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THESIS

CASE STUDIES OF TEACHING AND LEARNING

ABOUT PHOTOSYNTHESIS IN THAILAND:

AN INNOVATIVE APPROACH

SIRINAPA KIJKUAKUL

**A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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This interpretive research aims to develop the photosynthesis teaching intervention as a model to enhance Grade 11 students' understanding about photosynthesis in Thailand. The subjects are three biology teachers and 118 students. They study photosynthesis as an advanced biology subject at public high schools in the Bangkok suburban area. Three case studies are conducted. Twelve of the students are also selected for an in-depth study. This research uses surveys, observations and interviews to interpret the impact of the intervention on both the teachers and the students.

The findings indicate that this research contributes to enhance the students' understanding after the teachers implemented the intervention based on its guiding principles. These include correcting students' misconceptions, taking account of the Thai National Science Content Standards, relating photosynthesis knowledge to environmental issues, using historical narratives to illuminate the nature of science, regarding Thai culture and society and encouraging participation in the learning activities.

Also, the findings indicate that the teacher's belief in student learning, the science content and the perception on the roles of teaching appear to influence the implementation of the intervention. Teachers, who believe in a constructivist approach, who have strong knowledge of science contents and who regard to the Thai socio-culture of learning, consistently appear to implement the intervention based on those guiding principles. Their students corrected their misconceptions, understand the advanced concepts and the nature of science, apply their knowledge of photosynthesis to conserve the environment, and are confident to participate in learning activities. On the other hand, teachers who emphasize a teacher-centered approach and have weak knowledge of science content, appear to implement the intervention based on the guiding principles inconsistently. Their students appear to learn less about photosynthesis and are not confident enough to participate in classroom activities. Some of these students tend to study biology at private tutorial institutes to make up for the resulting lack of knowledge.

Sirinapa Kijkuakul

Student's signature

Naruemon Yutakom

Thesis Advisor's signature

27 / 04 / 06

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CHAPTER I

INTRODUCTION

This chapter begins by describing the significance of the study including the background to the research study, the educational value of photosynthesis, biology education in Thailand, and the rationale for developing a new photosynthesis teaching intervention. It also presents research objectives and questions, anticipated outcomes, delimitation of study, and operational definitions of terms.

Significance of the Research Study

1. Background to the Research Study

A big change in my life brought me to an interest in the study of photosynthesis teaching and learning, especially in regard to Thai culture and society. In 1999, I became a senior high school biology teacher in a small rural school after having spent almost all of my education life in the metropolis of Bangkok. The rural students there studied biology as a compulsory subject in the study of science. They had no plans for higher education and did not understand why they should learn biology. However, I was not concerned with the students' future plans, but concentrated on developing their conceptual understanding of biological concepts, aiming towards their taking university entrance examinations. Many teaching strategies such as cooperative learning and preparing a science project were used, but most of the students still did not understand biology concepts, and often were not happy during biology classroom study. These situations stuck on my mind and I puzzled about a possible solution to the problem. Perhaps a better way of teaching biology would not only focus on development of students' conceptions, but also encourage them to appreciate learning biology as it related to their own culture and society.

2. Biology Education in Thailand

The education system in Thailand has long been based on the National Social and Economic Development Plan. As a result of the Asian economic crisis, the floating of the Thai baht on July 2, 1997 as well as the lower international ranking of Thailand education on various educational indicators brought the political constitution to be changed (Fry, 2002). This was followed by the implementation of the eighth National Education Plan (1997-2002) which aimed to improve citizen's quality of life and to develop human resources in science and technology to compete with others in the world of globalization (Office of the National Education Commission [ONEC], 2002).

The National Education Act of 1999 was established in response to the constitution. Eight areas of basic education were identified: health and physical science, arts, music and drama, mathematics, Thai language, social studies, science and technology, foreign language, and work-orientation and careers. Education is compulsory from Grades 1-9 or Ages 7-15. Government-funded education, including science education, is available to all Thai citizens from primary through secondary school levels.

Due to the education reform in 1999 the relationship between knowledge and society has been recognized for better learning of Thai students (ONEC, 2000b: 10-14). The students should be taught for their understanding and experience in management, conservation and utilization of natural resources and the environment. In the scope of biology, the students are also expected to achieve an understanding of both scientific content and the nature of science (IPST, 2002). With this expectation, teaching and learning in the classroom should be developed in line with the reform.

The Institute for the Promotion of Teaching Science and Technology [IPST] has been the organization that plays an important role in developing the teaching and learning of science and the nature of science in Thailand (Boonklurb, 2000: 70). The establishment of the National Science Curriculum by IPST following the reform has

led to improvement in the promotion of science education, as reformed for 2000 and beyond.

In the case of biology education, this has been developed as an integrated part of science education. At the primary school level and junior high school level, children study biology as a unit of science subjects (Ministry of Education, 1991a). At the senior high school level, biology was separated from other science subjects (Ministry of Education, 1991b). Children study biology as a particular science subject. According to the National Education Act (ONEC, 2000a); however, biology education was reformed. All levels of biology contents were schematized in the area of “Living Things and Life Processes”, and integrated in area of “Nature of Science and Technology”.

Photosynthesis has been described as a component of the biology content standards (Ministry of Education, 1991a; 1991b; IPST, 2002). The standards are guidelines for students to acquire an understanding of organisms, link the living structures and functions, use of scientific inquiry, and communicating and applying knowledge in everyday life. The elementary and junior high school children are expected to learn about structures and functions of plants, photosynthesis materials and the ecological niche of plants in the environment. Similarly, but at a more sophisticated level, high school science students need to understand the process of photosynthesis that is essentially based on prior knowledge about biochemical molecules, bio-energy, chemical bonds and reactions.

What follows is some brief information about the importance of photosynthesis for people in Thailand.

3. Educational Value of Photosynthesis in Thailand

“All the food we eat and all the fossil fuel we use is a product of photosynthesis, which is the process that converts energy in sunlight to chemical forms of energy that can be used by biological systems” (Vermaas, 1998: 158).

Enhancing photosynthesis products will assist people to find more food and energy resources in Thailand. For example, the study of Taprab, *et al.* (2003) developed the photosensitive lowland rice that was tolerant to acid sulphate soil, in Pathum Thani province in the Eastern part of Thailand.

Environmentally, photosynthesis can help reduce the level of air pollution. It uses carbon dioxide, the major cause of “Global Warming” and an air pollutant, as a raw material for the synthesis of carbohydrate. The by-product of the process, oxygen, is also given off to the atmosphere to be used in normal metabolism for human and other aerobic organisms (Suzuki, 1997). In addition, photosynthesis brings an understanding of the importance of trees in the forest which produce oxygen, habitat, and recreation for Thai people. Jarusombuti, *et al.* (2005) thus studied using products of agriculture for tree substitution. Thai people could use the products for everyday living, and the trees could remain in Thai forest.

Although photosynthesis has been valued in Thailand, some research findings illustrated an ambiguous photosynthesis conceptual understanding of Thai students.

4. Students’ Learning Difficulties of Photosynthesis

According to the Thai research findings, IPST (1989) which explored 12th grade students’ conceptions of plant food-making and the mechanism of the photosynthetic process. IPST summarized that the students did not understand the role of water, chlorophyll, and carbon dioxide in the process. They were unclear what hydrogen ion (H^+) was in oxidation-reduction reactions and the Calvin cycle. Then, Jantranon (1999: 58) reported in a study of high school students’ conceptions of food that some students thought that water was food because it was plant food; in that it helped plants to operate photosynthetic reactions. Other students thought that the water was food because it was animal food. Sukpimontree (1988: 80) studied 11th grade students’ understanding of concepts in biology. The findings showed that some students had difficulty understanding the function and the role of water. They understood that soil and water were the raw materials of the photosynthesis process,

water worked as food transported within plants, and proteins and lipids were nutrients produced by photosynthesis.

In my prior study during 2002 (Kijkuakul and Yutakom, 2004), the findings also illustrated the learning difficulties of photosynthesis. Students displayed misunderstanding about photosynthesis in the following topics: 1) photosynthesis materials and products 2) conversion of O_2 and CO_2 3) plant respiration 4) light and dark phases and 5) the relationship among process, time, and product. For example, the students understood that CO_2 would be changed to O_2 ; dark reaction was plant respiration, and plants produced CO_2 at noon because plants photosynthesized at noon.

In addition to foreign research findings, Barker (1985), and Barker and Carr (1989a) found that those 10-17 year-old New Zealand children who were taught by guided discovery methods had ambiguous understanding of scientist's views about photosynthesis; namely, they didn't understand that plants produce carbohydrates, store energy from sunlight, or make food by themselves. Amir and Tamir (1990); Hazel and Prosser (1994); Songer and Mintzes (1994) found a large number of confusing conceptions were held by students, including the relationships between cellular respiration and photosynthesis, the ideas of chemical energy produced by photosynthesis underlying the ecology system, and the respective roles of carbon dioxide and oxygen. For example, students thought plant cellular respiration was different from human respiration, and they needed only carbon dioxide but no oxygen.

The office of the National Education Commission (ONEC, 2001) referred to many relevant factors that concerned the poor development of conceptual understanding of students e.g. the curriculum, the teaching and learning process, teacher development, and assessment. Consequently, the development of teaching and learning process was claimed to be a way of finding a solution (Barker and Carr, 1989b; German, 1989; Sitti, 1994; Lumpe and Staver, 1995; Appleton, 1997). Similarly, this process was cited in the National Education Act B.E.2542 (ONEC, 1999), which showed that teaching development was an important activity. Teachers

need to help develop Thai children's understanding of science and to use science for surviving in their lives. Therefore, the development of teaching and learning about photosynthesis should be done gradually to enable Thai students to understand photosynthesis concepts, and then relatively to use the concepts for surviving in their environment.

