:

CA1: “When many scientists study or experiment, they find more knowledge such as they now know about oxygen, carbon dioxide and its structure and property. They got more understanding and rethought through respiration as to why we have to respire. The explanation of Galen was unbelievable. ” (Last interview)

D. Scientific Knowledge as Socially Constructed

As for the results from the first interview, there were six students held that a naïve understanding and two students that held a mixed understanding of scientific knowledge as socially constructed. For the naïve understanding students of which there were six, they understood that scientific knowledge was straightforward from the data of the investigation. The scientists were unbiased and the conclusions corresponded to their data and anyone could reproduce the data if they did the same experiment without bias or error. They ignored any arguments about conclusions from the others. Two students that held a mixed understand said that scientists either work individually or in groups and they should share their results, conclusions and explanations for their conclusions with other however they understood they understood that scientists try to find errors rather than try to build on knowledge.

In the interview with the students about their investigation they understood that the process of drawing conclusions happened by discussion within their group and in the classroom with the teacher. They indicated that their working through the process of presentation and discussion was similar to the scientists working. However, only four students exhibited understanding that the purpose of discussion about the conclusion is shaping their conclusion to increase completion of a conclusion and this is not the same as the scientists. They said like this: "however, it (conclusion) is not totally the same as scientists because they have more knowledge and are cleverer and they do it again and again. But when we presented our conclusion, we will adapt our conclusion to be more complete." (SB1: third interview)

As for the last interview, all students accepted that scientists can do both individual and group work. The scientific knowledge derived from the findings of many researches and fields however, there were four students who held a mixed understanding that group work, presentations and discussions by scientists only showed evidence that supported and validated the scientific knowledge learned from their research in many fields of science. This was contrasted by the four students who held informed understanding that scientific knowledge is constructed and interpreted based upon the background knowledge, logic, creativity and imagination of scientists. Therefore, the argumentation and sharing of ideas was only one part of scientific knowledge construction. They could relate their performance to those of scientists working in groups using terms like cooperation and sharing of ideas. They think like this:

CA2: “Scientists present their finding and discoveries to others. It is the same with our discussions about the conclusion we tried to make clear explanations and accept them together as a group.” (Last interview)

E. Diversity of Scientific Method

As for the first interview, all students held naïve understanding that the scientific method which is the experiment’s structure, ordered and certain way of doing. They said similarly that, “the scientific method is a group of orderly steps that start from observation and curiosity about natural phenomena and then formulate a hypothesis and do the experiment looking for a conclusion to their question.” (CA1, First interview) In addition, they understood that the observation or survey is the experiment or initial step of the experiment and they can find the answer if they follow the orderly steps of the scientific method.

When students were asked about the meaning of the experiment in the second interview and third interview, five students clearly understood about the meaning of the experiment that the experimental study relates with the variables or factors, testing and comparing variables since the second interview. In addition, they explained the difference between the dissection study and the experimental study is in terms of manipulation and variable in the third interview. For example, one student explained the comparison of the dissection and the experimental study and said, “We did not test anything like in an experiment. We just dissected and observed it. It did not have a control set and an experimented set.” (CA2, Third interview) While three students failed to understand the meaning of the experiment in the second interview, one of them developed understanding about the meaning of the experiment and explained the differences between the dissection study and the experimental study in the third interview.

Result from the last interview showed that six students held informed understanding about the diversity of the scientific method. They exhibited understanding of the existence of more than one method of science and distinguish among the aspects of the experiment and an observation. Moreover, three of them gave examples of the knowledge of respiration development that came from more than one method. For example:

CB2: "The development of knowledge about gas exchange came from experiment and observation. When we study the structure of organ we observed them in the study of mechanism, we must do experiments." (Last interview)

F. Science as Social Activity

When students were asked about the relationship between science and society, all students held mixed understanding that science affects society however; they ignored that society affects science as well. They understood that science is an important part of society development including healthy, technologies, economic, prosperity, and convenience. For example, one student said,

"Science helps discover medicines that cure us of sicknesses and things like that" (CA3, First interview)

There was no student understanding that the values and expectations of the culture determine what and how science is conducted, interpreted, and accepted.

As for the last interview, five students did not change their understanding about the relationship between science and society. Although some of them understood that scientific knowledge is interpreted based on background knowledge however, they did not claim about society and culture that scientists are immersed in during their daily lives. While three students exhibited the informed understanding that not only scientists but also people from society contributed to science. Science is influenced by the society and culture in which it is practiced. For example

CA2: "They (science and society) are interacted each other. Science has to follow the needs and demand of society and scientific knowledge may be evaluated from society."

Researcher: "What do you mean "evaluated"?"

CA2: "It seems if people are interested in whatever, it is studied and experiment. Such knowledge is distributed and utilized."

(Last interview)

3.3.2 Development of Understanding of the Key Concepts of Respiration

Before and after implementation of the respiration instructional unit, eight students were asked to respond to the respiration concept survey and interview. The result of pre surveying were used as a baseline for explaining the development of student understanding about the key concepts of respiration in four main topics namely the definition of respiration, aerobic respiration, anaerobic respiration, and the relationship between cellular respiration and gas exchange. Before describing the development of student understanding regarding their knowledge of respiration the results of the pre survey are described below.

Before the implementation, all students held alternative conceptions about the four concepts related to the definition of respiration. Three students (CA4, CB2, and CB4) defined respiration as breathing in and out while five students (CA1, CA2, CA3, CB1, and CB3) explained the meaning of the respiration in terms of the respiratory system. For example, CA2 explained that:

"Respiration is taking in oxygen from the air into the body through respiratory organs such as the nose, trachea and lungs. Also it takes out carbon dioxide as a waste product of the body back into the air." (Pre interview)

All students understood that the purpose of respiration is to provide oxygen for survival. However, they did not explain the role of oxygen to survival. In addition, they failed to understand anaerobic organisms. They understood that all organisms must use oxygen to remain alive. None of the students related the nutrients or organic substrates with the respiration. All students held alternative conception that the food is used to give us energy to move, to breathe, and many other activities directly after digestion and absorption, without the cellular respiration process. Moreover, three students could not explain the relationship between cellular respiration and gas exchange in terms of oxygen, carbon dioxide, and producing energy. Five students, who explained this relation, were categorized in an alternative conception pattern 1 (figure 5.6). They understood that we wanted more energy when we exercise and we got it from taking oxygen in and breathing out carbon dioxide.

As for which organisms respire and when, four students (CA4, CB2, CB3, and CB4) understood that respiration occurs just only in plants and animals, it did not occur in microorganisms. They gave the reason that microorganisms are small organisms, thus oxygen and carbon dioxide could diffuse into the cell directly. Although four students (CA1, CA2, CA3, and CB1) understood that respiration occurred in all organisms including microorganisms, they however, gave the reason that the purpose of respiration is taking oxygen into the body and cells of living things so they can stay alive. Microorganisms are living things thus they have to respire.

According to the meaning of respiration of students, all students understood that plants respire in their leaves, stomata, roots, or stems for gas exchange. Moreover, they understood that plants respire only at night. Six students (CA2, CA3, CA4, CB2, CB3, and CB4) gave the reason for this understanding as the oxygen came from the process of photosynthesis which is used in the respiration process and this can only happen at night when the sunlight is unavailable. Two students (CA1 and CA2) gave the explanation that the respiration process changed oxygen to carbon dioxide and the photosynthesis process is an opposite reaction to respiration. When students were asked why plants will die when they are flooded, all students held alternative conceptions that plants die because they cannot respire and the root is rotten so they are deficient in oxygen and nutrients.

After the implementation, all students understood the definition of respiration as being a chemical process that breaks down organic substrates to make energy available for the metabolism process that occurs in all living organisms. However, there were some students who held alternative conceptions about the four concepts related to the definition of respiration. Three students (CA4, CB1, and CB4) held alternative conception about respiration in plants that only cells of leaves and roots perform respiration for producing the energy for whole plants because leaves and roots were used for gas exchange. Contrasted with animals, particularly human, all cells can perform respiration because they had the circulatory system to transport oxygen and carbon dioxide. Two of them (CA4 and CB4) held alternative conception that glucose is only organic substrate for the respiration process to release energy. Plants respire only at night because the respiration is opposite to photosynthesis. There were five students (CA1, CA2, CA3, CB2, and CB3) who exhibited correct conceptions of the definition of respiration in all four concepts (Figure 5.2).

As for the concepts of aerobic respiration, there were two students (CA4 and CB4) who were categorized in the alternative conceptual pattern 1 of aerobic respiration (Figure 5.7). Two students (CA3 and CB1) were categorized in the alternative conceptual pattern 3 of aerobic respiration (Figure 5.9). Four students (CA1, CA2, CB2, and CB3) were categorized in the alternative conceptual pattern 4 of aerobic respiration as shown in figure 5.15. This pattern differs from the others that students understood the role of oxygen as a terminal electron acceptor in the electron transport chain. However, they ignored the water which is one product of respiration that comes from the electron transport chain that relates with oxygen as a terminal acceptor. Moreover, they did not explain how where heat comes from during the respiration process.

As for the knowledge of anaerobic respiration, two students (CA4 and CB4) were categorized in the alternative conceptual pattern 1 of anaerobic respiration (Figure 5.10). Four students (CA3, CB1, CB2, and CB3) were categorized in the alternative conceptual pattern 2 of anaerobic respiration (Figure 5.11). There were two students (CA1 and CA2) who exhibited correct conceptions of anaerobic respiration as follows in figure 5.4. They added more understanding that some aerobic plants and animals are able to use anaerobic respiration for short periods of time. They indicated correctly about the amount of ATP and CO_2 and the step was its producing. Moreover, they explained that aerobic plants and animals are able to perform Glycolysis when oxygen is not enough and perform fermentation related with the balancing between $NADH_2$ and NAD^+.

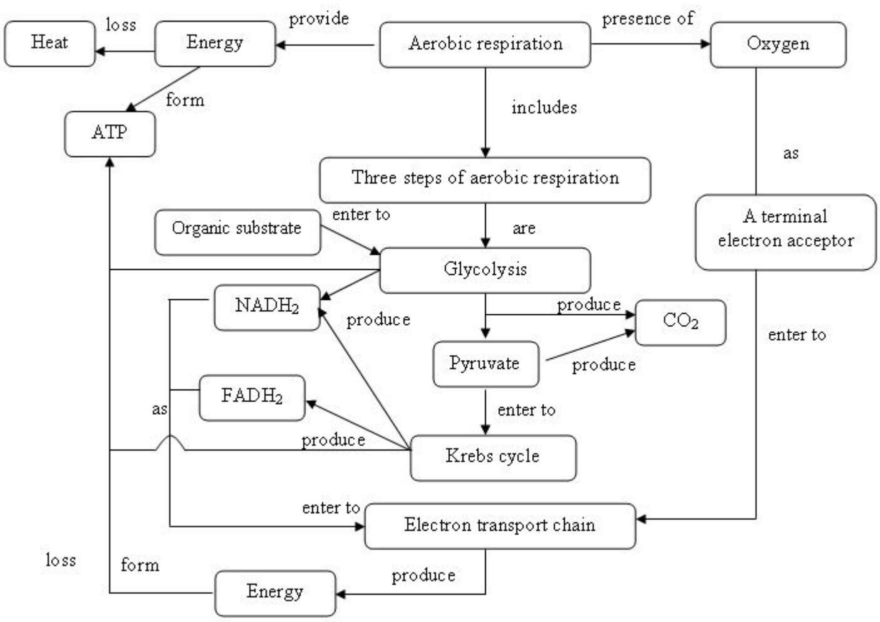

Figure 5.15 Alternative Conceptual Pattern 4 of Aerobic Respiration

As for the relationship between the cellular respiration and gas exchange, CA4 was categorized in the alternative conceptual pattern 2 of the relationship between cellular respiration and gas exchange (Figure 5.12). Five students (CA3, CB1 CB2, CB3, and CB4) were categorized in the alternative conceptual pattern 3 of the relationship between cellular respiration and gas exchange (Figure 5.13). They indicated that oxygen from breathing in entering the cellular respiration process for producing energy and carbon dioxide which is breathed out came from cellular respiration. However, they could not explain the role of oxygen to produce energy. There were two students (CA1 and CA2) who exhibited correct conceptions of the relationship between cellular respiration and gas exchange as follow in figure 4. They clearly understood about the role of oxygen which as the terminal electron acceptor to produce energy, in particular ATP.

3.4 Teaching Practices and Students' Understanding

Chatchai's teaching practices are described in two sections as his teaching practices influence on students' understanding the knowledge of respiration and the NOS. Data from classroom observation field notes, focus group discussions, and students' interview were analyzed for describing both sections.

3.4.1 Teaching Practices Related with Students' Understanding the Knowledge of Respiration

There are two themes regarding the relationship between Chatchai's teaching practices and his students' understanding of the knowledge of respiration. Each theme is described as follows:

Theme 1: Making clear students' understanding about their activities and linking the concepts from one activity to another is helping students to success in their construction of knowledge.

As for Chatchai's implementation, he tried to change his role in the class from lecturer to facilitator. At the beginning of each activity, he tried to make sure that students understood their tasks by asking question and giving clear explanations before let them start. This assisted students as they took on more responsibility for their learning.

The data from classroom observation field notes showed that Chatchai emphasized that students understand about the objectives of the activity before they did the activities. He asked many questions to make sure that students understand the procedure of the activities and they would do the activities by themselves. Students have reported that understanding why they did activities made them understand what they were doing and what they were to do next. Moreover, he guided students to construct their knowledge by linking the concepts from the activities together.

An example of making students clearly understanding the activity and linking the concepts is the lesson of aerobic respiration, activity 4: Krebs cycle. In this activity, students learned Krebs cycle from tracing the step of Krebs cycle by role play activity and then in a discussion with the teacher. Volunteer students were assigned to act out roles to show the series of steps that showed that two carbons of acetyl-CoA are oxidized to CO_2. Before the activity, Chatchai explained this activity by saying, "this activity wants you to see what happens with Acetyl CoA thus before you do you have to answer the questions about the Acetyl CoA, how many carbon atoms, where they exits and enters" After students answered the questions, he asked the questions point out to students to observe how Acetyl CoA changes, for example "what is the target point in this role play" and "what is it that you followed?" After finishing the role play, Chatchai asked students to draw diagrams to show what they understand from the role play. When he discussed the student diagrams, he guided students to recall the role play such as "Look at your diagram. Do you remember, how many CO_2 that you observed from the role play which one keeps CO_2?" or "How many the number of carbon atom of Acetyl CoA?" "Who acted as the Acetyl CoA?, How many carbon atoms do you have?" During discussion regarding the details of the chemical process of the Krebs cycle, he compared the diagrams of students to the sophisticated diagrams of Krebs cycle. Most students reflected that this activity has made it easier for them to understand the overview of the Krebs cycle reactions.