5. Rationale for Developing a Photosynthesis Teaching Intervention

From my prior observations (Kijkuakul and Yutakom, 2004) of teaching and learning in Grade 11 at a high school in the 2002 academic year, before the science education reform would be operated compulsorily in the 2003 academic year, I found that some teachers used traditional strategies to teach the students about photosynthesis. They often used 'yes-no' questions and accepted correct answers or followed a teaching manual. The teachers did not give their students enough opportunities to discuss, to argue or to present what they learned and what they would like to know. I found that this had a domino effect. The students learned photosynthesis concepts separately and did not see the relationship among the photosynthesis concepts. The students' learning difficulties of photosynthesis had been addressed in previous sections.

The constructivist belief is that learning plays an important role in developing a teaching approach. The approach assumes children's learning is dynamic. Not all knowledge can be transferred from one person to others, despite children's meaningful interactions in the constructivist learning environment. This includes interactions among students, their friends and teachers, bringing them to process knowledge understanding, attitudes, and skills (Vygotsky, 1978; Bybee and Sund, 1982; von Glasersfeld, 1995). There are several instructions based on the constructivist approach. For example, Osborn and Wittrock's generative learning model was developed for New Zealander teachers to implement in the junior secondary level (Barker and Carr, 1989b). The research finding presented a goal that would result in 70% of the students linking prior knowledge with new ideas and meaningful learning in the particular topic of photosynthesis outputs. Later, Lumpe and Staver (1995)

suggested peer collaboration for high school biology students to obtain relevant concepts in plant nutrition. Each group member was randomly selected and combined with respect to the student's prior ability and desire to work with peers. Peer collaborative work effectively helped children to furnish scientific ideas. However, German (1989) found that the directed-inquiry approach integrated many teaching and learning methods such as Karplus's learning cycle (exploration, invention, and application) in leading students to learn concepts and conceptual systems. Novak's concept maps helped students revealing important relations between facts and concepts, had little effect on developing the students' ability to learn science process skills and/or scientific problem solving.

As a biology teacher, it seemed to me that some teaching development was needed to overcome Thai students' learning difficulties concerning photosynthesis. A new teaching intervention based on constructivist approach would be established based on the National Education Act in 1999, the National Science Curriculum (IPST, 2002), and the literature review carried out for this study.

Research Objectives and Questions

The general purpose of this study was to develop the photosynthesis teaching intervention as a model for the progress of Grade 11 students' understanding about photosynthesis. The teaching would emphasize the understanding of photosynthesis knowledge integrated with nature of science, and the applying of photosynthesis knowledge for environment in Thai contexts. There were two main questions generated to address the extent of this study:

1. How can the students' understanding of photosynthesis be enhanced through its relation to the environment and the nature of science?
2. What is the impact of the teaching intervention on teachers and students?

Anticipated Outcomes

1. Thai biology teachers would have a teaching unit that is based on the goals of the National Education Act B.E. 2544 (ONEC, 2000a) and the National Science Curriculum (IPST, 2002). Then, they could adapt the teaching unit to teach about photosynthesis in their classrooms.

2. Thai and international science teachers and science educators would receive information detailing developmental processes of a new teaching unit for learning in a specific context. This would enable them to adapt the process to create their own teaching unit.

3. Thai and international science educators in the Faculty of Education might use the information for teaching and learning about photosynthesis to further develop the pre-service teacher education program.

Delimitation

1. Subjects

The subjects consisted of 118 Grade-11 students and three biology teachers in three public high schools in the Bangkok suburban area. The students were oriented in science Level 4 based on the National Science Curriculum (IPST, 2002). The teachers taught photosynthesis in the second semester of the 2004 academic year.

2. Scope of Photosynthesis

Two sets of photosynthesis concepts were concerned in this study. The first set were *introductory* photosynthesis concepts including the roles of chlorophyll, what materials are needed by plants, the relationship between plant food and energy, between plant and light energy, and the simple photosynthesis process and equation. The second set was *advanced* photosynthesis concepts including the roles of

chloroplasts and pigments, the light dependent (light) phase, the light independent (dark) phase, and factors that affect the photosynthesis rate.

Definitions of Terms

1. Teaching

Teaching was defined as practices in the teaching process. It included teaching planning, classroom organizing, conducting learning activities including talking and interacting with the students, assessing students' learning, and using teaching materials. The practices would be revealed through classroom observations and interviews with teachers and students.

2. Learning

Learning as understanding referred to students' explanations and examples about photosynthesis along with its relation to the environment and the nature of science. Learning also included students' ability of using photosynthesis knowledge for environmental conservation and participating in learning activities. The learning was probed through students' writing in surveys and assignments, and conversations in the interviews and in the classrooms along with performing classroom observations.

3. Teaching Intervention

Teaching intervention included the photosynthesis teaching unit and two surveys. The unit was aimed to promote students' understanding of advanced photosynthesis integrated with nature of science, and applying of photosynthesis knowledge to environmental conservation. The unit comprised of seven lessons for twelve 50-minute periods. Each lesson detailed learning outcomes, scientific concepts, learning activities, materials, evaluation and anticipated student

misconceptions. According to the two surveys, Introductory Photosynthesis Survey (IPS) and Advanced Photosynthesis Survey (APS), those were aimed to probe students' understanding of photosynthesis along with its relation to the environment and the nature of science before and after teaching respectively.

4. Environmental Conservation

There was the students' practice on using/applying knowledge of photosynthesis to conserve the environment around their place, school and community. The practice was observed and/or interviewed based on their planning; operating and reporting on the science project. The project could be collection and experiment, survey and report, poster/display, model and demonstration or research project, and provide basic information for the environmental conservation.

5. Nature of Science

The nature of science which was integrated in the teaching intervention emphasized the three aspects of science (IPST, 2002) which are that scientific ideas are subjected to change, science demands evidence, and science is a complex social activity. The nature of science was addressed in the two surveys, the interviews and the learning activities such as historical narrative, experimentation, problem-solving and a science project.

Summary

Thai students had been expected to understand photosynthesis based on the National Education Act of 1999 (ONEC, 2000a) and the National Science Curriculum (IPST, 2002). However, Grade 11 students' learning about photosynthesis had not appeared to accomplish the expectation. Also, old traditional teaching about photosynthesis did not obviously appear to promote better learning. Consequently, the development of a teaching approach that was based on constructivist belief of learning was claimed to be a way to promote better learning. Therefore, this study

would like to develop a new teaching intervention following this belief to enhance the students' understanding based on the Act and the Curriculum in Thai contexts.

Next, the literature review in chapter II discusses the belief and some teaching strategies to enhance the understanding of photosynthesis. Chapter III Methodology has revealed the design of developing, implementing and evaluation the teaching intervention that was developed to enhance the understanding of photosynthesis. Chapter IV illustrates the teaching intervention, and Chapter V results its impacts to teachers and students. Chapter VI is the conclusion and discussion of this research study.

CHAPTER II

LITERATURE REVIEW

This chapter begins by discussing the widening purposes of biology education worldwide and also in Thailand. Although the purposes have been identified, these have not been achieved completely. There is research into students' learning about photosynthesis which offers evidences that student learning achievement has been affected by the misconceptions that students hold, in particular about concepts such as photosynthesis. One reason for these misconceptions may come from their learning without an awareness of the relationships among photosynthesis, society and the environment. This thesis investigates the use of teaching strategies that consider constructivist teaching and learning perspectives, the socio-cultural influences affecting the teaching and learning, and understandings of the nature of science as the means of addressing the problem of holding misconceptions. Some emerging pedagogies also suggest ways to enhance learning in photosynthesis. Finally, this chapter provides the summary of the theoretical approach for this thesis which may enhance student learning in photosynthesis.

Widening Purposes for Biology Education Today

Conceptual understanding traditionally and properly occupies a central place in any catalogue of the purposes of science education at large, and biology education in particular. Reiss, Millar and Osborne (1999: 29) have emphasized this point: at the heart of the whole cultural contribution of science is a set of major ideas about the physical and biological world and how it behaves in everyday situations. The quest for scientific literacy has, at its core, the need to improve the ideas of all students: "Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (National Research Council, 1996: 22). Additionally, integration of the major ideas is important in the quest for scientific literacy. Biology education is an example in which knowledge of certain facts and

concepts, such as absorption of light by photosynthesis pigments and chemistry of plants, can be synthesized into a broader substantive understanding of the importance of plants to living things (Roberts, 2001: 113). However, that an appropriate contemporary vision of biology education encompasses more than cognitive aspects has been emphasised by Dreyfus (1995) and Roberts (2001). Dreyfus (1995: 216) argued that biology education was not only the learning of the things that scientists know and have found out, but also leading learners to develop their critical values and attitudes towards other living things. Awareness of natural and environmental importance and making decisions about biology issues, e.g. ecosystem, energy supply and environmental organization, are also aspects of biology education (Roberts, 2001: 115).

Biology education in Asia and the Pacific had focused on development of unifying biological themes, conceptual frameworks and connecting theories during the 1960s and 1970s. Yager (1993: 44) indicated that there was no link between biology and technology; biology was developed as biology for future scientists. However, with the emerging idea of *science for all* in the 1980s, biology education was then developed relatively to technology and also to society. Children were expected to learn biology with technology; constructing meaning for themselves in everyday contexts. In the mid 1990s, the Pacific Science Association (PSA), the UNESCO, and the World Bank similarly reported this change in biology education.

However, development of biology education (at least in England and Wales) had been little influenced by a holistic view of science education (Slingsby, 2003: 160-161). Firstly, the biology curriculum had been largely unaffected by changes of science curriculum structure which resulted from science education reform. Secondly, specific practical work and activities emphasized too much on assessment such as microscope work, observation and field work which were not related to everyday biology. These perhaps limited the variety and creativity in organization of biology experiences for students. Thirdly, in many biological experiments demonstrated by teachers, the concern was mainly with Health and Safety issues and animal welfare e.g. making blood smears, collecting cheek cells and conducting

microbe incubation. This approach was decreasing students' interest in biological study. Fourthly, some outdated biological knowledge, which was no longer important, was still studied. Reiss, Millar and Osborne (1999) also discussed more recent (1995-2000) successes and failures of biology education in England and Wales, where school biology had been reformed. Even though students succeeded in formal examinations, the students' interest in biology was significantly decreasing. Over-emphasis on content, less emphasis on the nature of knowledge and less development of students' scientific capability as well as disproportional assessment, were apparently decreasing interest.