Theme 2: Teacher emphasized how students know more than what they know enhances students' understanding of the chemical process.

Chatchai asked questions to help students to construct their knowledge instead of him lecturing. However, there were different levels of his questions in different concepts, for example, Chatchai's question in teaching cellular respiration.

Chatchai assisted students to construct the knowledge of the chemical process of aerobic respiration by using questions and discussion with students from materials such as animation of cellular respiration, students' activities, and investigations. Concerning his question, he asked students to think about the series of the process besides just the number of products of the process. In teaching the Glycolysis and Krebs cycle, he asked "how and why" questions, for example, "How many CO_2? How does the CO_2 come from? Why does the electron transport chain occur in and on the inner mitochondrial membrane? Why do you think that yeast is a living thing?" These questions lead students to think and share their ideas in their group and discuss in the class with teacher more than to recall their memory. Moreover, he emphasized discussing with students about the relationship of the three step of aerobic respiration besides just the products of each step. Students could make links among these steps, for example, students indicated that the pyruvic acid link between the Glycolysis and Krebs cycle and break down to CO_2. There was also a linkage of two steps; Glycolysis and Krebs cycle with the electron transport chain are $NADH_2$ and $FADH_2$. However, in the concept of the electron transport chain, he asked the products of ATP in this step and ignored asking about the process of oxidation and reduction of the electron transporter chain and how O_2 come from.

3.4.2 Teaching Practices Related to Students' Understanding of the NOS

Two themes of the relationship between Chatchai's teaching practices and students' understanding of the NOS are described as followed:

Theme 1: Explicit connecting the history of respiration with the NOS enhances students' understanding of the NOS.

In the first lesson of the implementation following the respiration instructional unit, students were assigned to inquiry about the meaning of respiration from the history of the respiration knowledge development and investigation how scientists know about there are carbon dioxide and oxygen in the air we breathe. The history of science is discussed for understanding of tentativeness of the knowledge of respiration and the construction of scientific knowledge. Chatchai let students read the articles, investigation, and answer the questions in students' worksheet without discussion until the end of class. After teaching, he felt that he failed to teach this lesson because he was not familiar with this history and he had inadequate preparing for teaching and discussion with students. He did not grasp the main ideas from both the history of the development of the respiration knowledge or of the NOS. After that, he read and discussed with the researcher about the NOS that related to the history of Glycolysis and Krebs cycle before teaching.

Chatchai changed his teaching practices from the first lesson regarding teaching about the history of Glycolysis and Krebs cycle. This is an example of his teaching the NOS in the lesson of Krebs cycle. In this lesson, students were assigned to discuss about the history of Krebs cycle. Chatchai assigned students to read about the development the knowledge of Krebs cycle and then he asked students to read and discuss about the construction of the scientific knowledge, in particular the knowledge of Krebs cycle. At the beginning of the discussion, he asked that "how the knowledge of Krebs cycle does come from" and most students answered that "from the discovery of Krebs" then he pointed out students to understand that the knowledge of Krebs cycle derived from discovery some parts of the sequences by many scientists. Then he asked students that "If you have data or know (the parts of the sequences) the same as Krebs, do you think that you would have discovered the cycle or not?" Most students answered "No". They gave the reasons "because of different intelligence and different thinking" He explained that the pieces of data came from the experiments but the Krebs cycle was built from the ideas, creativity and imagination of Krebs for constructing the explanation and relating the data and then creating the cycle. As to students understanding of the NOS, all students who had informed understanding gave the examples from the history of respiration for supporting their understanding of the NOS.

Theme 2: Teacher focus on being a "facilitator of learning" and moving towards being a guided for inquiry.

During Chatchai's implementation, his role in students' investigation was a closely a facilitator. In the first student investigation about the anaerobic respiration of yeast, he worried about the science process skills of the students and their responsibilities in their investigation. He told the researcher that the students rarely had opportunities to investigate because of the limitations of time and the biology content. Thus, he thought that students should prepare to do their investigation by using his explanation. He began this activity as a way to review about the scientific method and some science process skills such as hypothesis and observation before the students began investigation. He used the questions from student worksheets to be the guide for the problem, the hypothesis, and the data collection. He asked random students to answer the questions. Then he told them the problem, hypotheses, and method of data collection. Students performed the activity by gathering the data and making a conclusion. In this investigation, the students did Chatchai ordered. In conclusion, some groups read their conclusion without discussion. After that he provided the conclusion statement for students.

In the next investigation, the measurement of respiration, Chatchai did little to change his role and still provided the question to be explored. However, he used the questions from the student worksheets to guide the students in generating their own hypothesis and then he told them the procedure of data collection. He asked students to understand how to do and why to do in each step of procedure. Students presented their conclusions and compared them with the others. He also allowed each group to decide on their method of presentation for their findings. During the discussion regarding their conclusions, he asked students to think about their interpretations regarding the question "how do you explain your data?"

As for investigating the factors related to the rate of respiration, he let students think and share ideas regarding how to design an experimental procedure of how to study these factors. His role was only to serve as a facilitator to help the students design the experiment. He asked and talked about the meaning of the experiment. He emphasized with the students to think about the variables that would help them design the experiment. He asked, "Why do you set controls and "what is the dependent variable?" after each group presented and discussed their conclusion. In order for better student learning, most students seemed to learn more as active learners. They were enthusiastic about doing the investigation, paid more attention in class and were motivated to finish their investigations.

Case Study Three: Sirintip and Students

1. General Information about the Teacher's Background

Sirintip is a thirty-six year old biology teacher at Wanna School who earned her a Bachelor Degree in Education with a major in biology from Pranakornsriayutthaya Rajabhat University and a Master Degree in Education (science education) from Srinakharinwirot University. She first started teaching in a secondary school in Sakaeo province where she stayed for two years and she has now been in her present school for eight years where she teachers science and biology.

Sirintip did not originally want to become a science teacher. She was encouraged by her family to study education and while there she realized that she liked teaching science and that it was good fit for her. Her goal in teaching science is to enhance her students in both the area of scientific content and in the science processes. She believes that a teacher must help the students become aware of science in their lives and assist them to understand scientific knowledge and help then understand that it can be applied to everyday life. "I think that teaching should be governed by the objectives that students will be able to integrate or mobilize acquired knowledge and science processes skills in real life situations."

Sirintip mentioned that teaching science should relate scientific knowledge with students' real life which should make science learning was meaningful because science can be explained using their experiences. "Everyday life is involved with science. Therefore teaching science must be closely related with students' life. It is to teach science if we remember and understand it by demonstrating how its content fits in the context of real life."

The effectiveness of hands-on activities in teaching was to help students remember and understand. Moreover, teachers should make students have fun while learning at the same time. She believed that student motivation was important for inducing students to learn science.

2. Teacher's Understanding of the NOS and the Inquiry-based Approach and Her Practices before the Implementation of the Unit

Sirintip was interviewed about the NOS and the inquiry-based approach before her implementation of the respiration instructional unit. Sirintip understandings are described below.

2.1 Understanding of the NOS

Sirintip was interviewed about her understanding of the NOS and responded to the questionnaire before her implementation of the respiration instructional unit. Her understandings are divided to six aspects of the NOS namely the understanding of scientific knowledge based on empirical evidence, scientific knowledge as socially constructed, the role of creativity and imagination, the tentative nature of science, diversity of scientific method, and science as social activity. Sirintip's understanding was placed into three categories, naïve, mixed, and informed understanding.

The results showed that Sirintip held informed understanding in three aspects of the NOS and held mixed understanding in three aspects of the NOS. The three aspects of the NOS that she held an informed understanding was scientific knowledge based on empirical evidence, scientific knowledge as socially constructed and diversity of scientific method. The three aspects of the NOS that she held mixed understanding of were the role of creativity and imagination, the tentative nature of science, and science as social activity. The descriptions of Sirintip's understanding in each aspect are presented below.

2.1.1 Scientific Knowledge Based on Empirical Evidence

To define scientific knowledge, Sirintip understood that scientific knowledge is the explanation of the nature of why something occurred or happened. It derives from the scientific method. The characteristics of scientific knowledge are reasonable and logical knowledge. Moreover, Sirintip held an informed understanding that the evidence is relevant to the acceptance of the knowledge claims to be considered scientific. She identified that the evidence is presented for supporting scientists' explanation about the phenomenon such as the knowledge about the gas exchange in the lung.

"We knew that the air we breathe comes in the lung. The lung is the organ for gas exchange because when we breathe in, the air has more oxygen but when breathe out, the air has less oxygen. Thus, the lung is the place for gas exchange." She said.

2.1.2 Scientific Knowledge as Socially Constructed

Firstly, Sirintip understood that scientific knowledge is derived from scientists' work by using the scientific method. Sirintip also exhibited an informed understanding that scientific knowledge comes from the acceptance of many scientists. Some scientists present their findings at meetings or publish in scientific journals. These processes enable scientists to inform others of their work and to expose their ideas to criticism by other scientists.

"Sometimes, I think, that one topic may be studied from many scientists at the same time and they may explain the same thing in many different ways, but in the end it depends upon which explanation is the most accepted, but all their findings must be considered for further development of scientific knowledge," she stated.

Moreover, Sirintip held an informed understanding that the scientific work is not only one scientist work but also included groups of them working together. She thought that scientists' work is similar in this way to other careers in that sometime people work alone and at other times in small or large groups. However, she did not give examples of scientific knowledge gathered from groups of scientists.

2.1.3 Diversity of Scientific Method

When we asked Sirintip about the meaning of science, she explained that science is the explanation of the nature through the use of the scientific method. Also, she explained the meaning of the scientific method as: “it is a guide to solving a problem or finding an answer. It is a systematized ways which involves formulating a hypothesis, observing, experimenting and making a conclusion.”

Sirintip held an informed understanding that the scientific method is not a series of the procedural steps and there is no a single method of science that is the same way by all scientists at all times.

“I thought that the scientific knowledge is derived from various methods such as experiment, survey, observation, and dissection. It depends on what they (scientists) want to know, and what they want to do.”

Although, Sirintip could make a distinction between an experimental study that involves controlling or manipulating something and an observational study which involves observing an existing situations that is not being manipulated by human interaction. However, she always used the term “the experiment” to represent all scientific methods.

2.1.4 The Role of Creativity and Imagination

Sirintip claimed that the characteristics that scientists should have include curiosity, endeavor, logic, integrity and creativity. She thought that these characteristics were embedded in the scientists’ work. Without these characteristics, scientists do not success in scientific work. When Sirintip was asked to specify the role of creativity and imagination in science, she showed a mixed understanding in this aspect.

Even though, Sirintip believed that the creativity and imagination are important characteristics for scientists. However, she underlined the role of creativity more than imagination in the science process. Sirintip identified the role of creativity in the science process as:

"Scientists use creative thinking right from the beginning of their investigations until the end. They used it for formulating the hypothesis, designing the experiment, collecting data and making a conclusion." (Interview, July 2007)

As to the role of imagination, Sirintip thought that it was necessary for creating technologies or science inventions and useful before an investigation is started rather than during the science process. She understood that during the science process, scientists used more often logic, reason and creative thinking because the scientist has to be objective.

2.1.5 The Tentative Nature of Science

To understand the tentative nature of science, Sirintip understood that scientific knowledge can be changed both from the development and the abolishment of the existing knowledge. Increasing of many researches and technological developments are the reasons for changing the knowledge. New findings are used to add to exiting knowledge. Regarding the abolishment of the knowledge, she stated that only uncertain scientific knowledge can be abolished. The uncertainty of that particular scientific knowledge is supported by inadequate data or limited investigations. Thus, it is easy to be abolished. She illustrated the example: "In the past we believed that the earth was flat but now we know that it is round. At that time, there had no apparatus to tell for sure that the earth is indeed round and not flat"

As for the knowledge of respiration, Sirintip held a strong belief that the knowledge of respiration had been changed. However, she could not illustrate a proper example because she had no idea about the history of the knowledge of respiration. To change in the future, she affirmed that it could be added to in more detail rather than be totally abolished.

"Our respiration occurs in the cells, uses oxygen and releases carbon dioxide. This knowledge is not changing but it may be explained more thoroughly."

2.1.6 Science as Social Activity

When asked Sirintip about the relationship between science and society, she said that "science is the basic knowledge of technology so the development of science impacts the development of technology as well as society. Science is also an important part of society. It is a way of life such as health, food, agriculture, etc."

As for the scientific research issue, Sirintip claimed that it was related to needs, solving a problem in society, background knowledge, and the interests of the scientists. However, she did not identify that bias, norm, and the culture of scientists influenced scientific research as well.

2.2 Understanding of the Inquiry-based Approach

To understand the inquiry-based approach, three domains emerged from the data of Sirintip. First domain, the investigation was the key idea of the inquiry-based approach. When asked about the meaning of the inquiry-based approach, she replied that it was teaching by using the 5E model of inquiry as follows in the IPST teacher manual. She described the steps of 5E model of inquiry as a way to engage the students in a motivating manner in which to stimulate and explore phenomenon by doing an experiment, observing or surveying to explain something as it relates to real life. However, Sirintip emphasized that the important steps of 5E model of inquiry as being an exploration which was the investigation. She explained why the investigation was viewed as the key idea of inquiry-based approach, as discussed above; she used the term “experiment” which meant the investigation.

“I understand that students must do the experiment because, I think, the objective of this approach is to have students have opportunities for inquiry or searching knowledge. They will understand scientific knowledge as well as scientific processes. If the students do the experiment, they will get a more deep understanding.”

Second domain, the inquiry-based approach required teacher guidance and motivation. When asked about the role of teacher in this approach, she said that the teacher should guide and motivate students to do the experiment. For Sirintip, guiding students meant helping them to think and to do experiment, what and how. Moreover, the teacher should guide students to clear understanding about the directions and the procedure of the activities. She said that the level of guidance during the experiment depends upon the students abilities.

“The level of teacher guide is more or less, I think, depended upon the students. If they are able to do the experiment by themselves the teacher may not have to guide them at all but if they are not able to formulate the hypothesis, design the experiment or even use the equipment, then the teacher has to provide more guidance and perhaps even have to tell them everything they need to do.”

To motivate a student of Sirintip meant making students more interested and keeping them focused on completing their task. She emphasized the willingness of students as an important factor for all teaching approaches including the inquiry-based approach. Thus teacher motivation was also an important role of the teacher themselves. She believed that if students are interested or pay attention, they will complete their task. She explained that she motivated her students by starting the lesson with a story, news or pictures. She gave one example of how she felt satisfied with that form of motivation.