For the future of biology education, Reiss, Millar and Osborne (1999: 68-69) recommended some solutions to those problems: biological knowledge, recognized as ideas in biology, should be studied as explanatory stories – these may bring the students to understand both ideas *in* biology and ideas *about* biology, how to acquire and how to be aware of knowledge; focusing on the students' ability to understand and interpret biological information rather than memorization skills should be more prominent in assessment schemes. In addition, Hodson (2003: 655-658) suggested that teaching approaches which were based on social issues may have a more powerful effect on biology education in the future. He suggested that a curriculum should consist of four components: 1) learning biology and technology for conceptual and knowledge development 2) learning *about* biology and technology for understanding of nature of science, awareness of the relationships between science, technology, society and environment (STSE) 3) doing biology and technology for developing skills in a practical work and 4) engaging in socio-political action for improving responsible behaviours toward society and the environment.

Biology education today focuses on better living for every child on Earth rather than only for the development of future scientists. Biological knowledge is still needed but also an understanding of the nature of science including the nature of scientific knowledge, the methods of scientific inquiry and the relationship between science and society is needed. Consideration of the relationships between scientific knowledge and the environment is also needed. By the way of these broader

conceptions, the scope of biology education has developed in Thailand. The next section describes the historical story of biology education in Thailand where biology education has never been separated from science education, and explores the curriculum, the learning reform, the educational purposes and the educational structure.

Biology Education in Thailand

In Thailand all secondary high school science subjects, in particular biology, have been combined with the development of the National Science Curriculum. During the late 1970s, the Ministry of Education developed a new science curriculum which was issued in 1978 and revised in 1990. The purposes of biology education during 1978-1998 were to encourage Thai students to understand these principles and theories of basic biology such as characteristics, boundaries and limitation of biology. Students should inquire and develop biology and technology knowledge, have attitudes toward biology, recognize relationships between biology, technology, humankind and the environment, and apply biological and technological knowledge to advance society and life (Ministry of Education, 1991b; Puchai, 1992: 24). However, there was little regard to the importance of other aspects of biology education such as understanding of the nature of science and awareness of the application and ability to solve problems in everyday situations.

In 2000 Sub-Committees on Learning Reform of the National Education Commission of Thailand (ONEC, 2000b) reported that the quality of biology teaching and learning based on the implementation of the previous curriculum could not achieve the social needs of Thailand. Learning only subject matter from written texts, teaching by transmission methods, and practical work failed to link local wisdom and modern technology were giving no vision or irrelevant knowledge and experiences in everyday life for the children. Alternative attempts made by the government of Thailand appeared in the eighth National Social and Economic Development Plan (NSED) (1997-2002) and then the National Education Act of 1999. The NSED aimed broadly to improve quality of life and develop human resources while the NEA

emphasized the importance of biology education with a globalizing science view; “...all citizens in all societies [should] become literate in [biology]...” (Boonklurb, 2000: 69).

The Institute for the Promotion of Teaching Science and Technology, IPST (2002) supported the government policy by establishing eight content standards in the National Science Curriculum to promote literacy in science education including biology education. The standards are 1) living things and living processes 2) life and environment 3) substances and their properties 4) force and motion 5) energy 6) earth changing processes 7) astronomy and space and 8) nature of science and technology. Thai students would be able to:

- understand the principles and theories of basic science,
- understand the boundaries, nature and limitations of science,
- use skills to inquire about and explanation of science and technology,
- develop thinking processes and imagination, their ability to solve problems, management, communicative skills and decision making,
- realize influentially and affectively the relationships among science, technology, human beings and environment,
- use knowledge of science and technology to advance society and everyday life,
- be a human who has scientific attitudes, moral, ethics, values for utilizing science and technology creatively (IPST, 2002: 3).

Using the National Science Curriculum (IPST, 2002), all students need to study eight basic science content standards. Table 2.1 shows where biology fits into the structure of these science standards. Elementary and junior high school students study biology in terms of integrated science including eight basic science contents. Senior high school students could be categorized in two groups: science and non-science students. In Grade 10 both groups of students need to study introductory (basic) biology based on the eight basic science contents, especially in Contents 1, 2,

3, and 8. In Grades 11-12, the science students studies the advanced biology subjects, based on advanced science content and established by the school.

Table 2.1 Structure of Science Education Related to Biology in Thailand

| School Level | Grade | Age | Level Content Standard | Basic Science Content ¹ | Biology | |
|------------------------------|-------|-----|------------------------|--|---------------------------------------|--------------------|
| Elementary school (6 years.) | 1 | 7 | 1 | Content 1: Living things and living processes | Integrated science ² | |
| | 2 | 8 | | | | |
| | 3 | 9 | | | | |
| | | 4 | 10 | 2 | Content 2: Life and environment | Integrated science |
| | | 5 | 11 | | | |
| | | 6 | 12 | | | |
| Junior high school (3 years) | 7 | 13 | 3 | Content 3: Substance and their properties | Integrated science | |
| | 8 | 14 | | | | |
| | 9 | 15 | | | | |
| Senior high school (3 years) | 10 | 16 | 4 | Content 4: Force and motion | Integrated science | |
| | 11 | 17 | | | | |
| | 12 | 18 | | | | |
| Senior high school (3 years) | 10 | 16 | 4 | Content 5: Energy (physical) | Basic Biology subject ³ | |
| | 11 | 17 | | | | |
| | 12 | 18 | | | | |
| Senior high school (3 years) | 10 | 16 | 4 | Content 6: Earth changing processes | Advanced Biology subject ⁴ | |
| | 11 | 17 | | | | |
| | 12 | 18 | | | | |
| Senior high school (3 years) | 10 | 16 | 4 | Content 7: Astronomy and space | Advanced Biology subject ⁴ | |
| | 11 | 17 | | | | |
| | 12 | 18 | | | | |
| Senior high school (3 years) | 10 | 16 | 4 | Content 8: Nature of science and technology | Advanced Biology subject ⁴ | |
| | 11 | 17 | | | | |
| | 12 | 18 | | | | |

Source: IPST (2002, 2003)

Photosynthesis is one topic which is a part of the biology curriculum (Table 2.2) and can be taught so that it fulfils the purposes of science education laid out in science content and standards based on the National Science Curriculum (Ministry of

¹ All grade students need to study *eight* basic content standards.

² Biology is taught in terms of *integrated science*

³ Basic biology subject is concerned with *basic* science contents. All students in Level 4 have to study this subject.

⁴ Advanced biology subject is concerned with *advanced* science contents and is taught only for students who would like to emphasize studying science.

Education, 1991a; 1991b; IPST, 2002). The elementary (Levels 1-2) and junior high school (Level 3) students are expected to be introduced to the knowledge about structures and functions of plants, photosynthesis materials and the ecological niche of plants in the environment (Table 2.3). This study calls this knowledge “*introductory* photosynthesis knowledge”. Similarly, but at a more sophisticated level, senior high school or Level 4 – in particular Grade 11 students – who focus on science study are expected to have advanced knowledge of the process of photosynthesis including the history of photosynthesis knowledge development such as light dependent and independent reactions and chlorophyll functions and factors affecting photosynthesis rate. The knowledge also includes understanding of the nature of science, relationships between science, technology, society and environment. These are referred in this study as “*advanced* photosynthesis knowledge”.

Table 2.2 Science Content and Standard Related to Photosynthesis Concepts

| Content | Standard |
|--|---|
| <i>Content 1:</i> Living things and living processes | <i>Standard Sc 1.1:</i> 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. |
| <i>Content 2:</i> Life and environment | <i>Standard Sc 2.2:</i> 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. |
| <i>Content 3:</i> Substances and their properties | <i>Standard Sc 3.1:</i> Understand that matter possesses its own individual structure and properties. <i>Standard Sc 3.2:</i> Understand that matter goes through physical and chemical changes. |
| <i>Content 8:</i> Nature of science and technology | <i>Standard Sc 8.1:</i> Understand the nature of science and nature of technology and appreciate the interaction between science, technology and society. |

Source: IPST (2002)

Table 2.3 Basic Science Content Standards in Each Level Related to Photosynthesis Study

| Content | Level Content Standard | | | |
|--|---|---|--|---|
| | Level 1 (Gs 1-3) | Level 2 (Gs 4-6) | Level 3 (Gs 7-9) | Level 4 (Gs 10-12) |
| Content 1: Living things and living processes (Standard Sc 1.1) | 1. Observe, investigate and compare <i>living things</i> with non-living things. Understand the <i>structure and function of plant and animal parts</i> as well as their adaptations to local and distant environments. | 1. Observe, explore, discuss, and explain the <i>structures and functions of plant structures</i> , life cycles, reproduction, expansion, <i>some factors necessary for growth photosynthesis</i> , response to environmental stimulation and apply this knowledge. | 1. Investigate and explain about <i>characteristics and structures of cells and multiple cells, functions of plant and animal cell</i> , including movement of substances into and out of cells. 2. Observe and explain about the important <i>factors and results of photosynthesis</i> , explain why photosynthesis is <i>important</i> to living things and the environment. | 1. Investigate and explain about <i>structures of cells and functions of organelles</i> in living things. 2. Experiment, analyze, investigate and discuss about <i>structures and properties of biochemical molecules</i> related with components and processes of cell such as carbohydrate, lipid and protein. |
| Content 2: Life and environment (Standard Sc 2.2) | 1. Investigate discuss and explain the consumption of natural resources, as well as the consequences and problems created locally by this consumption. | 1. Observe, explore, examine, discuss and describe the natural resources in a local area, how natural resources are affected by natural and human behaviours, describe how humans can take care of natural resources and ensure their longevity. | 1. Explore and analyze local natural resources, present concepts concerning the maintaining of an ecological system balance; using sustainable natural resources by applying science and technology to an environmental problem. | 1. Explore, analyze the situation of environment problem, and natural resources at local, national and international spheres, analyze cause of problem, make a plan and practice cooperatively with community in preventing and solving the problem, conserve and develop natural resources and environment. |