"I taught about blood type. I created a story for the students to find a relationship among the players in finding their blood type by using names and pictures of real players and the students were interested."

Third domain, the inquiry-based approach is difficult. As for the obstacle of teaching inquiry, Sirintip thought that planning to teach science as inquiry is hard work and it is difficult to balance between how time consuming and student understanding. Teachers must think about planning and preparing carefully. For Sirintip, the difficultly in the process of planning teaching as inquiry was the step of exploration especially in abstract concepts which could not be observed directly.

"I think that it (the inquiry-based approach) has limits. It is quite difficult to design the lesson plan. Sometimes I had no idea what the student should do in the exploration. That particular content is text, explanation, or an abstract concept. I didn't know what will be observed such as the chemical processes of cellular respiration," she said.

According to Sirintip, the purposes of student inquiry are students understanding the content knowledge and process. In addition, she understood that it is difficult to persuade students into the inquiry process and getting the knowledge. She stated that:

"It is difficult. Even when I guided them (students) or told them, they did not sometimes get it and sometime even when they did the experiment they did not know how they got their conclusion or why they did the experiment. As well it was often difficult to get them to it all by themselves."

2.3 Teaching in Respiration

In this section, Sirintip's typical teaching of respiration and her teaching practice that related to understanding the inquiry-based approach and the NOS are described. Data comes from the interview about her teaching of respiration and three classroom observations on the topic of cellular respiration. The details of Sirintip's teaching practices are as follows:

Sirintip taught the respiration unit after students had learned the digestion unit in grade 10, in the second semester. In respiration, her instructional topics were based on teachers' manual of the IPST. There were two main topics namely the cellular respiration and gas exchange. The cellular respiration was comprised aerobic respiration and anaerobic respiration. As for the gas exchange, there were two sub-topics as gas exchange in living organisms and gas exchange organs in humans. The table 5.5 shows a brief summary of the instructional sequence of Sirintip.

In the cellular respiration unit, Sirintip used lecture with diagrams and assigned students to do worksheets both in groups and as individuals when teaching aerobic respiration. Corresponding to her understanding about the inquiry-based approach, she did not teach by using the inquiry-based approach because she thought that the concept of aerobic respiration could not be observed or experimented upon directly. She could not create an activity that would ensure an inquiry activity for the students. As well the knowledge of aerobic respiration was difficult for the student to understand. The way to help students better understand she believed was to have the teacher explain and the students do the worksheets. As for anaerobic respiration, Sirintip created her lesson plan following the 5E model of inquiry. She engaged students by having them do the experiment about yeast fermentation. For the gas exchange topic, she taught using lecture but with pictures of gas exchange organs of animals like fish, frogs, insects, pigs and humans.

The results from classroom observation showed that Sirintip often used questions for guiding her students to remember the procedure more than to think about the procedure. In the yeast experiment, Sirintip called upon one student to read the directions of the lab experiment and then she asked students to state the problem and the variables of the experiment. Each group wrote their hypotheses and presented them in the class without discussion about their hypotheses. After that she revised the procedure of the experiment by asking questions such as, "after you mix the yeast and syrup, what do you do next? What is the amount of yeast and syrup in each tube? There were few questions about the reasons behind the procedure such as “why do you add the bromothymol blue? Why do you put the oil on the surface?

Although students were required to collect the data and write the lab report about their results and conclusions by themselves, Sirintip told them the correct results and made sure all the students eventually copied down the conclusion she gave them so they would all have the same correct one. This showed that she emphasized the product more than the students learning process and their construction of the knowledge.

To motivate students, Sirintip began the lesson by using the pictures and asking questions to stimulate student interest in the lesson. For example, before students doing the yeast experiment, she showed a colorful picture of beer and wine. Then she asked students to think about the process for producing beer and wine and to link this process to the anaerobic respiration of yeast. During her teaching, she stimulated students to participate in the lesson by having students compete with each other in answering the questions.

The NOS did not explicitly appear in her teaching. As described above, she was more concerned about the content knowledge than the process. The question about scientific processes rarely appeared in the student worksheets and was not asked by Sirintip. Although, Sirintip understood that the NOS should be integrated in the teaching of science knowledge, she believed that doing experiments was the best way for them to understand the NOS

Table 5.5 Summary of Sirintip's Teaching of Respiration before Implementation the Respiration Instructional Unit

Topics	Sub-topics	Time	Activities	Materials
Cellular respiration	Aerobic respiration	6	- Teacher lectured on the process of aerobic respiration. - Students did the worksheet.	1. Pictures of food 2. Diagrams in student textbooks 3. Student worksheets
	Anaerobic respiration	2	- Students investigated anaerobic respiration in yeast. - Teacher lectured on the process of anaerobic respiration. - Students did the worksheet.	1. Materials for the yeast activity 2. Diagrams in student textbooks 3. Students worksheets
Gas exchange	The structure and function of gas exchange organ in living organisms	3	- Students searched for information and presented about gas exchange in living organisms. - Students did the worksheet.	1. Pictures of gas exchange organ of animals 2. The pictures in students' text book 3. Students worksheet
	The structure and function of gas exchange organ in human	8	- Teacher demonstrated the dissection of a pig lung. - Teacher lectured on the lung capacity, mechanisms of breathing. - Students did the worksheet.	1. Pictures of lungs 2. The pictures in student textbooks 3. Students worksheets
	Total	19		

3. The Implementation of the Respiration Instructional Unit

3.1 Teaching Context

Sirintip began the implementation of the respiration instructional unit in the first week of December, 2007 and finished in the last week of January, 2008. During that time, there was one week for the New Year holiday and one week for midterm examinations and sport activities. But her implementation time was 21 hours which was the same as what she had planned. Below is a description of the impacts of the respiration instructional unit, teaching context and teacher preparation.

At that time of the study, the number of students of Sirintip classroom was 37 students, 30 females and 7 males. Sirintip taught biology in the biology lab that was located on the second floor and its size was 8 x 16 m. It had two doors on one side and twelve windows on the other. At the front of the room there was a wall-mounted horizontal whiteboard and at both sides of it were bulletin boards displaying colorful photos of ecosystems and details of the day's events. There was one hanging projector monitor in the front of the classroom, a table with a computer for the teacher. There were continuous lab counters with four sinks on the same side of the room as the windows with closed cabinets beneath. Two cabinets were open to collect student portfolios and these were located next to one of the doors. The middle of the room had nine tables, eight for the students to sit in groups of six and one free table. In the right back corner area, there were three open cabinets for presenting the models and storing some science books. At the back of the classroom, there were two wood cabinets to store microscopes and chemical substances and one big metal cabinet to store science equipment and supplies. Figure 5.16 shows the classroom setting.

Classroom observation spanned 16 class periods, each period lasting 1 hour. According to Sirintip, the students in this class were high achievement students in grade 10 in the school. However, Sirintip claimed that her students had moderate to low achievement level in content areas and their ability to understand the science process skills when they were compared to the better students in other schools in

Pranakornsriayutthaya province. According to Sirintip's criterion, students were divided into groups by mixed achievement including their GPA, their biology grade, level of science process skill and gender. Two groups of students were selected randomly to be participants in this study for assessing their understanding of the NOS and the key concepts of respiration knowledge.

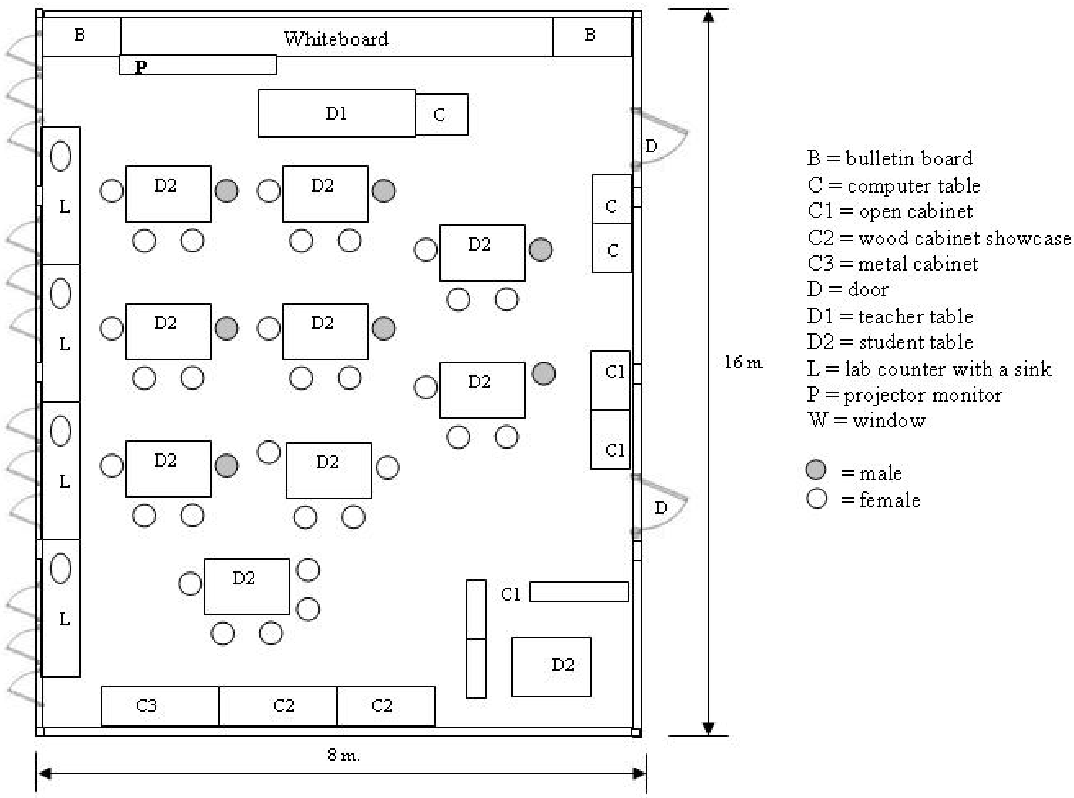

Figure 5.16 Sirintip's Classroom Setting

3.2 Teacher Preparation

As for Sirintip's preparation, she was worried about her understanding of the knowledge of respiration and the best questions to ask in order to probe her students understanding of the content or to guide their thinking. Thus, she read the lesson plan, discussed with the researcher the objectives and the sequence of activities and questions, and also checked her understanding about respiration concepts before teaching. In preparing to teach the NOS, she usually asked about the objectives of the

NOS and the activities or questions for the students to reach those objectives, but rarely checked her understanding regarding the NOS.

3.3 Students' Understanding of the NOS and the Key Concepts of Respiration

In this section, the impact of the implementation of the respiration instructional unit with students' understanding is described as two topics namely their NOS understanding and their understanding of the key concepts of respiration.

3.3.1 Development of Understanding of the NOS

The data from four students' interviews were analyzed the development of students' understanding of the NOS. The understanding of the NOS included six aspects of the NOS namely scientific knowledge based on evidence, the role of creativity and imagination, the tentative nature of science, scientific knowledge as social constructed, diversity of scientific method, and science as social activity. The students were primarily placed in three categories: naïve, informed, and mixed understanding that mentioned above. Table 5.6 summarizes students' understanding, with a one in each aspect of the NOS from pre and post interview. Symbols were used to represent each student. For example, SA1 meant student No.1 from group A of Sirintip's classroom, and SB2 meant students No.2 from group B of Sirintip's classroom.

Table 5.6 Development of Sirintip Students' Understanding of the Six Aspects of the NOS from Pre and Post Implementation

Students	Evidence		Creativity and imagination		Tentativeness		Socially constructed		Diversity of method		Social activity	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
SA1	M	I	M	I	M	I	N	I	N	I	M	I
SA2	M	I	M	I	M	I	N	I	N	I	M	I
SA3	M	M	M	M	M	M	N	M	N	I	M	M
SA4	N	I	M	I	M	I	M	I	N	I	M	M
SB1	N	I	M	I	M	I	M	I	N	I	M	M
SB2	N	I	M	M	M	M	N	M	N	I	M	M
SB3	N	M	M	M	M	M	N	M	N	M	M	M
SB4	N	M	M	M	M	M	N	M	N	M	M	M

I = informed understanding

N = naive understanding

M = mixed understanding

A. Scientific Knowledge Based on Evidence

Before the implementation, five students held a naïve understanding regarding evidence in science. They understood that the science is the study of natural phenomena or the world and scientific knowledge is truth finding that comes from scientists' working, in particular, an experiment. Scientists repeat their experiments again and again and they came to the same result until they are sure that their finding is the truth. However, they did not claim about the data or evidence and the role of the interpretation by scientists when constructing scientific knowledge. Three students held a mixed understanding that science is the explanation of the cause and effect of natural phenomena and scientific knowledge is the set of knowledge in different fields of science such as biology or chemistry and there was sufficient data from experimentation and observation to support it. They indicated that the evidence came directly from an experiment or observation.

As for the second and third interviews, students were asked about the evidence in their own investigations and although all the students understood that their conclusions came from their investigation the trustworthiness of those conclusions came from experimentation and observation. However, three students claimed that their conclusion came directly from their observation. In other words the data could actually be observed directly. Five students understood that their conclusions did not come directly from their observations, but from the inferences they made regarding the data.

SB1: we measured the amount of gas that came from the different bottles (different amounts of yeast), by measuring the amount of carbon dioxide and we could make reference to which one had more respiration by comparing the amount of carbon dioxide because carbon dioxide was one product of respiration. (Third interview)

The last interview, there were five students holding informed understanding that consisted of three students who changed from naïve understanding and two students who changed from mixed understanding. Three students held mixed understanding that consisted of two students who changed from naïve understanding and one student who still held mixed understanding.

B. The Role of Creativity and Imagination

In the first and last interview, students were asked to respond to the question, "Do you think scientists use their creativity and imagination during their works?" All students exhibited mixed understanding that scientists use the creativity and imagination in some stages of scientific investigation. Six students indicated that the scientists use it for conjecturing or formulation the hypothesis and designing the experiment. Two students added in the stage of presenting the result. They also understood that the creativity and imagination are necessary for inventing something new such as the materials, technologies, or models. However, no one indicated that the creativity and imagination are used for constructing the scientific knowledge or interpreting the data.

As for the second interview about the role of creativity and imagination in the experiment regarding the factors of the rate of yeast respiration, all students understood that they used their creativity and imagination during the experiment. However, four students mentioned that they used their creativity and imagination for interpreting the data, but four other students did not mention it. This result differed from the result of the third interview about the dissection of gas exchange organs of animals. All students understood that they did not use their creativity and imagination in formulating the hypothesis or in designing the dissection procedure. They used it for the presentation their result. However, four students excluded the role of creativity and imagination in the process of conclusion because they thought that the conclusion came from the reasonable or logic thinking rather than creativity and imagination. Four other students still mentioned the role of creativity and imagination in the interpretation of the data. For example one student said that:

"I think we used both the creativity and reason when we made conclusions how the general structures of gas exchange organs. We had to call to mind its structure and relate it to the data gathered from many animals." (SA4, third interview)

The results from the last interview, in general, all students agreed that the creativity and imagination are essential for the invention of new thing such as technologies, materials, or models. Four students held the mixed understanding that creativity and imagination are used during scientific investigation but that it excludes interpretive data and the explanation. On the other hand, four other students changed from a mixed to informed understating about the role of creativity and imagination including in interpreting of data and the explanation. Moreover, they could give an examples for supporting their understanding. For example:

SA1: "I think about the history of Krebs. I knew that he used creative, logic, and reason to connect each chemical substance and create the cycle."

SB1: "The knowledge of respiration, scientists can not see directly. They have to imagine it and create the knowledge to explain respiration from the data and findings." (Last interview)

C. The Tentative Nature of Science

Before the implementation the unit, all students held a mixed understanding about the tentative nature of science. Although they understood that general scientific knowledge can be changed in two ways by adding more detail and it can be abolished, but they believed that the content that they learn in the biology textbook can only be changed by the addition of new details. Their reason was that such knowledge is basic and that general knowledge can be incrementally built upon and such knowledge has been proven to be true in the past. Moreover, their reasons for knowledge changing were better technologies, new evidence, new data, and new discoveries.

As for the results regarding the tentative nature of science in student investigations, both the experiment about the factors of the rate of yeast respiration and the dissection of gas exchange organs in animals showed similar results. In the experiment about the factors of the rate of yeast respiration, four students claimed that their conclusion could change in two ways by adding more details or by abolishing it altogether. Regarding the addition of more details they believed that because their experiment was similar and did not necessarily follow the exact methodology or use the exact same materials as the previous experiments of scientists more details could be added by their results. They did not believe that they were discovering something new which would not change existing knowledge. Regarding errors in their experiments they felt is these happened then the data they collected would be abolished.

"It (the conclusion) may change, if we made an error in measuring the amount of gas or to put unequal amount of the yeast in each tube, the data will be wrong. So if we do this experiment again and we do it right in all steps, our conclusion can change." (SA2, Third interview)

Similarly in understanding the dissection of the gas exchanged organs in animals they claimed that if they observed carefully these organs and got more data their conclusions would be the same as those of scientists and could not be changed.

On the other hand, there were four students who exhibited an informed understanding about the tentativeness of their conclusion and the knowledge of respiration. They understood that their conclusions and the knowledge of respiration can be changed both by adding details and by getting rid of it altogether. If they had more knowledge, information, and new data their conclusion could be changed. Moreover, they believed that someone may come to a different conclusion from the other even confronted with the same data because of different thinking, creativity, and prior knowledge. For example one student said that:

SB2: "If we know more than this and think carefully, our conclusion may change. May be we misunderstanding or we interpreted the data incorrectly."

SA4: "I think that the other groups makes similar or different conclusions from our because of different ideas and knowledge."

(Third interview)

For the last interview, four students held mixed understanding while three students held an informed understanding of the tentativeness of scientific knowledge. Four students understood that scientific knowledge can be changed by added details and that it could also be abolished because of new data and evidence or advancements in technologies, their reasons did not include the reinterpretation of existing data. In contrast to the four students who had informed understanding who indicated that scientific knowledge can change because it was developed from interpretation of data. For example one student gave the example of a change of scientific knowledge as:

SA4: "I guess, Krebs cycle, for example, I think about the history of the discovery of the Krebs cycle which came from many pieces of knowledge about the chemical substances and enzymes and then Krebs linked it all together. If someone had new ideas and rethought about it, the original cycle could perhaps be broken up into two cycles."

(Last interview)

D. Scientific Knowledge as Socially Constructed

In the first interview, six students held a naïve understanding that scientific knowledge is the facts from scientists find or discover. They believed that the scientific knowledge came from the work of individual scientists more than teams or groups of scientists. Furthermore, they understood that the scientist gets the knowledge after he or she repeated investigations many times until he or she had confidence that the result was right without argument from others. Correspond with they said about the characteristics of scientists that the scientists must be unbiased, straightforward, logical and an objective persons. They ignored that scientists is subjective.

For two students who held a mixed understanding, although they understood that scientists can work both individuals or in groups but they stated that the main purpose of group work is to help in formulating the hypothesis and/or collect data excluded conclusion because they believed that the conclusion came directly from the data. In addition, they understood that scientific knowledge is the explanation about the natural phenomena in terms of cause and effect that scientists use their logic and reasoning. However, they ignored the other parts in the scientific process such as the inference, creativity and imagination, prior knowledge and existing theories of the scientist.

As for the interview about students' investigation, all students indicated that their works were similar to that of scientists in terms of using the scientific method, presentation, discussion, and group work. There were four students who explicated understanding that the purpose of presentation and discussion about the conclusion is to show the data that supported their conclusion and provided opportunity to share different idea and change their conclusion to be right conclusion. Even though, they used the word "right" but they accepted that it can change if someone had a better conclusion. One student said: "It (conclusion) can change if a new one is based upon good reason and explanation." (SB1, Second interview)

In the last interview, all students developed their understanding that scientific knowledge is derived from the findings or results of a lot of research either individual or team of scientists. Nevertheless, there were four students held an informed understanding that scientific knowledge is constructed or interpretation based on prior knowledge, belief, logic, and creativity and imagination of scientists. Also the argumentation and sharing ideas are the part of the scientific knowledge construction. While four students held a mixed understanding that scientific knowledge derives from the data or evidence. The presentation and argumentation of scientists is only the evaluation of the investigation procedures, examine the evidence excluding suggestion alternative explanation or interpretation for the same data. They said like this:

"Scientific knowledge has been proven by others concerning the procedure, how to procure data, and the correctness of the conclusion. If data collecting is correct then the conclusion will be correct as well."

(SA3, Last interview)

E. Diversity of Scientific Method

Before the implementation of the unit, all students understood that scientific knowledge is derived from scientists' work. When asked about how scientists work, they understood that all scientists use and follow the scientific method which is the process of working. Although some students said about the way of scientists work more than one method such as the experiment, observation, dissection and survey, however, they can not distinguish the meaning among these methods. They held a naïve understanding that these methods are the same thing as the experiment which as orderly step procedure and certain way. For example, when asked them about the dissection for study of the gills by Wechai, they think like that,

SB3: "His task was scientific work because he did the experiment.

Researcher: "What does the experiment mean?"

SB3: "It is the scientific method including observation, questioning, and the hypotheses, testing hypotheses, experiment, collecting data, and making a conclusion. It is a systematic work."

As for the second and the third interview about the student investigations, the results showed that six students developed their understanding about the meaning of the experiment and dissection. They understood that the experiment study differs from the dissection study in terms of testing variables. One student indicated that

"If it is an experiment, it has to put something or test the result of something but our doing (dissection) is not the experiment because we did not test anything. We just observed and drew the structure." (SB2, third interview)

In the last interview, six students exhibited an informed understanding and two students exhibited a mixed understanding. For the informed students, they understood that scientists use the scientific method as the way for answering their questions. Although it is a series of step by step procedure they are able to go back and repeat a step before moving forward if necessary. For example,

SB1: "If they (scientists) found that they made a mistake, they can go back to a prior step and fix it. Otherwise during working, if they suddenly think of something new or come up with a new question they can start over again."

They indicated that there are more than one method to inquiry such as experiment and observation. They could indicate differentiate between the observational study and the experimental study. Furthermore, two of them could give examples of the diversity of scientific method about the development of respiration knowledge. For example,

SA4: "The knowledge of respiration came from the experiment, collecting information and finding of many researches of many scientists such as the discovery of Krebs cycle. Krebs concluded and created the cycle. He did not conduct any experiment at all but it was science." (Last interview)

For two students who held mixed understanding since the second interview, they accepted that scientific method had more than one way to find the answer of scientific question. However, they failed to distinguish the experiment from the observational study. Moreover, they understood that all scientists must do the experiment. The observation was the initial method of the experiment. They still believed that scientists must follow the orderly step procedure of the scientific method.

F. Science as Social Activity

The first interview, all students showed mixed understanding about the interaction between science and society. Although they indicated that science responds to societal needs, problems and development. However, they understood that science is a solitary or individual pursuit. They ignored that science is affected by their social and culture. For example,

SB2: "Scientists do the experiment that they find interesting. They produced knowledge that can be applied as basic knowledge for developing the technology and producing medicine. Science helps and develops our society."

(First interview)

As for the last interview, six students still held mixed understanding about the interaction between science and society. While two students changed from a mixed understanding to an informed understanding. They added more understanding that scientists' work is influenced from society because scientists are part of society. When scientists work, they have to be aware about the law and acceptance of society. One student gave the example about cloning that:

"Scientists want to clone humans and I think they can do it but it is not accepted by society and it is illegal." (SA1, Last interview)

3.3.2 Development Understanding of the Key Concepts of Respiration

There are four main topics of respiration knowledge in the respiration concept survey and interview namely the definition of respiration, aerobic respiration, anaerobic respiration, and the relationship between cellular respiration and gas exchange. Eight students of Sirintip were asked to respond two times, pre and post implementation. They were interviewed after completed the respiration concept survey. Before the description of the development of understanding of the key concepts of respiration after the implementation, the understandings of students before the implementation are described.

Before implementation of the unit, none of the eight students identified the terms of respiration as corresponding to the four concepts that related to the definition of respiration (Figure 5.2). Five students (SA2, SA3, SA4, SB3, and SB4) explained the meaning of respiration as the gas exchange between oxygen and carbon dioxide in different organs. They had an alternative conception that just only plants and animals perform the respiration. Therefore, respiration does not occur in microorganisms because microorganisms are small organisms. They have no organ for respiration. Moreover, oxygen and carbon dioxide can diffuse into the cell directly. Three students (SA1, SB1, and SB2) had a correct understanding that the respiration occurs in all living organisms however, they gave the alternative reason that respiration is breathing to take oxygen in and giving carbon dioxide off. It is a life process and its purpose is to keep organisms alive. Therefore, microorganisms are living things so they have to respire.

All students understood that all living things need energy for growth, to be able to respire, movement, and doing any activities. Nevertheless, none of the students had understanding that energy was produced from the respiration. They had alternative conception that food or nutrients are the source of energy which is broken down from the digestion in animals while in plants, the energy comes from photosynthesis. Thus, they held an alternative conception that not all part of plants and animals can perform respiration. In animals, respiration occurred in the respiratory organs such as lungs, gills, trachea while in plants, it occurs in the stomata, leaf, and root.

Although, they understood that energy is needed all the time for any living organisms to perform life functions, all students held an alternative conception that plants respire only at night. Three students (SA2, SA3, and SB3) gave the reason that in the day, plants perform the photosynthesis process to change carbon dioxide to oxygen. This process needs light. At night, oxygen that comes from the photosynthesis process is used in the respiration process and this process change oxygen to carbon dioxide. Five students (SA1, SA4, SB1, SB2, and SB4) gave the reason that respiration is exchanging between oxygen and carbon dioxide so it can occur after finishing photosynthesis. For photosynthesis, it needs light energy.

All students did not understand the role of oxygen in aerobic cells to produce energy or to ensure cell survival and they had no understanding that anaerobic organisms that they did not need to use oxygen to be alive. When students were asked about the relationship between breathing and cellular respiration, two students (SA3 and SA4) explained only that we wanted more oxygen to provide enough energy for exercise. Three of them (SA2, SB1, and SB4) understood that we want more gas exchange between oxygen and carbon dioxide than normal but did not claim about the energy. Three students (SA1, SB2, and SB3) were categorized in the alternative conceptual pattern 1 (Figure 5.6) that we need more oxygen than normal because oxygen was used to produce the energy we need and we want to take off carbon dioxide at the same time but they did not claimed about the process of respiration.

After the implementation, all students developed their understanding about the definition of respiration. In general, they held correct conception that respiration is the chemical processes to release energy, in particular ATP from organic substances. It occurs in all living organisms. However, there were four students (SA2, SA3, SB3, and SB4) who held an alternative conception in some concepts from four concepts that related to the definition of respiration.

Although three of the four students (SA2, SB3, and SB4) understood that all cells need energy all the time for cell function, they held an alternative conception that plants respire only at night because plants use the organic substances in particular glucose from photosynthesis. Also they understood that only cells of leaves, stomata and roots perform respiration for producing the energy because leaves and roots were used for gas exchange. For the respiration of animals, they understood that it occurs in all cells and all the time because animals have a circulatory system to transport oxygen, organic substances and carbon dioxide. One student, SA3 held alternative conception that glucose is the only organic substrate for the respiration process to release energy.

To understand the knowledge of aerobic respiration, one student (SA3) was categorized in the alternative conceptual pattern 1 of an aerobic respiration (Figure 5.7). Two students (SA2 and SB4) were categorized in alternative conceptual pattern 2 of aerobic respiration (Figure 5.8). Two students (SA4 and SB3) were categorized in the alternative conceptual pattern 3 of aerobic respiration (Figure 5.9). Three students (SA1, SB1, and SB2) were categorized in the alternative conceptual pattern 4 of aerobic respiration (Figure 5.15). All students ignored the water which as one product of respiration that comes from electron transport chain related with oxygen as a terminal acceptor. Moreover, they did not explain how heat comes from during the respiration process.

As for the knowledge of anaerobic respiration, three students (SA2, SA3, and SB4) were categorized in the alternative conceptual pattern 1 of anaerobic respiration (Figure 5.10). Two students (SA4 and SB3) were categorized in alternative conceptual pattern 2 of an anaerobic respiration (Figure 5.11). There were three students (SA1, SB1 and SB2) that exhibited correct conceptions of anaerobic respiration as follow in figure 5.4. However, only one student, SB1, explained about the balancing of NADH and NAD+ related with anaerobic respiration occurring.

As for the relationship between cellular respiration and gas exchange, there were three students (SA1, SB1, and SB2) that exhibited the correct conceptions of the relationship between cellular respiration and gas exchange as follow in figure 5.5. Three students (SA2, SA3, and SB4) were categorized in the alternative conceptual pattern 2 of the relationship between cellular respiration and gas exchange (Figure 5.12). They ignored the CO_2 which is the waste product from cellular respiration that affects to rate of breathing in and out of human. Two students (SA4 and SB3) were categorized in the alternative conceptual pattern 3 of the relationship between cellular respiration and gas exchange (Figure 5.13). They added more understanding of CO_2 as one product of cellular respiration. However, they did not clearly understand about the role of oxygen.