Table 2.3 (Cont'd)

| Contents | Level Content Standards | | | |
|--|---|--|--|---|
| | Level 1 (Gs 1-3) | Level 2 (Gs 4-6) | Level 3 (Gs 7-9) | Level 4 (Gs 10-12) |
| Content 3: Substance and their properties (Standard Sc 3.1) | None | None | None | 1. Examine, analyze data, discuss and explain about <i>chemical bond in molecules</i> or crystal, structure of substance; relationship between properties of substances about boiling and melting point and force between particles. |
| (Standard Sc 3.2) | None | None | None | 1. Examine, explain and draw <i>general chemical equation</i> including the effects of chemicals that were found by <i>chemical reaction on living things</i> and environment 2. Investigate, observe, discuss and explain <i>component properties, and utilization of carbohydrate, fat and fatty acid, protein and amino acid</i> reactions. |
| Content 8: Nature of Science and Technology (Standard Sc 8.1) | 1. Ask questions about the topics and situations studied as assigned and their own interest . | 1. Ask questions and do further research into a topic assigned in class. | 1. Ask questions about assigned issues or important variables in investigations or study interesting topics thoroughly and reliably. | 1. <i>Ask questions based on scientific knowledge</i> and understanding of interest or current issues that can be examined or studied thoroughly and reliably. |

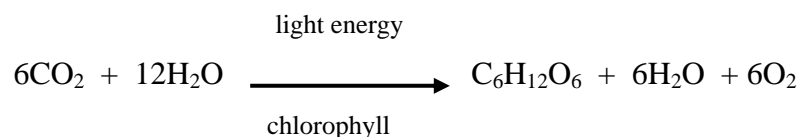
Table 2.3 (Cont'd)

| Contents | Level Content Standards | | | |
|--|--|--|--|--|
| | Level 1 (Gs 1-3) | Level 2 (Gs 4-6) | Level 3 (Gs 7-9) | Level 4 (Gs 10-12) |
| Content 8: Nature of Science and Technology (Standard Sc 8.1) | 2. Plan to observe, investigate or inquire using questions or ideas from students, group, class and teacher. Make hypotheses and propose the methodology of how to investigate or study the questions or ideas. | 2. Plan and design observations, investigations or inquiries, predict results. 3. Record and explain observations honestly, reasonably, using evidence they gathered. 4. Present and exhibit project research by oral presentation or by writing about the concepts, procedures in order to explain it to an audience. | 2. Develop hypotheses which are able to be examined and plan various investigations. 3. Develop new questions which lead to investigations about the related study and apply knowledge to new situations. 4. Accept changes of science knowledge when we get more data and new evidence in contrast to old knowledge. 5. Exhibit, write reports and/or explain about concepts, procedures, and projects or tasks to others. | 2. Develop hypotheses which are based on theories or prediction or create a model or pattern that leads to investigation. 3. Analyze, interpret and evaluate the correspondence of conclusions of main ideas with the stated hypothesis. 4. Aware of the importance in involving students to take responsibility, explain, infer, and summarise science learning to present the public accurately. 5. Record and explain the result of investigation reasonably, use evidence, finding reliable evidence, and accept that prior knowledge maybe changed when there are new added data and evidence. 6. Exhibit result, writing report, and/or explain about concepts, processes, and result of projects or assignment to others. |

Source: IPST (2002)

There are key ideas about photosynthesis at the advanced level of biology in the National Science Curriculum (Ministry of Education, 1991a, 1991b).

Photosynthesis knowledge has been developed through empirical data discovered by many historical scientists e.g. Van Helmont in 1648, Joseph Priestley in 1772, and Ingen Housz in 1779. Photosynthesis is the only biological process which can convert sunlight energy into chemical energy required to sustain life of all organisms on the Earth (Taiz and Zeiger, 2002: 113). The process is largely responsible for the oxygen content in the Earth's atmosphere, because plants use raw materials, carbon dioxide (CO₂) and water (H₂O) to make carbohydrate, in particular sugars, and release oxygen. The process also needs photosynthetic pigments such as chlorophylls to absorb light energy which is used to activate the process represented in the following equation:



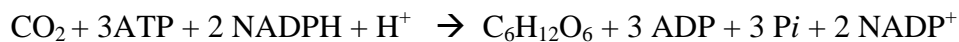
Photosynthesis comprises two reactions: light dependent (light) reaction (Hill, 1963 cited in Govindee and Gest, 2002) and light independent (dark) reaction (Benson, 2002). The light reaction occurs with chlorophylls, located in the thylakoid membrane of the chloroplast. The dark reaction takes place in the stroma (Campbell, 1996; IPST, 1998).

“The light reaction in the grana produce ATP and split H₂O, releasing oxygen and forming NADPH by transferring electrons from H₂O to NADP⁺” (Campbell, 1996: 201). H₂O is ionized/oxidized by light (photolysis) to provide the primary electron and release oxygen to the stroma of the chloroplast. Electrons are transferred through the non-cyclic electron transfer and the cyclic electron transfer processes. The energy released during the electron transfer is used to produce ATP and NADPH. The ATP and NADPH are then released into the stroma where the light independent (dark) reaction occurs to produce carbohydrate. The chemical equation of the light reaction in the thylakoid is:

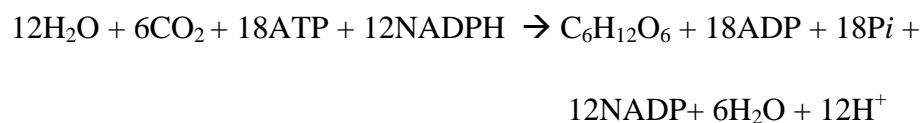
light energy and chlorophyll



The carbohydrate is produced through the Calvin-Benson cycle. This cycle proceeds in 3 stages: CO₂ fixation, reduction, and regeneration. Firstly, CO₂ and H₂O from the environment are enzymatically combined with a five-carbon acceptor molecule, ribulose biphosphate (RuBP). Secondly, the six carbon intermediate, the unstable molecule produced, is immediately split in half to form two molecules of 3-phosphoglycerate (PGA). An additional phosphate group of the ATP and NADPH generated photochemically adding in the structure of the PGA which is now becoming 1, 3 – bisphosphoglycerate or phosphoglyceraldehyde (PGAL), a sugar form. Thirdly, the CO₂ acceptor (RuBP) is regenerated from PGAL. Also PGAL is the first sugar molecule which plants use to produce other carbohydrates and organic substances for their growth development. The chemical equation of the dark reaction (Calvin Cycle) in the stroma is:



The summary equation of photosynthesis in plants is:



Even though the promotion of photosynthesis knowledge was the main aim of biology education in Thailand, there is evidence in the literature of some student misconceptions which may affect learning about photosynthesis. This thesis describes the learning in the following section.

Research into Student Learning about Photosynthesis

1. Overview: The Widening Focus of the Research

Biology education research into students' learning about photosynthesis has mainly focused on three areas. A very active area of the research is investigation and interpretation of students' understanding about the phenomena. Firstly, this initial research was based on teaching and learning about *photosynthesis itself* as a topic, separated from other topics, i.e. on a single process approach (Bell, 1981, 1985; Wandersee, 1983, 1985; Barker, 1985; Haslam and Treagust, 1987; Treagust, 1988, 1991; Amir and Tamir; 1989, 1994, 1995; Barker and Carr, 1989a, 1989b, 1989c; Anderson, Sheldon and Dubay, 1990; Eisen and Stavy, 1993; Hazel and Prosser, 1994; Lumpe and Staver, 1995; Griffard and Wandersee, 2001). The research found that all age students had conspicuously similar misconceptions about photosynthesis. This indicated the significance of students' prior knowledge about plants could influence their learning. Secondly, the middle to late 1990s saw studies which focused on understanding *photosynthesis in the context of other plant processes* i.e. on integrated knowledge (Waheed, 1992; Songer and Mintzes, 1994; Lavoie, 1997; Ozay and Oztas, 2003). It was argued in previous studies that there was a need for more effective biology teaching. Thirdly, the research focused on understanding photosynthesis in a broad environmental context, i.e. on the complex relationship between those integrated concepts, society and environmental systems. The research suggested that challenging students to understand aspects of science and the relationship between photosynthesis and environment might be an effective way of teaching photosynthesis (Eskilsson and Holgersson, 1999; Carlsson, 2002; Eilam, 2002; Ekborg, 2003). Finally, *Thai students' learning about photosynthesis* is discussed as background to why this research study would like to develop the teaching and learning of photosynthesis in Thailand.

The research that has been published in each of these areas is discussed next.

2. Photosynthesis Itself

Plants, algae, and cyanobacteria or blue-green algae are organisms which can photosynthesize (Campbell and Reece, 2002). This is because they have pigments which can absorb light energy. The light energy, pigments and also raw materials including CO₂ and H₂O are used by these organisms to produce carbohydrate as their food. In plants the process also releases oxygen into the Earth's atmosphere.

However, the studies of Haslam and Treagust (1987); Songer and Mintzes, (1994); Lavoie (1997); Ozay and Oztas (2003) illustrate that students' misconceptions in understanding this photosynthesis process have been found at different levels of schooling. The students perceive a plant as a producer. The plant used photosynthesis to produce energy for its growth. This understanding did not support the scientific ideas that the plant converted energy for the growth. The two complicated processes of photosynthesis, the light dependent and light independent (dark) reactions have been difficult for students to understand. As Campbell and Reece (2002: 180-181) described that "The light reactions are the steps of photosynthesis that convert solar energy to chemical energy, ...thus it is the light reactions of photosynthesis that give off O₂ as a by-product" (Campbell and Reece, 2002: 180). The other process in photosynthesis is the dark reaction also known as the Calvin cycle. It is the incorporation of CO₂ from the air into chloroplast to produce organic compounds in photosynthesis. However, college biology students, in a state university in North Carolina, believed that "The plant engages in photosynthesis, the light reaction of which consumes CO₂ and produces oxygen, and the dark reaction consumes oxygen and produces CO₂" (Songer and Mintzes, 1994: 632).