3.4 Teaching Practices and Students' Understanding

Data from classroom observation field notes, focus group discussions, and students' interviews about their learning and understanding were analyzed for describing the relationship between Sirintip's teaching practices and her students understanding of both the NOS and their knowledge of respiration.

3.4.1 Teaching Practices Related to Students' Understanding of the Knowledge of Respiration

There are two themes of the relationship between Sirintip's teaching practices and students' understanding of the knowledge of respiration. Each theme is described as follows:

Theme 1: Starting from students' prior knowledge and giving some example questions to facilitate students to generate their own questions for inquiry.

Concerning to introduce student asking questions, Sirintip was good guide to help the students to ask questions to aid in their inquiry into the knowledge of respiration. She began from probing students' prior knowledge by following the lesson plan. She asked some questions to make the students curious and interested in learning what come next. Moreover, her questions were the sample questions for motivating students to generate their own questions. In the first lesson, the introduction stage the following is the example to illustrate how Sirintip assisted her students to generate the questions.

After she reviewed with the students about nutrients and digestion from the previous lesson, she probed student understanding about the meaning of respiration. She asked them: "What happens after absorption of the nutrients from the digestive system." Most students answered that the nutrients are energy for life activities. She wrote the word energy and nutrient on whiteboard and then she asked students to think that "what is essential for being alive beside the nutrients". Most students identified that oxygen is essential for organisms to be alive and to respire. She wrote the words "oxygen and respiration". She continued to ask students about the meaning of respiration. Most students answered either it is breathing or it is the gas exchange of oxygen and carbon dioxide. She told them that the meaning of respiration in biology is not defined just only by breathing and gas exchange and students will learn that from this unit. Then she assigned each group to write two or three the questions about the respiration. She provided one example: "Why we want oxygen, why it is essential for alive" after the students finished, each group read their questions such as "Why we breathe out CO_2" "Why we can not use CO_2 like oxygen to remain alive?" She picked up some questions that related to anaerobic respiration and told students that they would be able to answer these questions after they finished the cellular respiration unit.

Theme 2: Making clear students' understanding about their activities and linking the concepts from one activity to another helps students to success in construction their knowledge.

As for Sirintip engaging the students in learning activities, she first reviewed the previous lesson and probed students' prior knowledge before following the lesson plan. She explained the overview of the activities in the lesson. Sirintip gave clear objectives and explanations for the students to do the activities. She often called some students to review the procedure of the activities after she explained to ensure that all students know what they do and how to perform. Sirintip motivated students to keep on their task by walk around and telling the time remain of each activity. She used questions to help students to take corrective action such as "What are you doing?" What you will do next, look at your worksheet?" or "What is the thing that you want to observe?"

Moreover, Sirintip was effective in her transitions from and linking to concepts from one activity to another and in keeping her students on task while developing their knowledge.

3.4.2 Teaching Practices Related to Students' Understanding of the NOS

The two themes of the relationship between Sirintip's teaching practices and students' understanding of the NOS are described as follows:

Theme 1: Explicit discussion and connecting to the history of respiration with the NOS enhance students' understanding of the NOS.

As for teaching the NOS from the history of science, Sirintip discussed and provided students opportunities to reflect upon their understanding of the NOS from the history of the knowledge of respiration development. She assigned each group to read the history of the knowledge of respiration developments. Then, students shared their ideas within group to answer the questions after reading. She used student answers to discuss with them about the NOS. This is a dialogue between Sirintip and her students when they discussed about the tentativeness of the purpose of respiration.

Sirintip: From the article that you read, what knowledge of respiration was changed or abolished?
Arin what is your group answer?

Arin: The purpose of respiration. In the past, Aristotle and Galen believed that respiration helped to reduce our temperature. Galen explained that heat came from the heart burning. After that it changed when scientists explained that respiration is a chemical process for producing energy by using oxygen and nutrients.

Sirintip: Your answer is that the purpose of respiration changed from reducing temperature to producing energy. Who wants to add to or disagree with Arin's group?

Some students: Same as Arin.

Sirintip: Do you agree with Galen?

All students: No

Sirintip: Why?

Nicha: There are many results from experiments of scientists that disagree with Galen. They show that Galen's explanation about respiration was wrong.

Sirintip: How did the experiments show that?

Nicha and some students:
The data and results.

Sirintip: The results, data as evidence from the experiments caused scientists to disagree with Galen. What else?

Pim: There was discovery about the chemical knowledge such as the knowledge of the oxygen, carbon dioxide, and combustion. It made scientists know more about respiration such as knowing that we breathe in oxygen and breathe out carbon. They explained the relationship with respiration and combustion.

Sirintip: Thus, discovery of related knowledge such as oxygen and carbon dioxide made scientists understand more about respiration. It showed that the development of respiration knowledge in biology is related with the development of chemistry and this you will learn next. What else?

Students: Quiet.

Sirintip: Write the conclusion of the reasons why the knowledge of respiration changed from our discussion on your worksheet.

Theme 2: Teacher explicitly discussions in the NOS in student investigation help to facilitate students' understanding of the NOS.

As for the diversity of scientific methods, Sirintip assisted students' understanding of the diversity of scientific method by explicit discussion and providing student reflected their understanding from their investigation. For example, in students' experiment about the factors affected on the rate of respiration. Sirintip assigned students to write about the different between observation study and experimental study and discussed after students finishing their investigation. During students' investigation, she pointed out students to think about the variable of students' experiment and manipulation of the experiment. Moreover, she motivated students to formulate a hypothesis and to design the way to collect the data after students chose one factor for investigation. She said: "Suppose you are scientists, you work as team research. What do you do next after you chose factor? Most students said like that: formulate hypotheses and design the experiment.” Sirintip said that: “If scientists do experiment, they did not follow from textbook. They used their knowledge about scientific process skill and related knowledge for study. I want you (students) to practice like scientists thus you try to think and design the experiment by using your prior knowledge. Think about the last experiment, what method that you do experiment of yeast. Can you apply to this experiment? ” After students finished their experiment, she provided students to edit their writing and then she discussed with students about the different between observation study and experimental study. From students worksheet, most students indicated that the experimental study differ from the observational study because of manipulation something, testing the variables, and having control group.

To understand the meaning of scientific method, Sirintip only reviewed about the scientific method by asking the meaning of scientific method before students’ investigation about the yeast respiration. Most students understood that it is orderly step procedure. Sirintip explained that “scientific method consist of four main steps which are setting a question, formulating hypothesis, designing to collect data such as experiment or observation depend on question, and then discussion and conclusion but it is not necessary through these steps orderly. Sometime scientists may change their questions while collecting data or change their hypothesis.” However, she did not give the example for students. Correspond with students’ understanding about the meaning of scientific method; two students did not change their understanding that the scientific method is orderly step of procedure.

Cross Case Studies

In this section, the results from three cases are analyzed across cases about students' understanding about the NOS and key concepts of respiration, and the relationship between the teachers' teaching practices and students' understanding.

1. Students' Understanding of the NOS and the Key Concepts of Respiration

1.1 Development of Understanding of the NOS

Students showed a variety of levels of the NOS understandings. Table 5.7 summarizes students' understanding of the NOS with a one in each aspect of the NOS from post interview. There were six students who held an informed understanding of all aspects of the NOS while three students held a mixed understanding of all aspects of the NOS. Concerning each aspect of the NOS, diversity of scientific method had the highest number of students with an informed understanding while science as social constructed had the highest number of students with a mixed understanding. Comparing the number of the students understanding in each category, scientific knowledge based on evidence, scientific knowledge as socially constructed and diversity of scientific method had the students with an informed understanding more than a mixed understanding while the tentative nature of science and science as social activity had students with an informed understanding less than a mixed understanding. There was one aspect of the NOS that students held an informed understanding equal a mixed understanding as the role of creativity and imagination. The details of each aspect are described as follows.

Table 5.7 Students' Understanding of the Six Aspects of the NOS of Post Implementation

Students	Evidence	Creativity and imagination	Tentativeness	Socially constructed	Diversity of method	Social activity
PA1	I	I	I	I	I	M
PA2	I	I	I	I	I	M
PA3	M	M	M	M	I	M
PA4	M	M	M	M	M	M
PB1	I	I	I	I	I	I
PB2	I	M	M	I	M	M
PB3	I	M	M	I	I	M
PB4	I	M	M	I	I	M
CA1	I	I	I	I	I	I
CA2	I	I	I	I	I	I
CA3	I	M	M	M	I	M
CA4	I	M	M	M	M	M
CB1	I	I	I	I	I	I
CB2	I	I	I	I	I	M
CB3	M	I	M	M	M	M
CB4	M	M	M	M	I	M
SA1	I	I	I	I	I	I
SA2	I	I	I	I	I	I
SA3	M	M	M	M	I	M
SA4	I	I	I	I	I	M
SB1	I	I	I	I	I	M
SB2	I	M	M	M	I	M
SB3	M	M	M	M	M	M
SB4	M	M	M	M	M	M

I = informed understanding N = naive understanding M = mixed understanding

To understand the evidence in science, before the implementation, half of the students held a naïve understanding about the evidence. They understood that scientific knowledge is the facts that scientists discover from observing natural phenomena. Another half of students held a mixed understanding that scientific knowledge requires the evidence, sufficient data from the experiment or observation to support it. However, they understood that the evidence that support scientific knowledge come directly from an experiments or observations. Some of the students understood that scientific knowledge has been proven and can be repeated by someone to show the same result or data as the evidence for right knowledge and being scientific knowledge. After implementation, most students developed to have informed understanding that scientific knowledge comes from the data interpretation, is constructed and inference based on the evidence but seven students still held a mixed understanding regarding the evidence in science.

As for the role of creativity and imagination before implementation, all students held a mixed understanding that scientists use their creativity and imagination to create new things such as instruments or technologies. During scientists' investigation, none of students indicated that creativity and imagination are used in making a conclusion the data or construction the knowledge or explanation. After implementation, half of the students developed an informed understanding that the creativity and imagination are used in all stages of scientific investigation including the formulation of hypotheses, the design of the investigation and the interpretation of the resulting data.

Before implementation, all students understood that scientific knowledge will be changed in the future because new technologies, new data, and more researches. Scientific knowledge can be changed in terms of adding new things or details more than abandonment. None of them mentioned about reinterpretation with the existing of data and gave the example of scientific knowledge changed. After implementation, eleven students held an informed understanding that the scientific knowledge can be changed in terms of adding in detail, replacement or abandonment, reinterpretation with the existing of data because such knowledge is constructed from the interpretation of data. Thirteen students still held a mixed understanding.

As for understanding about scientific knowledge as socially constructed, almost all of the students (twenty-two students) held a naïve understanding before implementation. They did not claim that scientific knowledge was socially constructed. Even though they understood that new knowledge develops from existing knowledge or the result of other experiments, they did not claim about the group of people who join together and sharing their ideas. They ignored about the argument of conclusion from the others. They understood that scientists work as individual. After implementation, ten students hold a mixed understanding that scientific knowledge is derived from the findings or results of research either done by individual or team of scientists. Scientists present their results and then have them discussed by fellow scientists. However, these processes are only the evaluation of the investigation procedures; examine the evidence excluding suggestion alternative explanation or interpretation for the same data. Contrast to understand of fourteen informed students, they understood that the argumentation and sharing ideas is one part of the scientific knowledge construction.

As for the diversity in the scientific method, all students hold a naïve understanding in this aspect. They understood that all scientific knowledge came from scientists from using the orderly step by step procedure of the scientific method. Some students indicated scientists used observation and surveying. However, it is the experiment or initial steps of the experiment which they use as the way to find answers. After implementation, most students exhibited an informed understanding about the diversity of scientific method. Six students hold mixed understanding. Informed students understood that scientists used the scientific method as the way for answering their question. Although it was a series of steps in a procedure they could still go back and forth between the steps. In addition, students indicated there were differences between an observational study and an experiment.

As for the last aspect of the NOS, science as social activity, this aspect is the understanding of the interaction between science and society. Before the implementation, all students hold a mixed understanding that science affected society however, they ignored that society affected science as well. After implementation, six students developed an informed level of understanding that not only scientists contributed to science, but also the people living in the society. Scientists' work is influenced by society because they are members of the society. When scientists work, they have to aware of the laws and acceptance levels of the society.

1.2 Development of the Understanding of the Key Concepts of Respiration

There are four main topics of respiration knowledge namely the definition of respiration, aerobic respiration, anaerobic respiration, and the relationship between cellular respiration and gas exchange. The results from three cases found that all students improved their conceptions regarding the respiration knowledge. However, none of students had correct conceptions in all main topics.

Before the implementation, all students had alternative conceptions about the definition of the respiration. None of the students mentioned about the energy or nutrients, glucose or any related compounds. Students defined respiration differently such as breathing, taking in oxygen and giving off carbon dioxide, and the respiratory system. All students held an alternative conception about the energy for metabolism that it came from the digestion of food in animals, and it came from photosynthesis in plants.

As for which organisms respire and when, all students understood that plants respire only at night. Seventeen students understood that respiration occurred just only in plants and animals. Microorganisms do not perform the respiration because gas, oxygen and carbon dioxide diffuse into the cell directly or microorganisms do not have specific organs for respiration. Seven students understood that respiration occurs in all living organisms. However, they gave the alternative reason that the respiration is taking oxygen in and giving off carbon dioxide. It is a life process and its purpose is being alive. Therefore, microorganisms are living things so they have to respire.

After the implementation, all students changed their understanding about the key concepts of respiration. Eleven students had correct conceptions in four concepts of the definition of respiration. All students held understanding that respiration is the chemical process occurring in all living organisms. However, half of the students had alternative conception about the respiration in plants. They understood that respiration takes place only the cells of leaves, roots and lenticels because the gas exchanges occur in those cells. In animals, they understood that oxygen is transferred by the circulatory system to all cells thus all living cells can respire.

As for the purpose of respiration, all students had correct conceptions that releasing energy from organic substances or energy rich compound is the purpose of respiration. Three quarter of the students identified that some energy is lost as heat from respiration. However, they did not explain how lost heats come from which process. Thus, this showed that they had unclear understanding about the concept of the production of energy. They did not understand about the process of producing energy from breaking down organic substances in each step of aerobic respiration and only Glycolysis of anaerobic respiration.

Most students (17 students) were categorized in alternative conceptual pattern 1-3 of aerobic respiration as shown in figure 5.7- 5.9 respectively. These patterns show that students fail to understand how oxygen is used in aerobic respiration to produce energy, in particular ATP. It was not surprising that they ignored the fact that water is a product of this process. Seven students were categorized in alternative conceptual pattern 4 of aerobic respiration (Figure 5.15) that identified oxygen as a terminal electron acceptor. However, they failed to understand that the electrons are combined with hydrogen ions and oxygen to make water.

All students had no idea about anaerobic respiration at the beginning of learning of respiration. They understood that oxygen is needed for all organisms. After the implementation, all students developed an understanding about anaerobic respiration. However, eight students were categorized in the alternative conceptual pattern 1 of anaerobic respiration (Figure 5.10). This pattern explained that anaerobic respiration produces energy, ATP but it is indicated that two ATP come from Glycolysis. Concerning to their understanding of aerobic respiration, six of them were categorized in the alternative conceptual pattern 1 of aerobic respiration (Figure 5.7). They understood that there are three series steps of an aerobic respiration namely Glycolysis, Krebs cycle, and Electron transport chain. They failed to understand that ATP is produced from Glycolysis. Although, they identified the substrates of aerobic respiration which are oxygen and glucose, its products are ATP and CO_2. They did not indicate that Glycolysis produces two ATP.

Moreover, five students were categorized in correct conceptions of anaerobic respiration. They had clearly understanding about Glycolysis process that aerobic plants and animals are able to perform Glycolysis when oxygen is not enough and perform fermentation that related with balancing between $NADH_2$ and NAD^+

As for the relationship between cellular respiration and gas exchange, thirteen students were categorized in the alternative conceptual pattern 3 (Figure 5.13). Six students were categorized in the alternative conceptual pattern 2 (Figure 5. 12). There were five students who had correct conceptions regarding the relationship between cellular respiration and gas exchange (Figure 5.5).

2. Teaching Practices and Students' Understanding of the NOS and Respiration

The result from three cases showed that three teachers' teaching practices related with students' understanding the knowledge of the respiration and the NOS. Even though, they tended to follow teaching activities and questions as guided by a teacher manual of the RIU but they had different teaching practices. These practices affected to students' development of their understandings.

For teaching the NOS aspects in the lesson, the result showed that the explicit and reflective teaching about the NOS from students' activities in the lesson is effective to students understanding the NOS. For example, Pimpan and Sirintip explicitly discussed and provided students reflection about the diversity of scientific method from students' investigations by writing their understanding. Chatchai explicit discussed the diversity of scientific method from students' investigation and the history of respiration. For students' reflection their understanding the NOS, three teachers often provided students to write their understanding and answer questions in students' worksheets.

However, some teaching practices were obstacle students understanding the NOS. For example, using the structure inquiry that students rarely role of responsibility of their investigation and providing the conclusions of the investigations for students obstructed students' understanding the role of creative and imagination during investigation and after collecting data. Correspond with students' respond the interview about the role of creativity and imagination, most students said that they did not use their creative and imagination for creating or designing the dissection procedure because they do follow the step from teacher. Some students thought that their creativity and imagination were only used to present their data.

Concerning the teacher role in students' inquiry and students construction the knowledge, Sirintip and Chatchai focused on being a "facilitator of learning" moving toward guide inquiry. They emphasized how students know more than what they know enhance students understanding both the NOS and the knowledge of respiration. They began with students' prior knowledge and giving some example questions to facilitate students generating their questions for inquiry. Sirintip was good guide to help students asking the questions for inquiry the knowledge of respiration. She asked some questions to make students be curious and interested in learning next. Moreover, her questions were the sample questions for motivating students to generate their questions. Chatchai tried to change his role from teller to facilitator. He often asked questions for students to think and understand about their activities. He also allowed each group to decide about their investigation more than do follow his order.

CHAPTER VI

CONCLUSIONS, DISCUSSION, AND IMPLICATIONS

This chapter consists of 1) research questions; 2) the conclusions and discussion of this research results with regard to the literature reviewed in Chapter II; 3) implication of the research study for science teachers who will be active in developing students' understanding of respiration and the nature of science, as well as science educators who design and implement in-service professional development programs to enhance teacher teaching as inquiry and the NOS; and 4) recommendations for future research.

Research Questions

1. What understandings of the nature of science are held by level 4 biology teachers?

1.1 What are biology teachers' general understandings of the nature of science?

1.2 What are biology teachers' specific understandings of the nature of science in relation to their knowledge of respiration?

2. What pedagogical understandings do level 4 biology teachers hold in relation to teaching of respiration?

2.1 How do biology teachers typically conduct their teaching of respiration?

2.2 What are biology teachers' general understandings of inquiry teaching?

2.3 How do teachers typically use inquiry when teaching the topic of respiration?

3. How do teachers implement the instructional unit on respiration, which integrates the nature of science aspects using explicit and reflective inquiry-based approaches, enhance students' understanding the nature of science and knowledge of respiration concepts?

3.1 How do students' understandings of the nature of science develop over the course of an instructional unit on respiration?

3.2 How do students' understandings of key concepts of respiration change over the course of an instructional unit on respiration?

3.3 In what ways do teachers' teaching practices influence students' understandings of the nature of science?

3.4 In what ways do teachers' teaching practices influence students' understanding of respiration?

Conclusions and Discussions

The conclusions and discussions of this study are organized into three sections regarding to research questions. This section starts with a conclusion and discussion about the teacher participants in terms of understanding of the nature of science and inquiry-based approach and the teachers typically used inquiry teaching in the topic of respiration. The second section is conclusions and discussions about students' understanding of the nature of science and key concepts of the respiration knowledge after they learn by explicit and reflective inquiry- based approach. Then teachers' practices that influence students' understanding of the NOS and respiration are discussed.

1. Teachers' Understanding of the Nature of Science and Inquiry-based Approach and Teacher Practices before the Implementation the RIU

The first and second research questions were exploring about teachers' understanding of the NOS and inquiry-based approach and their typical teaching practices in respiration that related with inquiry-based approach before the implementation of the RIU. Three teachers were interviewed about their understanding of the nature of science and inquiry-based approach and then they were observed their teaching. Conclusions and discussion about the three teachers before the implementation are described as follows.

1.1 Teachers Understanding of the Nature of Science

The nature of science in this research consists of six aspects namely: 1) scientific knowledge based on empirical evidence; 2) scientific knowledge as socially constructed; 3) the role of creativity and imagination; 4) the tentative nature of science; 5) diversity of scientific methods; and 6) science as social activity. Three teacher participants had a variety of understandings of the nature of science. They had inadequate understanding in many aspects. Pimpan held informed understanding in two aspects namely scientific knowledge based on empirical evidence and social activity. She held mixed understanding in the other aspects. Sirintip and Chatchai held informed understanding in three aspects namely scientific knowledge based on empirical evidence, scientific knowledge as socially constructed and diversity of scientific methods. They held mixed understanding in the other aspects.

As for the understanding of the scientific knowledge as constructed, it is contributed from understanding of three aspects in this research namely empirical evidence, socially constructed, and the role of creativity and imagination. All teachers understood that the evidence is an important for scientific knowledge. However, the role of the evidence in science is viewed differently. For Pimpan, the scientific knowledge was affirmed to be true from the evidence. Chatchai understood that the confidence of scientific knowledge depended on the trustworthiness of data or evidence. Sirintip understood that evidence is relevant to the acceptance of the knowledge claims to be considered scientific. In deed, science relies on empirical evidence (McComas and Oleson, 1998). Scientific knowledge is not accepted because it is “true” but because people are persuaded of its value, i.e., its adequacy as an explanation, or its utility, or some other standard (Sandoval, 2005: 639). The notion about the role of evidence to accept the knowledge, related with scientific knowledge is socially constructed includes cooperation, collaboration, and competition. Chatchai and Sirintip held informed understanding that scientific knowledge was accepted by the scientific community.

To understand my interpretation, Pimpan held naïve understanding that scientists will come to the same conclusion when confronted with the same data. This showed that she understood the scientific knowledge directly from seeing it—there is no room for interpretation (Akerson, Hanson, and Cullen, 2007: 761). Contrast with Chatchai and Sirintip understanding, they understood that scientific knowledge derive from the inference of data and evidence. However, they did not indicate that bias, norm, and culture of scientists influenced to a scientific research issue beside needs, solving a problem of society.

Human creativity and imagination plays an important role in the development of scientific knowledge (Sandoval, 2005). Three teachers understood that scientists use imagination and creativity in their work and investigation such as formulating hypotheses and designing of the investigation. None of them indicated that scientists used their creativity and imagination for making a conclusion or the invention of explanations, models or theories. Although, Chatchai and Sirintip understood that scientific knowledge derived from the interpretation of the data, they understood that the interpretations use logic and reasoning more than creative thinking because the scientists are acting as objective persons.

The status of scientific knowledge, all teachers believed that scientific knowledge changed over time. However, they stated that the knowledge changed in terms of adding the details or new knowledge more than abolishment of the existing knowledge. Sirintip stated that there was only uncertain scientific knowledge to be abolished. The uncertainty of scientific knowledge was supported by inadequate data or limited investigations. Similarly, Chatchai noticed that at that time, such knowledge was either uncertain or wrong because of the limit of data, technology and investigation. However, they did not identify that the scientific knowledge changed because of the reinterpretation of existing data or the new competing ideas.

As for the scientific method, Pimpan understood that scientific method had orderly steps, in particular the sequence of observation, question, hypotheses, experiment and making a conclusion. Similarly, much research has revealed that both pre-service and in-service teachers understanding that scientific knowledge come from rigid scientific method (e.g. Brickhouse, 1990; Lederman, 1992; Akerson *et al*., 2007). To understand about diversity of scientific method, all teachers' responses showed a wide diversity such as observation, survey, and the experiment. However, Pimpan and Chatchai had unclear understanding of the differences among these methods.

1.2 Teachers' Understanding of the Inquiry-based Approach and Teaching Practices

The three teacher participants in this research understood about characteristics of inquiry- based approach differently. Pimpan understood the inquiry-based approach as engaging students to do like scientists that required high level of achievement students and 5E model of inquiry planning. Chatchai understood the inquiry-based approach as students learning from doing activities such as hands-on, investigation, and searching and presenting information. Inquiry-based approach required the structure and direction while students must be active learner and responsibility. Sirintip understood the inquiry-based approach as engaging students in investigation that required guidance and motivation from teacher. The inquiry-based approach was difficult because there were many factors related such as students' abilities, teacher's skill and knowledge, and time.

As for teaching practice, three teachers' understandings were not reflecting completely in teaching practice. All teachers used lecture more than inquiry teaching, although Pimpan indicated that students investigate like scientists do. This understanding did not reflect in students' investigation. It was teacher-directed more than students-directed. In students' investigation, all teachers provided students with a problem to investigate, the procedures, and materials, but did not inform them of expected outcomes. Students followed precise teacher instructions to complete an investigation. Moreover, students communicated results only to course instructor through lab reports. It was similar to "cookbook" lab that teacher provided more direction to students than structured inquiry (Colburn, 2000; Martin-Hansen, 2002).

Inquiry teaching is concerned with the five essential features of inquiry consist of: "(1) learner engages in scientifically oriented questions, (2) learner gives priority to evidence in responding to questions, (3) learner formulates explanations from evidence, (4) learner connects explanations to scientific knowledge, and (5) learner communicates and justifies explanations" (NRC, 2000: 29). The inquiry-based approach in classroom is being student-directed more than teacher-directed. The understandings of inquiry-based approach and teaching practice of three teachers were incomplete and left out essential features of inquiry. Moreover, all teachers did not understand about the level of inquiry that can vary from very structured, "Guided Inquiry", to very open, "Open Inquiry" (NRC, 2000; Colburn, 2000; Martin-Hansen, 2002). These findings correspond with many research results that have revealed that there is a deficiency in teachers' understanding of inquiry-based approach across all levels of education (e.g. Keys and Bryan, 2001; Hayes, 2002; Brown and Melear, 2006; Brown *et al*., 2006).

As for the role of teacher in inquiry-based approach, Pimpan indicated that the teacher was the supporter and planner following the 5E model. Chatchai understood that inquiry teaching was directed from teacher, teacher as director. Sirintip indicated that teacher was a guider and motivator for students keeping on their tasks. Crawford (2000) reported that there are many roles of science teachers in inquiry-based classrooms: a model, mentor, collaborator, learner, motivator, diagnostician, guide, innovator, experimenter, and researcher. From classroom observation, all teachers often exhibited the characteristics of explainer or lecturer. They provided the conclusion statement or corrected answer for students without discussion and asking any question to motivate students constructing the conclusion and answer. This practice differs from the role of the teacher as a facilitator which as another important feature of inquiry teaching according to Schwab (1962) and NRC (2002). Schwab (1962:67) stated that the questions a teacher asks in this type of classroom are not designed to assess whether a student's answer is right or wrong, but to encourage and support the student to constructing answers.

All three teachers believed that inquiry teaching was not appropriate with all students. In another word, inquiry teaching required the specific characteristic of students such as active learner, high level of achievements, attention and responsibilities. This understanding reflected their prior experience with unsuccessfully attempting to implement inquiry teaching. Thus, the inquiry-based approach was viewed as difficult for implementation in a science classroom. Correspond with Windschitl (2003) claimed that prior experience of implementation inquiry teaching has a direct relationship to understandings of inquiry.

2. Students' Understanding of the Nature of Science and the Key Concepts of Respiration.

2.1 Understanding of the Nature of Science

In this section, the aim of the research question is to investigate student understanding of the nature of science after implementing the respiration instructional unit. To improve students understanding of the nature of science, much research suggested that the nature of science must be taught explicitly and in conjunction with reflective written exercises and/or discussions regardless of students, in- service and pre-service teacher (Abd-El-Khalick, 2001; Khishfe and Abd-El-Khalick, 2002; Schwartz and Lederman, 2002). Comparing between implicit inquiry-based approach and explicit and reflective inquiry-based approach to develop students' understanding about the nature of science from review of literature, many researches found that explicit and reflective inquiry-based approach is more effective than the implicit approach in enhancing students' understanding of the nature of science (Meichtry, 1992; McComas, 1998; Lederman and Abd-El-Khalick, 1998; Moss *et al.*, 2001; Khishfe and Abd-El-Khalick, 2002; Schwartz and Lederman, 2002). However, the result also show that students' understanding of the nature of science after explicit instructional implementation and reflective inquiry-based approach created a range of understandings with respect to the nature of science depending on the subject matter content (Brickhouse *et al.,* 2002).

According to these arguments and suggestions, much research has shown that explicit teaching of the nature of science out side of the science content has only a limited effect on changing and improving understanding of the nature of science. The nature of science activities and discussion can appear to be an add-on, if not tightly linked to science content (Driver *et al.,* 1996; Brickhouse *et al.,* 2002; Khishfe and Abd-El-Khalick, 2002). In this view, the nature of science is integrated with the science content. In this research, the respiration instructional unit was developed based on explicit and reflective inquiry-based approach. The nature of science was instructionally integrated with the knowledge of respiration.