Kinchin (2000a) argued that students' similar misconceptions might come from their misunderstanding of important basic concepts related to photosynthesis e.g. plants and food. Subsequently, the concepts are discussed below.

Students' concepts about animal, plant and living things were surveyed by Bell (1981: 10). This survey aimed to clarify a New Zealand students' understanding of the meaning of those three words used in a biology classroom. In the scientific view, plants are living things which utilize external materials, H₂O, CO₂, minerals and light energy to produce sugar. These are metabolized for their growth energy. But, the survey found that in some students' views, trees, grasses and vegetables were not plants because of their size, cultivation and edibility respectively. This clarifying indicated that students recognized 'plant' in a classroom differently from 'plant' in their everyday life.

Students' conceptions of plant food have been widely studied, across ages and countries. Cross-age elementary to tertiary American students (Wandersee, 1983), Grade 9 Turkey students (Ozay and Oztas, 2003), non-science American college students (Anderson, Sheldon and Dubay, 1990) and age 8-17 New Zealand children (Barker, 1985) were studied in relation to what they understood about the concepts. These four studies reported similar misconceptions of the students who believed that plants obtained their food from external resources such as H₂O and minerals in the soil, as well as CO₂ from the air. These findings indicated that the students' ideas of food might be physical things which they could touch and sense.

Students' misunderstanding about the role of chlorophylls in relation to plant nutrition was also investigated by Bell (1985) and Haslam and Treagust (1987). The scientists view chlorophyll as a pigment which has green colour and can actively absorb light energy. The light energy is an energy source to produce nutrients in plants by photosynthesis (Haslam and Treagust, 1987; Taiz and Zeiger, 2002: 630). However, the British students recognized chlorophyll as a word in everyday situations (Bell, 1985: 216). They described chlorophyll as green substances which were able to protect the flowers and attract anything outside e.g. sunlight. The plants, thus, could eat food even if they did not have the chlorophylls. Also, Haslam and Treagust (1987: 206) evaluated secondary students' misconceptions in Western Australia. They found that the students of years 8-12 had an erroneous idea connected to the role

of chlorophyll. The students believed that chlorophyll had to combine with CO₂ to produce sugar and H₂O.

Student misconceptions about photosynthesis e.g. the process, meaning of plant, plant food, role of chlorophylls and photosynthesis factors indicated that they had difficulty understanding photosynthesis because they often used words in everyday experiences to construct their ideas about photosynthesis. Investigating the ideas and clarifying what students already understood about photosynthesis before additional development of new ideas about photosynthesis, thus, should be considered for better teaching about photosynthesis.

3. Photosynthesis and Other Plant Processes

An understanding of a student's prior knowledge about plant processes is necessary to develop their advanced understanding about photosynthesis. The following is the research integrated with this idea.

Student teachers' ability to explain everyday phenomena was investigated by Eskilsson and Holgersson (1999). After the student teachers studied in a basic science course in a teacher training program, they were assigned to answer some questions. For example, "If you plant potatoes in the spring you can lift new potatoes in the summer. From each potato seed you will get many new potatoes. Where does all the material for the new potatoes come from?" (Eskilsson and Holgersson, 1999: 233). The student teachers' concepts about the transformation of matter involved in photosynthesis were thus determined. As a result the researchers noted that even though their subjects were student teachers, who probably would be science teachers in schools, they still frequently misunderstood about the phenomena and felt uncomfortable while they were solving the problem in science tasks.

According to scientists' views, the aerobic (oxygen-requiring) cell respiratory process in plants "...is similar to that found in animals and lower eukaryotes" (Taiz and Zeiger, 2002: 223). This respiration process commonly used glucose or starch

stored by photosynthesis as the substrate for releasing energy, ATP, for plant growth. However, the difference between respiration and photosynthesis, the day-time and night-time balance and gas exchange are three big issues of students' misconceptions (Wandersee, 1985; Haslam and Treagust, 1987; Waheed, 1992; Eisen and Stavy, 1993; Amir and Tamir, 1994; Songer and Mintzes, 1994; Lavoie, 1997; Canal, 1999; Ozay and Oztas, 2003).

Songer and Mintzes (1994: 632) studied biology college students' misconceptions and found the students believed that "photosynthesis is the plant's form of cellular respiration." Also, Lavoie (1997: 5) found that elementary education major college students believed that plants obtained energy from H₂O and CO₂ by the respiratory process. Eisen and Stavy (1993: 123) found that Grade 8 Israeli students were questioned about their learning about autotrophic feeding and respiration. In this study, the results indicated that these students believed either that "*plants' breathing was... photosynthesis*" or "*plant breath only at night while performing photosynthesis during the day.*" Some students argued plants respired only during the night (Haslam and Treagust, 1987: 120; Lavoie, 1997: 5; Ozay and Oztas, 2003: 69). Carlsson (2002) examined student teachers' ecological understanding connected with the photosynthesis processes, the cycling of matter and the flow of energy. The result showed that photosynthesis and respiration were understood in terms of process transformation in plants. The gas, CO₂, and H₂O were transformed to produce sugar and oxygen by photosynthesis. These products then were restored for the next cycling of photosynthesis by respiration which needed oxygen and energy stored in sugar to produce CO₂ and H₂O.

These findings indicated that students had difficulty of understanding relationships between photosynthesis and other plant processes e.g. transformation of matter, plant respiration and ecology. Songer and Mintzes (1994) suggested that the difficulty might have come from learning without rethinking of the knowledge. To provide an adequate chance to illustrate and discuss this relationship, the topics need to be addressed in new teaching strategies about photosynthesis.

Up to this point, those previous studies still reported similar student misconceptions about photosynthesis. This might have been caused by teaching without awareness of complex relationships between photosynthesis and the environment.

4. Photosynthesis and Environment

The study of photosynthesis integrated in environmental education is an approach which some researchers have used to illustrate students' awareness of complex relationships concerning photosynthesis, society and the environment. There have been only a few research studies and these are discussed below.

Ten Swedish student-teachers' understanding of photosynthesis in terms of ecology was studied by Carlsson (2002). Ecology is a whole system of various processes of photosynthesis, recycling of matter and energy, and it "deals with relations between organisms and their environment" (Carlsson, 2002: 683). Using interviews, the students' understanding was interpreted in the four following views: 1) photosynthesis is input and output process 2) photosynthesis is the first material transformation process of the world 3) photosynthesis is a transforming process between photosynthesis itself and respiration and 4) photosynthesis is energy transformation. The findings showed that the students had separate understanding about these processes, and independently experienced the whole complexity of photosynthesis. In considering these findings, this study should be concerned with integration of photosynthesis, ecology and the environment.

Ekborg (2003) argued that the study of photosynthesis integrated in environmental education assisted in the development of student understanding of photosynthesis. In Malmo University, the students in the primary teacher education program were investigated. They were tested about their understanding of photosynthesis, and were interviewed to probe the understanding of relationships between their scientific knowledge and the knowledge in their learning processes. An environmental issue in a newspaper article was used to probe the understanding. The

results showed that the students had a better understanding of the photosynthesis content, but they could not understand the relationships completely. In this case, Ekborg suggested that challenging students to understand the nature of science and to be aware of the difference between science context and everyday context might help them to relate science in the classroom with science in their environment.

Therefore, integrating photosynthesis in environmental education may be a better way for student learning. In this case, encouraging students to use their understanding of photosynthesis from their environmental experiences should be recognized.

5. Thai Student Learning about Photosynthesis

In Thailand, there has been a small amount of research concerned with learning about photosynthesis. The research showed that Thai students were retaining many misconceptions about photosynthesis. IPST (1989) investigated Grade 12 student understandings of plant food-making and the mechanism of the photosynthetic process. The findings illustrated that they did not understand the roles of H₂O, chlorophyll, and CO₂ in the process. They were unclear about how the hydrogen ion (H⁺) worked in oxidation-reduction reaction and the Calvin cycle. In addition, two master's theses in education at Kasetsart University presented student misunderstanding of concepts in biology. Sukpimontree (1988: 80) found that some Grade 11 students in the Southern area of Thailand had difficulty of understanding the function and role of H₂O in photosynthesis. They wrongly understood that soil was a raw material of the photosynthesis processes, that H₂O worked as a plant food transporters and that proteins and lipids were nutrients produced by the processes. Jantranon (1999: 58) argued that the high school students, Grades 7-12, also had misconceptions about food. These students thought that H₂O was food because it was plant food; it helped plants to operate photosynthetic reactions. Others thought that the H₂O was food because it was animal food. All studies concluded that the students were confused about the differences between plant food and animal food. The studies made it clear that Thai students had difficulty in learning photosynthesis,

partly because of the biology education of the 1980s and 1990s, and that modern information about photosynthesis teaching and learning situation of the 21st Century was needed for this thesis.

The prior study of 2002 (Kijkuakul and Yatakom, 2004) also indicated holding misconceptions about photosynthesis. The subjects were 38 senior high school students comprising of 15 Grade-10 students, 13 Grade-11 students and 10 Grade-12 students in a public high school. The study investigated their views of photosynthesis using a paper-pencil test. It was open-ended questions and multiple choice including explanations (adapted from Barker, 1985). The students' concepts of plants and plant food, chlorophylls, electron roles, energy sources, photosynthesis process, plant respiration and photosynthesis factors were investigated and analyzed.

The results showed that the students still had misconceptions about photosynthesis. Most students believed that plant food was H₂O absorbed from soil. This was more like Van Helmont's photosynthesis conception about plants' food (Wandersee, 1985: 593). In addition for the conception of chlorophyll, even most students understood that chloroplasts were important organelles that had chlorophyll as a place of photosynthesis, they did not understand why chlorophyll was necessary in photosynthesis. Less than 10 percent of students across all grade levels understood that chlorophyll works as a light receptor with electrons in photosystem of photosynthesis. The understanding of plant energy was poor in students across all grades. Most students believed that plants also obtained other energy sources, not only sunlight energy, e.g. that source energy is CO₂ and the sun because plants obtain energy from their respiration and photosynthesis.