The result of this research showed that six students held informed understanding of all aspects of the nature of science while two students held mixed understanding of all aspects of the nature of science. Although students' participants in this research had mixed understanding, some naïve understanding did not to be change. All students in this study improved their understanding of the nature of science in different aspects.

The naïve understandings of the NOS from this research show that students held the following conceptions of science after the implementation of the respiration unit:

1) Scientific knowledge comes directly from the data.

2) Scientific knowledge has been proven and can be repeated by someone to show the same result or data as the evidence for right knowledge and being scientific knowledge.

3) Creativity and imagination are used during investigations except for making a conclusion from the data or construction of the knowledge or explanation.

4) Scientific knowledge will be changed in the future because new technologies, new data, and much research except reinterpretation with the existing of data.

5) Scientific knowledge will be abolished only because it is determined to be wrong and in error.

6) All scientific knowledge came from scientists using an orderly step procedure of scientific method.

7) Presentation and argumentation of scientists are the only evaluation of the investigation procedures; examine the evidence excluding suggestion alternative explanation or interpretation for the same data.

The students held the following notions about scientific knowledge as constructed knowledge; it contributes from three aspects of the nature of science in this research namely empirical evidence, socially constructed, and the role of creativity and imagination. All students understood that scientific knowledge required the evidence. Most students had informed understanding about the role of evidence. Brickhouse *et al.* (2002) claimed that this notion is easy to understand for students because students come to class with some notion that the evidence was important in science.

The students held naïve understandings that scientific knowledge comes directly from the data. This was viewed as evidence that the students held inadequate understanding of the role of scientific data interpretation. Moreover, inadequate understanding of interpretation effect understanding of the role of creativity and imagination, and science as socially constructed. Providing the conclusion statement and correct answer is the cause of students ignored thinking about their data, trying to make inferences and sharing their idea about their conclusion.

Concerning the role of creativity and imagination, some students have difficulty understanding that the scientific knowledge, in particular, a conclusion of investigation derives from creativity and imagination because they strongly understand that science is reasoning, logic, and straightforward. Similarly, to understand the evidence, it is easy for students that in general, all scientific knowledge can change in terms of adding because new technologies, new data, and more many researches. Students believe that scientific knowledge will be abolished because it is wrong or that it contains error due to inadequate instruments used at that time. Regarding specific knowledge, students understood that knowledge in textbook cannot be abolished because it is certain. Moreover, it is hard to understand that the chemical process is abolished in the future because students had inadequate understanding of the role of creativity and imagination. This result supports the argument that teaching the nature of science is interwoven in science content (Driver *et al.,* 1996; Brickhouse *et al.,* 2002; Khishfe and Abd-El-Khalick, 2002).

As for the understanding about the diversity of activities that fall under the title of scientific method, most students had informed understanding. Although they understood that it is series of stepwise procedures, scientists can move forward and backward during these steps. In addition, they indicated to differentiate between the observational study and the experimental study. This result reflected about explicit discussion of the diversity of scientific method about students' investigation. This is strong instruction. All teachers discussed from their investigation to understand diversity of scientific method.

2.2 Understanding of the Key Concepts of Respiration Knowledge

There are four topics of respiration knowledge that were investigated with respect to students' understanding in this research namely the definition of respiration, aerobic respiration, anaerobic respiration, and the relation between cellular respiration and gas exchange. Most students exhibited partial understanding of the respiration such as students gave the correct understanding in some part of concepts but omitted important ideas.

For most students, the definition of respiration is that of the chemical process. Much research that explores the respiration concepts found that both students and teachers had alternative conception about the definition of respiration (Sander, 1993; Songer and Mintzes, 1994; Alparslan *et al.*, 2003). Based on four concepts in definition of respiration in which alternative understanding can occur as a chemical process occurring in all organisms all the time to break down the organic substances to provide energy. After implementation, all students understood that respiration in biology is a chemical process because teachers often emphasized this concept. Some students had alternative concepts of "all organisms and all time". In animals most students had correct conceptions that all living cells respire all the time. Contrast with in plants, half of students had alternative conception that only in the cell of leaves, roots, lenticels respire. Their reasons to explain this alternative conception related with gas exchange and circulatory system of animals. Concerning the reason, it implies that students learn gas exchange from animal more than plants. They may have alternative conceptions about plants.

As for the concepts of the chemical processes of respiration, there are two types of respiration as aerobic and anaerobic respiration. In this research, students were categorized in five alternative conceptual patterns of aerobic respiration. Each pattern can explain the alternative conceptions in aerobic respiration.

Pattern1: students understood that aerobic respiration is the process to provide energy in form of ATP when oxygen presented. They identified the substrates of aerobic respiration, oxygen and glucose, its products as ATP and CO_2, and three series steps of aerobic respiration. However, students could not explain the relationship among theses steps in terms of products: CO_2, ATP, and electron donor and receptor. Moreover, they ignored that heat is one product of aerobic respiration.

Pattern 2: this pattern represents some progress over the previous one in that students indicated that energy is lost as heat. However, they had no idea how the heat is produced. They understood that $NADH_2$, CO_2, and ATP are produced during the process of Glycolysis and Krebs cycle. However, they had no idea that $NADH_2$ are transferred to the electron transport chain for producing ATP. Moreover, they ignored the role of $FADH_2$ and oxygen during the respiration process.

Pattern 3: students added more understanding that $NADH_2$, $FADH_2$, and oxygen are entered to the electron transport chain for producing ATP. They understood about the role of the electron carriers, $NADH_2$, $FADH_2$ is producing ATP. However, they did not explain about the transferring of electrons from $NADH_2$, $FADH_2$ to oxygen molecules to form water molecules (H_2O).

Pattern 4: it differs from the others in that students understood about the role of oxygen which is a terminal electron acceptor in electron transports chain. However, they ignored the water which is one product of respiration that comes from electron transport chain related with oxygen as terminal acceptor. Moreover, they had no idea where heat comes from during the respiration process.

In the topic of aerobic respiration, none of the students had correct concepts. From four patterns, they showed that the concepts of oxygen, heat, and water are the most difficult for understanding. Moreover, the concept of energy producing is unclear. The concept of heat relates with breaking down carbon bond and producing energy as ATP and heat. Teacher explanation only points out about the kind and number of products. Such a general statement does not explain in terms of the chemical nature of the end products. Moreover, textbook accounts usually fail to convey a comprehensive and accurate picture of the processes to students (Yip, 2000) such as diagram of aerobic respiration textbook ignored to identify the heat.

As for anaerobic respiration, there are two alternative conceptual patterns. Pattern1: students understood that some microorganisms perform anaerobic respiration and also some cells of aerobic animals, for example, muscle cell can perform anaerobic respiration for short periods of time. Nevertheless, they ignored anaerobic respiration in plants. They understood that muscle cell can switch aerobic respiration to anaerobic respiration when the amount of oxygen is not enough. Moreover, they had no idea how ATP comes from and ignored the CO_2 which product of alcoholic fermentation.

Pattern 2: students ignored that anaerobic respiration occurred in plants for short period of time such as plants flood. They explained that two ATP are produced from Glycolysis before pyruvic acid is broken down in alcoholic fermentation and lactic fermentation. However, they did not identify that plants or animals perform Glycolysis even oxygen is not enough to produce ATP. Moreover, they held correct conception that our muscle cells can produce energy from both processes, aerobic and anaerobic respiration together when oxygen is not enough. Although they identified that CO_2 is produced from alcoholic fermentation. They could not compare the amount of CO_2 between aerobic and anaerobic respiration.

Concerning the students understanding of both aerobic and anaerobic respiration, in pattern 1, it shows that students who had unclear understanding about Glycolysis lead to alternative conception of anaerobic respiration. In pattern 2, aerobic plants can perform anaerobic respiration. This concept usually ignores the conceptual information that is provided by the teacher during teaching anaerobic respiration.

As for the relation between gas exchange and cellular respiration, there are three alternative conceptual patterns.

Pattern 1: students understood that the energy is produced when we exercise from taking oxygen in and taking out carbon dioxide. There are missing links between oxygen with the energy.

Pattern 2: students indicated that oxygen from the environment enters the cells from gas exchange to produce energy. However, they ignored the CO_2 which is the waste product from cellular respiration that affects to the rate of breathing in and out of human.

Pattern 3: they could connect between gas exchange and cellular respiration process in terms of oxygen, carbon dioxide, and producing energy. They could explain the path way of oxygen from environment to the cell and the steps of the cellular respiration process that produce carbon dioxide that is released during exhalation. However, they did not clearly understand about the role of oxygen in electron transport chain and the role of the electron carrier to produce ATP and H_2O.

Most students were categorized in pattern 3. It supports that students not clearly understand the aerobic respiration in concept of energy.

2. Teaching Practice Related Students' Understanding of the Nature of Science and Knowledge of Respiration.

The three teachers participants implemented the respiration instructional unit that was developed based on the explicit and reflective inquiry-based approach. In general, research shows that inquiry teaching produces positive results such as the NOS, scientific process, and conceptual understandings. While research says inquiry teaching can produce positive results, it does not, by itself, tell teachers exactly how to do it (Anderson, 2002). Teaching practices are essential in supporting students learning and understanding. In this section, teacher practices from three cases are discussed in terms of relation with students' understanding both the nature of science and the knowledge of respiration. As for teaching practices, the results of this research revealed that teaching practices affect to students understanding.

As for the role of three teachers during the implementation, they had a variety of roles in teaching such as facilitator, guide, motivator, teller, director and lecturer. The teachers used different approaches for assisting students learning and constructing their knowledge through the lesson. They often were lecturer and explainer for the conclusion of the lesson.

Concerning teacher discussion with students, both three teachers and their students were unfamiliar with discussion. For Pimpan's discussion, she tried to provide students discussion as following the lesson plan. She used questions from the lesson both guiding her to discuss with students. However, her discussion seemed to be asking and questioning more than sharing idea. She often gave the correct answer and the explanation for students more than discussion with students. Chatchai and Sirintip effectively discussed with students. They let students share ideas within a group and then discuss in the whole class. Students had opportunities to provide their reasons behind the answers.

Correspond with the questions that teachers used during implementation, Chatchai and Sirintip often used the questions "why and how" more than "what" that differed from Pimpan. Chatchai often emphasized students about the chemical process more than the products of the step of cellular respiration both aerobic and anaerobic respiration. He accepted that the chemical process is difficult for students understanding. However, he believed that if students link the process with the products, it made students understanding the concepts. Using why and how questions are effective way to help students to grasp and understand not only the chemical process of knowledge of respiration but also the nature of science.

Additionally, the result of this research support contextualized nature of science that the NOS is interwoven in content. The nature of science aspects are taught as a stimulus to the students while teaching the science content (Driver *et al.,* 1996; Brickhouse *et al.,* 2002; Khishfe and Abd-El-Khalick, 2002). Explicit discussion and reflective were used about the nature of science aspects, for example, all teachers discussed about the diversity of scientific methods. They used students' investigation as the examples to assist students to understand the diversity of scientific methods by comparing between the experiment about factor of rate of respiration and dissection the gas exchange organ. The result showed that most students had informed understanding in this aspect. Similarly, Crawford (2000) reported that situating instruction in authentic contexts is effective teaching practice to teach the nature of science.

All teachers reviewed and probed students' prior knowledge and alternative conception. The findings from the three cases showed that if teachers know and are aware about alternative understanding, they emphasized and probed students understanding during teaching and provided students with opportunities to reflect their understanding. The definition of respiration, for example, three teachers emphasized about the definition of respiration as the chemical process occurring in all living cells for releasing energy and often review it meaning by asking question or providing students to write their understanding before and after for correcting students understanding. For the nature of science, they are aware to use term "the experiment" and "observation". They explicitly discussed the meaning of the experiments and compared the experiment with other methods such as observation and dissection. These practices are useful for students to think, recall and pay more attention.

Chatchai and Sirintip explicitly facilitated to keep on students' inquiry. They guided students' engagement in investigations and hands-on activities and by giving clearer explanations, objectives, and directions. They used effective forms of explanation to support students understanding of their learning goals. Most students responded that these practices helped them to know what they do and how to perform correctly. Chatchai exhibited helping students to design the experiment and conclusion by asking understand about the variable and data that support their result. These practices help students to understand the logic behind scientific inquiry practices that why they need to include evidence and reasoning to support their claims (Kuhn *et al.,* 2000).

As for teachers' teaching practices during students' investigation, all teachers provided what question is to be explored. Pimpan decided the hypotheses and data collection in all students' investigations. Students collected data, analyzed their data, drew conclusions. Chatchai and Sirintip tried to reduce their direction to students driven the investigation. The students had opportunities to participate in the formulation of hypothesis and develop an experimental procedure to be used. After the teacher approves the procedure, the students carried it out, analyzed, and made a conclusion. However, all teachers rarely discussed about the students conclusion and compared the different viewpoints to connect the nature of science aspect. They often gave the conclusion statement for students. Moreover, all teachers ignored guiding students to propose additional questions that could be explored after finishing investigation. These practices supported students to understand that their investigation is a confirmatory investigation with a single correct answer.

Implications for Science Teacher Professional Development

To be able to implement a professional development in-service program regarding the instruction of the NOS through the explicit and reflective inquiry-based approach and the development of student understanding of respiration, the findings of this research suggests three things.

- First, this research found that the quality of discussions in relation to the six aspects of the NOS influenced student learning. Teacher discussion with students is essential for student reflection about their understanding of the NOS. Professional development programs should be designed base upon strategies that best facilitate effective discussion. Teachers should understand how to discuss in a way that supports their students' learning.

- Second, the findings regarding the development and implementation of the unit in this research came from integrating the NOS in the context of respiration. Professional development programs should produce opportunities for teachers to collaborate in designing curricula which incorporate the explicit and reflective the teaching of the NOS for other topics in biology.

- Lastly, the results from this research show that the teachers are well aware that students possess a variety of alternative conceptions and therefore taught in a manner aimed at correcting those alternative conceptions. They have to be willing to diminish alternative conceptions. This implies that teachers need to acknowledge that their teaching practices play a role in the formation of students' alternative conceptions. Therefore, professional development programs should construct teachers to be aware of and acknowledge that their teaching practices have played a role in the formation of students' alternative conceptions. Professional development programs should provide teachers with a way in which to understand; 1) what science education researchers have found regarding alternative conceptions; 2) how to probe and eliminate these alternative conceptions; and 3) what factors cause alternative conceptions. Moreover, teachers are also encouraged to keep more up to date with current science knowledge.

Implications for Future Research

There are several areas in which future research could be undertaken to create better understanding among teachers in using the explicit and reflective inquiry-based approach while implementing the respiration unit as a way of developing student understanding of the NOS and the topic of respiration.