The prior study provided information that the student misunderstandings about the photosynthesis process persisted throughout senior high school students. The concepts have been taught compulsorily, however, the results indicated that Grade 11 students still had misconceptions through Grade 11 and even into Grade 12. No more progression in understanding was found.

6. Summary: Learning about Photosynthesis in Context

Students' misconceptions still persist in many research studies about student learning in photosynthesis. There are some influences on the origin of the misconceptions. First, everyday language is frequently used to describe and explain phenomena in the context of biology. This may bring conflicting meaning for students to understand biological terminology. For example, plant food is viewed as a physical thing which should be seen and touched. Second, some prior misunderstandings about photosynthesis bring students to also misunderstand the new concepts. Third, students themselves do not integrate study information about photosynthesis. One example is their lack of linking between the concepts of food and the role of energy in photosynthesis as well as the basic chemical concepts. Another is the lack of linking between the inside and outside classroom information. Fourth, students have misunderstanding about photosynthesis because they have been taught by the teachers who hold the misconceptions and are not aware of their own conceptual development. Fifth, not regarding the relationships between photosynthesis and environmental education is an additional reason for the persistence of the misconception. Therefore, development of a new teaching intervention is needed to overcome student learning difficulties about photosynthesis.

There are, of course, various theoretical learning perspectives which this research would need to take into account in the basic principle of a new teaching intervention. The broad cluster of constructivist theories which have given rise recently to socio-cultural approaches is paramount among these perspectives.

Constructivist Theories as a Teaching and Learning Perspective

1. Overview: Development of Constructivist Perspectives

Constructivism is a major influence in contemporary science education. Psychologically, the original core of constructivism involves how beliefs are developed, not what makes beliefs true or what counts as scientific knowledge

(Matthews, 1997: 6). Philosophically, constructivism is recognized as views of learning. It assumes that knowledge is a construction of reality which can not exist outside the bodies of cognitive being and is known and understood by an individual (Tobin, 1990: 30). Developments of the constructivist perspective, thus, depend on various understandings of learner's beliefs and the personal and social construction of their reality (Osborne, 1996: 54).

The constructivism development towards a view of learning has informed the practice of formal science teaching since the late 1970s. As a basic principle of that development, Piaget's theory, known as cognitive development, was concentrated on and interpreted. The theory involved cognitive development in children and how children acquired knowledge (Bybee and Sund, 1982; Cobern, 1993; von Glasersfeld, 1995; Hodson and Hodson, 1998; Duit and Treagust, 2003). The original views of Piaget were that individuals constructed their own reality i.e. personal constructivism. However some limitation to this view led to a consideration of a more social view of constructivism (Vygotsky, 1978). From this Vygotskian view, social dimensions of learning science have appeared in science education. Students are individually encouraged to study scientific knowledge within the context of their scientific culture (Hodson and Hodson, 1998).

2. Cognitive Development

The cognitive developmental theory was established by the Swiss developmental psychologist, Jean Piaget (1896-1980), in the mid 1990s (Bybee and Sund, 1982; von Glasersfeld, 1995). While Piaget was an undergraduate studying biology, he was also interested in the study of philosophy. He tried to explain the logic of this action through *An Outline of Neo-Pragmatism*. The two fields of study brought him three ideas about gaining knowledge: *assimilation*, *accommodation* and *equilibration*.

Using his observations of children Piaget developed his theory of *cognitive development* with two central keys of how children acquire knowledge. The first is

the concept of cognitive structures relating children's ages with their stage of development. The other is the concept of cognitive processes describing how children develop their cognitive ability through assimilation, accommodation and equilibration (Piaget, 1950; Bybee and Sund, 1982; von Glasersfeld, 1995; Bettencourt, 2003).

“*Cognitive structures* are identifiable patterns of physical or mental action that underlie specific acts of intelligence (Bybee and Sund, 1982: 34)”. Piaget's stage theory is generally used to analyse the patterns of intelligent action. Piaget identified four periods of cognitive development. The first is the sensorimotor period (0-2 years). It is when the cognitive system is motoric at birth. The infants develop the cognitive structure through behaviour in environmental situations. The second is the preoperational period (3-7 years). Children demonstrate some internal thought process. They can view the world through their own perspective. The third is the concrete operational period (8-11 years). The children can transform an image of an object or event. They can also logically understand a concrete problem, but can not resolve an abstract problem. The fourth is the formal operational period (12-15 years to adult). The children can think logically and abstractly and can reason hypothetically. Their thinking has reached the highest and most powerful development of cognitive structure. Piaget used the terms organization and adaptation to describe the *cognitive process*.

Children construct knowledge through the mechanism of organizing and adapting processes. The internal idea of children is simultaneously organized. The intellectual structure order is shifted from simple to complex as the understanding of the knowledge is adapted. There are two complementary processes of that adaptation. In the first process, *assimilation*, children use their existing ideas to interpret situations. Their actions are patterned and implanted to result in desired and undesired expectation. A system of actions as a continuous series remains stable in the cognitive structures. This *equilibration* operates until a difference between the existing cognitive structure and a cognitive reference in the environment is provided, mainly by individual maturation, experience, and education. Shifting to the new higher order stage of intellectual structure then occurs. It results in an increase in the

understanding capability of environmental situations. The second process is called *accommodation*. It means the children can change their existing ideas to make sense of new knowledge (Bybee and Sund, 1982; Bettencourt, 1993).

Piaget's cognitive developmental theory argues that the children at different ages have different capacities to understand knowledge. Younger children's ability to understand reality is dissimilar to that of older children. The younger ones still need time to change their cognitive structure. Assimilation and accommodation with equilibration process, stresses the adaptive nature of cognition and the personal construction of knowledge.

Other educators have agreed with this personal construction view of learning, and their ideas are reviewed below.

3. Personal Constructivism

Personal constructivism interpreted through the Piaget's cognitive theory stresses the adaptive nature of cognition and the individual's construction of models of the world (Geelan, 1997: 17). At the end of the 1980s, however, Ernst von Glasersfeld, an American philosopher, introduced a new alternative assumption of how the learner constructs knowledge (Tobin, 1990; Bettencourt, 1993; von Glasersfeld, 1995; Gil-Perez, *et al.*, 2002). This radical view of constructivism used two principles:

1. "Knowledge is not passively received either through the senses or by way of communication; knowledge is actively built up by the cognizing subject.
2. The function of cognition is adaptive, in the biological sense of the term, tending towards fit of viability; cognition serves the subject's organization of the experiential world, not the discovery of an objective ontological reality" (von Glasersfeld, 1995: 51).

Knowledge is actively constructed by the learner his/herself (Tobin, 1990; von Glasersfeld, 1995). It can not be transferred from the environment of one person into that of the learner, but needs the process of individual transformation. The person has to have some ideas so as to be able to interact with others.

Because of the previous experiences and interpretations, such remembering and retrieving experiences and the ability to make judgement can bring about either desired or undesired results. Also, the scheme or the pattern of actions could be changed after dealing with the different experiential situation. So if too many unfitted situations were disregarded by the learner, the shifting based on the equilibrium process could not happen. Therefore, the knowledge is not passively constructed. Assimilation and accommodation need active organization and adaptation.

Von Glaserfeld's constructivist view seems to be a variation of Piaget's view but without empirical evidence (Good, Wandersee and Julien, 1993; Geeland, 1997, Matthews, 1997). The alternative views of personal constructivism brought the personal constructivist views of learning to point out teaching strategies and conceptual change focused on the cognitive individual. Students learn only when they are dissatisfied with their existing ideas and recognise the need to have new or better ideas (Posner *et al.*, 1982; Hodson and Hodson, 1998).

The limitations of the personal constructivism were argued by Matthews (1997: 9). At the heart of his criticism is a concern for scientific understanding. Scientific knowledge is more than personal belief. Constructivist knowledge formulation can not represent the realistic knowledge formulation. Knowledge construction is not only *making sense* of the world, but also *finding out* about the world. Science teachers need to introduce what and how scientists have developed and accumulated knowledge e.g. the concepts, ideas, understandings and theories (Hodson and Hodson, 1998: 34). Learning science, thus, involves the culture of science which needs both individual and social processes (Driver *et al.*, 1994).

4. Social Constructivism

The Russian developmental psychologist, Lev Semenovich Vygotsky, (1896 - 1934) introduced a social dimension to Piaget's learning theory. He studied in the fields of law, literature, philosophy, art and psychology (Berk and Winsler, 1995). His work was rooted in his interest to understand the social context of cognitive development and focused on the role of language in the development of higher cognitive functions (Vygotsky, 1978; Howe, 1996; Hodson and Hodson, 1998).

Social constructivism refers to the learning connection with social context that is recognized as an alternative learning view of American and some European psychologists (Hodson and Hodson, 1998; John-Steiner and Mahn, 1996). Using the social view of Vygotsky, action is not the initial step to develop cognitive structure, which is different from Piaget's view who argued that it was. Vygotsky believed that language created and organized through speech was an initially important key for problem-solving in the social environment. "The process being transformed continues to exist and to change as an external form of activity for a long time before definitively turning inward" Vygotsky (1978: 57). He argued that during early childhood a child used speech to verbally describe what he or she is dealing with in a situation. The problem-solving is planned to guide their own action. When the child grows older and more experienced, the action is externally performed, while the speech is organized and developed in his or her mind. The results of the language transformation process brings about cognitive development on the social level and then on the individual level (Vygotsky, 1978; Cobb and Yackel, 1996; Hodson and Hodson, 1998).

While Piaget believed that the learning could not be developed until a child had appropriate cognitive structure enabling them to function in a particular period, Vygotsky argued that the cognitive development could occur at almost any stage of development with the socially-interacting help of parents, family members, peers, knowledgeable adults and teachers, through *social interaction* (Hodson and Hodson, 1998; Berk and Winsler, 1995). Children cannot do tasks individually, but they can

solve with those helpers. The collaborative conversations occurring during the challenging tasks enable them learn to think and behave in ways that reflect their community culture. The strategies used are embedded in them to guide their own actions and accomplish skills on their own (Berk and Winsler, 1995). In Vygotskian terms, the *zone of proximal development* (ZPD) was recognized as a general law of a cognitive developmental state for teaching, especially understanding how students acquired scientific knowledge. ZPD was defined as “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (Vygotsky, 1978: 86). An active collaboration between teacher and child and among children themselves with teacher assistance and also using appropriate suggestions and comments or other features of the learning environment, were the social context which played the role of scaffolding the students. They could progress further than would be possible without this support (Linn and Burbules, 1993; Hodson and Hodson, 1998).

The constructivist perspective also was considered by Solomon (1987 cited in Geelan, 1997) and Cobern (1993). Solomon believed that although scientific ideas are held by a person, the social interaction in modifying the ideas is the single most important factor in science learning and attitudes to science. However, without awareness of the social nature of science learning, the scientific knowledge in a student’s mind could be accumulated separately. The students acquire the knowledge in separate ways, as scientific knowledge from school and from everyday experience. Taking this point, Cobern (1993, 1998) noted that exploration and understanding of the relationship between the culture of science and the culture of students are needed for learning science. The social interactions, thus, could not give the entire context for children’s cognition. The cultural context is the central force in the development and organization of student ideas. Therefore, both the culture of science and science education, and the culture of children’s science and science education should be identified to supply that social perspective.

5. Constructivist-Based Teaching about Photosynthesis

New teaching strategies based on constructivist perspectives were developed to improve teaching and learning about photosynthesis (Barker and Carr, 1989a, 1989b, 1989c; Eisen and Stavy, 1993; Lumpe and Staver, 1995, because the importance of photosynthesis was recognized in many school science classrooms. Barker and Carr (1989a) investigated photosynthesis teaching and learning situations with age 13 to 18 year-old students in the North Island of New Zealand. The findings showed that there were three teaching strategies used to introduce the phenomena in the science classrooms. The *guided discovery* strategy was used as story telling about how plants make food. The *element analysis* strategy was based on chemical analysis of matter, soil, air and plant materials. The *meaning of plant food* strategy was used to identify students' prior knowledge about plants and their food and student understanding of photosynthesis itself. Even though these strategies were widely implemented, the findings illustrated that the students had difficulty in learning the phenomena. They had only learned that "photosynthesis is a food-making process" (Barker and Carr, 1989a: 52), but they did not learn about what the food was and where the food came from. The conceptual understanding of chemical change related to plant nutrition as well as relationships between photosynthesis itself and other biology processes were still difficult for the students. Later, Barker and Carr (1989b, 1989c) implemented the *generative learning* strategy of Osborne and Wittrock (1985) to develop the basic concept understanding of the age 13 and 14 year-old or junior high school students. The strategy consisted of 1) exploring the student prior knowledge and challenging them 2) linking and generating new ideas about the concepts as well as 3) assessing their own ideas with anybody else in the classroom. A teaching package of paper-pencil tasks and teaching materials called 'Where Does the Wood Come From?' was thus introduced into the classes. The findings of Barker and Carr (1989b, 1989c) showed 71 percent of the students who were taught by this package had learned that carbohydrate was plant food produced by photosynthesis.

In 1993, Eisen and Stavy used constructivist view of learning to develop the teaching strategy about photosynthesis. These two researchers believed that students'

pre-existing ideas were very necessary to support their understanding of new accepted scientists' ideas. The eighth grade (age 14 to 15) students (N = 230) in a lower-middle-class area near Tel-Aviv, Israel participated in this study. The student control group (N=111) was taught without considering their pre-existing ideas about photosynthesis. The student experimental group (N=119) was taught with the new strategy. This was organized for correcting students' pre-existing misconceptions and to prevent student formation of new photosynthesis concepts. For example, the relationship between photosynthesis and respiration in ecosystem was emphasized to correct the misconception i.e. photosynthesis was a type of respiration. Some historical stories of science were introduced to show ancient misconceptions about photosynthesis. The photosynthesis content was also organized to deal with photosynthesis on more general levels such as emphasis of common relationships between photosynthesis and environment, in particular CO₂ that is an environmental material from the atmosphere, and plants. The student own life situation was used to motivate the understanding of photosynthesis concepts. The results of this study showed that the strategy had a positive effect on improving the students' understandings of photosynthesis. The experimental group had significantly better scores than the control group, responding the questionnaire at the end of the teaching process. However, students still misunderstood some chemical aspects of photosynthesis. Both groups thought that H₂O was the plants' element instead of the plants' component (Eisen and Stavy, 1993). Anderson, Sheldon and Dubay (1990) discussed student retention of photosynthesis misconception, that without the basic important concept understandings such as matter and energy and atomic-molecular theory, did not fully understand about photosynthesis. In addition, Smith and Anderson (1984) found that teachers with limited understanding produce teaching about the nature of science that would support student retention of misconceptions.

In 1995, Lumpe and Staver also used the social constructivist perspective, which emphasized people interactions, to develop conceptual understanding about photosynthesis in American Midwestern high school biology classrooms (Lumpe and Staver, 1995). Using a collaborative strategy, the treatment groups were composed of randomly chosen mixed-ability students who felt comfortable in working with their

peers, while the control group worked individually. The learning tasks, including the direction, questions and hands-on activities, were administered without any instructions. Both their prior and post knowledge were assessed through the Photosynthesis Concept Test (PCT) of the Institute for Research on Teaching (IRT). The results of their task and test responses indicated that the strategy enabled the treatment group to gain better understanding of the concepts.

These findings indicated that teaching strategies based on constructivist perspectives provided progression for student learning about photosynthesis, and therefore students held fewer misconceptions related to photosynthesis.

6. Summary: Relevance of the Constructivist Theory to Teaching

The constructivist perspectives have become an important reference for research and practice in science education. Educators have begun to consider the various backgrounds and interests of students as a way to understand teaching and learning contexts. Thinking about how children learn challenges educators to re-conceptualize educational situations. There are several teaching implications of the constructivist perspectives. Personal constructivism leads to an understanding of what knowledge is, and how students learn. Knowledge is a representation of reality that needs active learners to receive it. Students' prior knowledge needs to be considered in the process of this learning view, which is not memorization and recall. The teacher cannot transmit knowledge; the students have to construct it for themselves. As another consideration of the teaching implications of social constructivism, the teaching should focus on assisting individuals in their interpretations of concepts. Teaching should be moved from teacher-centred to student-centred learning (Hodson and Hodson, 1998). Socially collaborative learning with effective language communication should be encouraged to develop students' ability to learn (John-Steiner and Mahn, 1996). Also, motivation of students' learning in the classroom should be considered in parallel with an understanding of student learning context.

The development of constructivist approach is based on an awareness of the social and cultural world influencing student learning in classroom. The approach helps development of more effective teaching strategies. Teaching should know not only what is being acquired in the culture of science, but also how it relates to what students have already learned about their own society and the everyday culture of their society in general – family, community and environment. What follows, explores this more fully, namely, the interpretation and application of socio-cultural theory as it might underpin the understanding and facilitating of teaching and learning about photosynthesis.

Socio-Cultural Influences on Teaching Photosynthesis

1. Overviews: Emerging Socio-cultural Perspectives

Socio-cultural perspectives are concerned with the ways of thinking about human learning (Cobb, 1994; Cobb and Yackel, 1996; John-Steiner and Mahn, 1996; Marshall, 1996; Packer and Goicoechea, 2000). Two social perspectives which underpin the science teaching/learning areas are being debated (Alfred, 2002). The first, an epistemological perspective, focuses initially on the situated nature of knowledge construction by the individual. However, Vygotsky's social constructivist theory emphasized that learning occurs within a particular social world (Rogoff, 1990; Wertsch and Kanner, 1992). Therefore, a shift from focusing on the individual to the interactions within a larger social context occurs. The second, an ontological perspective places less emphasis on *knowing* and more on *being*. It holds that the individual's learning cannot be considered in any way to be context-free. The learning *always* relates to *being* part of a society and a culture (Cobb and Yackel, 1996; John-Steiner and Mahn, 1996; Marshall, 1996; Packer and Goicoechea, 2000; Alfred, 2002).

In Vygotskian social constructivism human knowledge construction involves the interdependence between the individual and social processes (John-Steiner and Mahn, 1996). Students learn through “the transmission of culture from one

generation to the next” (Cobb and Yackel, 1996: 186). Gradually, an individual develops such cognitive processing through *social sources* – social interactions. “It occurs through guided participation in social activity with companions who support and stretch children’s understanding of and skill in using the tools of culture” (Rogoff, 1990: Preface vii). The individual’s actions are motivated with the appropriated *semiotic mediation*, for instance, signs, languages and symbols, including psychological tools. In 1991, Wertsch considering the origin of mental and physical characteristics described how mediation can then dynamically internalize the *interconnecting* between the individual and society (John-Steiner and Mahn, 1996).

However, the perspective based on the Vygotskian framework was developed further by socio-cultural psychologists (Bredo, 1994; John-Steiner and Mahn, 1996; Packer and Goicoechea, 2000). The socio-cultural perspective of learning seems to be “a process of transforming participation in shared socio-cultural endeavours” (Rogoff, 1994: 210). There are three main ideas in this perspective; social sources, semiotic mediation, and interconnection. These maintain that the learning process is understood as representing much more than the individual mental construction of knowledge. This perspective emphasizes the notion that learning entails broader changes in human beings than knowing, it involves the mind and the world (Packer and Goicoechea, 2000). “One cannot independently define individual learning as separate from change in one’s social role or identity” (Bredo, 1994: 32). Therefore,

. . . Learning involves not only becoming a member of a community, not only constructing knowledge at various levels of expertise as a participant, but also taking a stand on the culture of one’s community, in an effort to take up and overcome the estrangement and division that are consequences of participation. Learning entails both personal and social transformation (Packer and Goicoechea, 2000: 228).