- Regarding participant selection for this research, the participants in this study consisted of two groups, three biology teachers who were experienced teachers who have taught more than ten years and their twenty-four students. To better understanding teacher implement the respiration instructional unit, future research teacher should be undertaken to the results of the implementation of the respiration unit with both new teachers. As this research was undertaken with a large sample size, therefore, future research should be done using a smaller sample size for more in depth study.

- This research was carried out using teacher participants who volunteered to participate to in the implement of the unit encompassing the explicit and reflective inquiry-based approach for developing the NOS and respiration knowledge. However, they had inadequate understandings of both the nature of science and explicit and reflective inquiry-based approach. Future research should go more beyond the deficit models that focus on factors that constrain inquiry and the NOS to investigate examples of teachers who successfully used the explicit and reflective inquiry-based approach in teaching the NOS.

- This study looked at inquiry teaching in a holistic manner. Future research should examine teacher understanding and practices in terms of the five essential dimensions of inquiry including: 1) learner engages in scientifically oriented questions; 2) learner gives priority to evidence in responding to questions; 3) learner formulates explanations from evidence; 4) learner connects explanations to scientific knowledge; and 5) learner communicates and justifies explanations.

- This study did not find out about teacher participants' prior understandings of both the nature of science and the inquiry-based approach, and the degree to which those conceptions changed after implementation of the unit. To understand the teachers' incoming understanding would be advantageous and would allow researchers to better understand how a change in their understandings could inform future development of instructional units that enhance the nature of science and science content knowledge. Therefore, longitudinal studies are needed to examine how teachers understanding and practices of inquiry change over a period of time as a result of interventions such as the one at the center of this research.

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APPENDICES

Appendix A

Teacher Semi-Structure Interview

1. The Interview Questions about Teacher's Understanding the Nature of Science

1. What does the nature of science mean to you?
2. What make science different from other disciplines of inquiry with regard to inquiry and the construction?
3. The knowledge of respiration (e.g. gas exchange and cellular respiration) do you think how scientists inquiry such knowledge and what evidence do you think the scientist used to explain the respiration?
4. "Scientific knowledge can be changed" Do you agree with the statement? Why?
5. The knowledge about the cellular respiration processes can be changed? Why?
6. In scientists' work, do you think the scientists use their imagination and creativity during their works or their investigations?

   If yes, which stages of investigations that scientists use their imagination and creativity? Please explain why scientists use imagination and creativity.

   If no, Please explain why. Please give example support your ideas.
7. Do you think scientists' work related with social? Please explain.
8. What aspects of instruction are required to meet the nature of science components of science standard 8?

   Is teaching about the nature of science only done is one or few section of the unit or is it integrated throughout the respiration unit? Explain and give example.

2. Interview Questions about the Inquiry- Based Approach and Teaching Practices in Respiration Topic

1. Are you familiar with the term inquiry-based approach? What does it mean to you?
2. Do you use inquiry-based approach in respiration unit? Explain and give the example.
3. What is the role of teacher of inquiry-based approach?
4. What is the role of students of inquiry-based approach?
5. What are importance things that support and obstacle for your teaching as inquiry?

Appendix B

Students Interview about the Nature of Science

1. The Interview Questions about the Nature of Science in General

1. What is science?
2. What make science different from other disciplines of inquiry?
3. What is the scientific knowledge? How it develop?
4. How has the scientific knowledge changed over time? How did scientist thinking influence this change?
5. How do scientists work?
6. Do you think scientists' work related with social? Please explain.
7. In scientists' work, do you think the scientists use their imagination and creativity during their works or their investigations?

If yes, which stages of investigations that scientists use their imagination and creativity? Please explain why scientists use imagination and creativity.

If no, Please explain why. Please give example support your ideas.

Have student read about Wechai's task and answer these questions

Wechai's task

"Wechai was interested in the characteristic of fish gills - the organ for gas exchange. He wanted to know that each kind of fish have the same or different characteristic of gills. He collected the picture of external and internal of fish anatomy. He dissected the gills of some kinds of fish that he bought from the market. He observed and drew these gills. He concluded that gill consists of gill arch and gill filament. Each kind of fish had different the number of gill arch and gill filaments. The surface of fish gill was thin and moist. These characteristics were suitable for gas exchange."

Questions

1. Do you think Wechai's task was scientific work or not? Explain your ideas.
2. Do you think this task is scientific experiment? Explain your ideas.
3. If you do the same with Wechai, do you think your conclusion will be the same of Wechai or not?

2. The Interview Questions about the Nature of Science in Students' Investigation

1. Can you explain this activity, what was the purpose of this activity? (why do you were doing this activity) What did you do or trying to do in this activity? Questions for probe:
   What were some of your predictions? How did you come up with that prediction? Why did you think that would happen? What did you observe? How close were your predictions and theories to your results? How did your predictions and theories relate to your results? How does evidence (data), and the analysis of that evidence, lead to the conclusion reached?

2. Do you all think what you were doing here was an experiment or not, and also tell me why you think so?

3. In this activity were you trying to get evidence for or against some theory, or hypothesis, or law, or something?
   - Yes probe: What was the theory/hypothesis/law and how did this help you to get evidence for or against it?
   - No probe: What were you trying to do?

4. Such knowledge (from No. 3) can change over the time or not? Explain.

5. How do you think your ideas here might change if you did this activity again?

6. How do you think what you did here is like or not like what scientists do?

7. Do you think you use your imagination and creativity during your works?
   - Yes probe: Please explain what stage that you use.
   - No probe: Please explain why.

8. Do you think the development of knowledge of respiration require only experiment?
   - If yes or no, please explain why.

9. How do you know? (for a respiration rate activity)
   - That yeast is organism?
   - That the carbon dioxide exhaled is the product of cellular respiration?

10. How do you know? (for the dissect gas exchange organ activity)
    - That gill or lung is the organ for gas exchanging?

Questions for probe in all questions

- Does anyone have anything to add to that?
- Does anyone else have a different idea?
- Does everyone agree with one of these ideas?

Appendix C

The Respiration Concept Survey

The Respiration Concept Survey

Two tier questions

1. All of the oxygen we inhale will be converted to energy.

Reasons

a. Oxygen moves into the cells and bind with nutrients to be changed energy.

b. Oxygen is conveyed to the cells and moves into the cells. Oxygen is changed to energy by enzyme in the cell.

c. Oxygen moves into the body and change with carbon dioxide then carbon dioxide moves out.

d. Oxygen is last electron accepter in cellular respiration that involves a set of chemical reactions in which oxygen and nutrients react to form energy.

e. Respiration is the process of getting energy from sugars and other chemicals and does not use oxygen. Oxygen is used in the cells in other processes that help keep the cells alive.

f. ……………………………………………………………………………..

2. The respiration occur just only plants and animals, it does not occur in microorganisms.

Reasons

a. Microorganisms are simple organisms so they do not have organ for respiration.

b. Microorganisms are small organisms. Oxygen and carbon dioxide can diffuse into the cells directly.

c. The purpose of respiration is taking oxygen into a body and cells. Microorganisms are living things so they have to respire.

d. All living things need energy for life. The purpose of respiration is providing energy so microorganisms perform respiration too.

f. ……………………………………………………………………………..

3. Plants perform respiration at night and photosynthesis at day

Reasons

a. In day, plants perform the photosynthesis process to change carbon dioxide to oxygen. This process needs light. At night, oxygen that comes from photosynthesis process is used in the respiration process and this process change oxygen to carbon dioxide.

b. The respiration process contrast reaction with the photosynthesis. In day, the photosynthesis produces glucose and oxygen for the respiration processes to produce energy, so it occurs at night.

c. The respiration occurs all the time because of it produce energy for the cells, it not depend on light.

d. The respiration is exchanging between oxygen and car bon dioxide so it can occur after finish photosynthesis. For photosynthesis, it needs light energy.

f. ……………………………………………………………………………..

4. All living things need energy from respiration that requires only oxygen.

Reasons

a. Oxygen is necessary for produce energy in the cells. This energy is used to cell activities

b. Some organisms can use other gases for a life such as nitrogen and carbon dioxide.

c. All living things use energy from nutrients or food. Energy is not related the respiration.

d. Some organisms can produce energy from the respiration which out requires oxygen.

f. ……………………………………………………………………………..

5. In plants, the respiration takes place in the leaves.

Reasons

a. The function of leaves is exchange between oxygen and carbon dioxide.

b. Leaves have stomata as the way of oxygen to move in plant cells and move out carbon dioxide into the air.

c. The respiration is a set of chemical reaction for energy production so it occurs in all life cells.

d. Plants can use leaves or roots or stems for exchanging between oxygen and carbon dioxide, depend on the kind of plants.

f. ……………………………………………………………………………..

6. In seed germination, seeds perform the respiration.

Reasons

a. The respiration is occurring in all living things. Seeds are living things so they perform the respiration while they germinate.

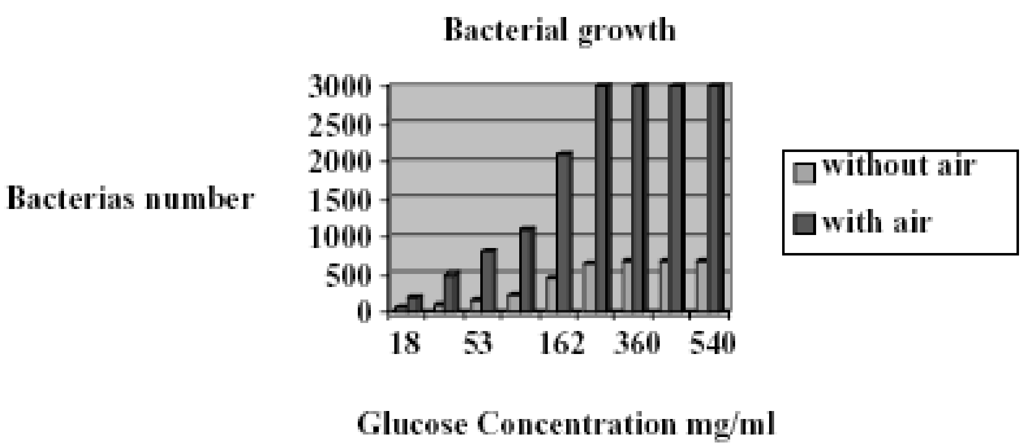
b. The purpose of respiration is producing the energy. When seeds germinate, they need energy so they respire.

c. When seeds germinate, seeds use oxygen and water as the substrate for a set of chemical germination process.

d. When seeds germinate, seeds use nutrients that they collect from the energy resource. Seeds start the respiration process when first leaf appears.

f. ……………………………………………………………………………..

<u>This graph for answer question 7-9</u>



7. Bacteria can rapid grow in environment that having oxygen.

Reasons

a. In the present air tube, there is the number of bacteria more than the absent air tube because the oxygen in the air. This reason concludes that bacteria well growth in air condition.

b. In the present air tube, there is the number of bacteria more than the absent air tube but it can not conclude that bacteria well growth in air condition because there are many gases in the air.

c. Bacteria growth is depended on the amount of nutrient as glucose and oxygen that is making bacteria survival. Thus, it not conclude that bacteria well growth in environment that having oxygen.

d. Bacteria growth is necessary the respiration process for energy production. This process use only glucose or glucose and oxygen. In equal glucose, the number of bacteria in the present tube air higher than the absent air tube so this result shows that bacteria well growth in oxygen condition.

f. ………………………………………………………………………………..

8. If measure the temperature two tubes that have equal glucose but one tube present air and other absent. We will find that in the present air has more high temperature than absent air.

Reasons

a. Because of the number of bacteria relate with heat energy.

b. Heat energy is one kind of energy is produced from the respiration. The respiration which uses oxygen can produce the energy more than the respiration without oxygen.

c. The respiration provides the energy as chemical energy, ATP, not provide heath energy.

d. Bacteria can not provide heat.

f. ………………………………………………………………………………..

9. We can test and find the carbon dioxide in the tube that present air more than absent air when equal glucose

Reasons

a. In break down carbon bond in glucose to produce carbon dioxide, the respiration which uses oxygen produce carbon dioxide more than the respiration without oxygen.

b. Because of the number of bacteria

c. It cannot predict because both the respiration with oxygen and without oxygen provide carbon dioxide.

d. The amount of carbon dioxide in the absent air tube higher than in the present air tube because the respiration without oxygen provides carbon dioxide more than the respiration with oxygen.

f. ………………………………………………………………………………..

10. When we exercise, the amount of oxygen is not enough for muscle cells so they can switch respires that require oxygen to not require oxygen.

Reasons

a. Because cells need more energy than normal.

b. When we exercise, the amount of oxygen is not enough.

c. Muscle cells can not perform the respiration with out the oxygen because we take the oxygen in and move the carbon dioxide out all time. However, we have to deep breathe when we exercise.

d. The respiration without oxygen provides energy less than the respiration with oxygen. However, when we exercise we need more energy and the amount of oxygen is not enough. Thus muscle cells will produce energy from both processes together.

f. ………………………………………………………………………………..

Open ended questions

1. When we exercise and after finish exercise, we deeply breath in and out. Please explain the relation between breathing and cellular respiration.

2. When plants were flood, those plants can live for a while and then they die. Please explain why.

3. Vitamin B3 (niacin) is a component of NAD+ (or $NADH_2$). Niacin is acquired through the diet. Please describe the consequences of niacin deficiency on energy production of cellular respiration and invent strategies a cell might use to maintain energy production under niacin deficiency.

Appendix D

The Guideline to Analyze the Participants' Understanding of the Nature of Science

The guideline to analyze the participants' understanding of the nature of science (Modified from Lederman *et al*., 2002 and Sandoval, 2005)

Nature of science aspects	Naïve	Informed
Scientific knowledge based on empirical evidence	No mention about the evidence related with scientific knowledge.	Scientific knowledge is base on empirical evidence and/or derived from observations of the natural world.
The tentative nature of science	Scientific knowledge does not change, or since everything changes therefore scientific knowledge change.	Scientific knowledge can change with new observations or with the reinterpretations of existing observations or with new competing ideas come to light.
The role of creativity and imagination	Scientists do not use their creativity and imagination in scientific works.	Scientists use their creativity and imagination in all step of their work. The scientific knowledge is created from human imagination and creativity.
Scientific knowledge as a socially constructed	Scientists work alone. Scientific knowledge was straightforward from the data of the investigation.	Scientists work both in group and alone. The argumentation and sharing ideas were one part of the scientific knowledge construction.
The diversity of scientific method	All scientific knowledge came from scientists to use an orderly step procedure of scientific method.	Understanding of existence of more than one aspect of the scientific method. The scientific method is non orderly step procedure.
Science as social activity	Science separate from society and culture.	Science is influencing and responding to social need. The society and culture determine what and how science is conducted, interpreted, accepted, and utilized.

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