This socio-cultural development of social constructivism obviously shows that while students do learn by themselves, they are strongly influenced by their social and

cultural environment. Their knowledge is constructed as they mature into their self-identity and an acceptance of responsibility for family, community and environment. Recognizing the role of these influences in student learning and allowing for teachers in planning teaching strategies, may give more complete help for students to understand science. Therefore, use of socio-cultural perspective is addressed in this study as a basic principle of development for a new teaching intervention.

2. Towards Socio-cultural Perspectives for Teaching Photosynthesis

Two perspectives to interpret the nature of knowledge construction have been discussed. Epistemologically, the socio-cultural perspective focuses on an individual's *knowing* in their society and the culture of the classroom. Ontologically, the socio-cultural perspective strongly views individual learning as human *being*. A child also has their own culture and language of the family and society influencing the learning in classroom. In this case, it is necessary that teaching must recognize the relationships between the child's classroom culture and their own social culture. One culture might not suit another, as John-Steiner and Mahn (1996) and Marshall (1996) noted.

The ontologically socio-cultural perspective also has relevance for a non-Western, and specifically the Asian perspective. Ogawa (1998) studied the history of science education in Japan. Here he noted that science education had been studied as an import of foreign culture. At the end of the discussion, however, he suggested that although science had been developed in Western countries it could be adaptively taught to the traditional worldviews of Asia. It was necessary that Asia considers and modifies the foreign culture to develop Western science for learning science in Asia.

From this perspective, the possible impacts of Thai society and culture influencing teaching and learning about photosynthesis were also important. These are briefly discussed as Thai living styles, Thai views about plants, the natural resources and environmental policies of Thailand, Thai educational values, and Thai school society.

2.1) Thai Living Styles

Thailand is agricultural based on society located in Southeast Asia. The total population exceeds 62.6 million with an approximate density of 120 persons per square kilometre (Fry, 2002). Thai people are Buddhists. The life style of the people is strongly bound to the social community. Young children are taught to respect elders in the family and the community. The father is considered as the family leader working outside while the mother is perceived as a house wife (Srivichit, 2004).

The living style indicates that Thai children pay more attention to what their family thinks and what their family would like them to do within the community. Investigating what they are thinking and doing relatively to photosynthesis in the community e.g. plants should be considered to identify student culture about photosynthesis.

2.2) Thai Views about Plants

Plants for Thai people are recognized for building and as valuable and spiritual substances. Wood and leaves of plants are used to build the traditional triangular–roof Thai house (Buffalo villages, 2003). Flowers, another part of plants, are used as a valuable *substance* to support and respect the Buddha image or monks. In Thai local areas plants, particularly huge trees such “Poe”, Ficus religiosa L., are also recognized as the *spirit house* or *forest* (Srivichit, 2004). The fact that plants physically provides *water resources* was additionally emphasized to the Thai people through the speech of His Majesty King Bhumibol Adulyadej of Thailand, on 4 December 1993. This speech was given to the audience of well-wishers on the occasion of the Royal Birthday Anniversary at the Dusidalai Hall, Chitralada Villa, Dusit Palace.

Thai people may have diverse views about plants. Some of them may think plants are producers or value plants as a spirit home which they would like to conserve for the next generation. The students’ views must be investigated and

recognised before being challenged with new advanced concepts concerning photosynthesis. The teacher would then be able to help the students to regenerate their own ideas and then link them to the new concepts.

2.3) Natural Resources and Environmental Policy of Thailand

Failures in the use of natural resources by industrial development and making urban communities, have forced the Thai government to establish a policy of restoring the natural resources and developing the environment (Bangkok Post, 2001a). The policy emphasizes improving the quality of natural resources and biodiversity, to prevent degradation and depletion of natural resources, and to recycle and reuse the natural resources and bio-diversity in a manner that is beneficial to the people's livelihood (Asia Time Online, 2001; Bangkok Post, 2001b). This national development must be well balanced and provide a basis for the sustainable economic and social development of the country. Especially in the Bangkok metropolis area, improving quality of life for the people is being emphasized by providing education and public health. The people are expected to restore and conserve the environment.

Understanding plant conservation for the environment was focused on a vision of learning science (IPST, 2002), but has not been an important part of the Thai culture. Encouraging students to apply photosynthesis knowledge for their environment should be integrated into the teaching strategy.

2.4) Thai Educational Values

The whole culture of learning in Thailand is evolving into a two-tier system, formal and private, with a consequent shift in what is valued. Thai students study in a formal educational system with a 6-3-3 year pattern: ages 6-11 in elementary school, ages 12-14 in junior high school and ages 15-17 in senior high school. In the elementary classes, most students enjoy studying science and mathematics. At the high school level, science-oriented students emphasize the studies of physics, chemistry, biology, mathematics, and English and Thai. These

focuses prepare them to take the National Entrance Examination for university level. However, they also spend 6-10 hours outside formal schooling studying in private tutorial institutions for the entrance examination and for regular schooling examinations (Buranakarn, 2003). This additional study is becoming an educational fashion of students and, even parents, who want higher marks in each examination. Unfortunately, the private tutoring which mostly emphasizes recalling technique rather than thinking process resulted in most students learning for taking examinations. Those often ask them close-ended question or multiple choice styles rather than open-ended questions asking them to analyze and critically think.

The educational values of students indicate that the formal education system is being changed by the private tutorial system. Some students learn biology particularly to assist them with the National Entrance Examination without really understanding the aims of biology education (p.20). Therefore, challenging students to rethink the value of biology in terms of its knowledge and its learning process for every day living is important in this research study.

2.5) Thai School Society

Every morning students and teachers begin their day by singing the national anthem, and clasping their hands and giving thanks to the country, to Buddha and to the king who upholds the Buddhist faith (Orihara, Wright and Knowlton, 1988). In school students wear school uniforms, and have a teacher advisor. They spend 20 minutes before teaching starts in meeting with their advisor. This meeting is called *home room*. The advisor announces school news and advises them on how to be a good student. Normally the first teaching period starts at 8.30 a.m. There are 6 one-hour teaching periods and one hour for lunch. The last teaching period finishes at 3.30 p.m.

In the classroom, students are expected to show considerable respect for authority, especially teachers (Triolo and Lewis, 1998). The relationship between teachers and students is formal, and the students rarely argue decisions made by the

teacher. Outside the classroom, students are expected to bow when walking past their teachers. At a celebration such as Teachers' Day, students bow low and present garlands or offerings to their teachers to show their reverence towards those who have taught them. On Friday afternoon students are required to attend a school assembly where they uphold the Buddhist faith and are taught about being a good student by a senior hierarchy teacher.

In classroom, teachers are expected to improve their teaching methods. The National Education Act in 1999 required the teacher to change emphasis from a teacher-centred approach to a student-centred approach. Traditional teaching which supports the students' rote learning and uses compulsory textbooks is no longer accepted. Teaching for student understanding, creativity and an inquisitive mind are the newly accepted norms (ThaiWorldView, 2004).

There are high expectations on both students and teachers to achieve the norms of society. The relationship between students and their teacher in school society could affect students' learning. The students may be puzzling how they should learn in the new style classroom and the teachers may be afraid of change. Students are being encouraged to express their own ideas while still giving a high level of respect to their teacher. Teachers are being required to radically change their teaching to new ways which contrast with their old tradition. In this study, investigating the student – teacher relationship was thus needed to understand real classroom culture. This would be useful to evaluate students' understanding in the classroom.

3. Summary: Adapting Socio-culture Perspectives for Teaching Photosynthesis

Using perspectives of socio-culturalists, a student is treated as a human being who develops their learning through social interaction in the contexts of the classroom and the family, the community and the culture. In Asian biology education, learning biology in the classroom is learning the biological knowledge of Western culture. In this study, photosynthesis in biology classroom culture is taught relative to Thai

culture. First, Thai existing views about plants which were learned from their parents, family and school would be investigated and recognized before challenging students to study the new advanced concepts of photosynthesis. Second, application of the new concepts for the environment would be integrated in the teaching strategy of the new intervention. Third, challenging students to rethink why they have to learn biology; whether only for taking of the National Entrance Examination or whether it is also for their everyday life, would be discussed at the end of the implementation of the intervention.

The understanding of the nature of science as an additional important idea should be taken into account in teaching photosynthesis (Smith and Anderson, 1984; Barker, 1997).

The Nature of Science for Teaching

The importance of understanding of the nature of science was introduced significantly in the United States through the National Science Foundation (NSF) curricular reforms during the 1960s and especially in *Project 2061* (AAAS, 1989). England and Wales also introduced this idea through the Science National Curriculum by the Department of Education and Science/Welsh Office (DES/WO) of the United Kingdom in 1989 (Driver *et al.*, 1996; McComas and Olson, 1998; Matthews, 1998). Identification and specification of the nature of science was presented to guide the selection and organisation of science curriculum elements including the goals of science education, namely understanding the boundaries, nature and limitations of science; and using scientific knowledge to advance society and everyday life. Especially since the middle of the 20th century the nature of science has increasingly become a part of major reform efforts in science education (Driver *et al.*, 1996; Matthews, 1998; Robinson, 1998a, 1998b; Abd-El-Khalick and Lederman, 2000; Lederman *et al.*, 2002).

1. Aspects of the Nature of Science

McComas, Clough and Almazroa (1998: 4) described the nature of science as

... a fertile hybrid arena which blends aspects of various social studies of science including the history, sociology, and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavours. . .

Also, the American Association for the Advancement of Science (AAAS, 1989), Matthews (1998: 988) and Driver *et al.* (1996: 12-15) noted that the understanding of the nature of science was a goal of science education present in most definitions of science literacy. This understanding was communicated within the disciplines of philosophy, history, sociology and psychology of science which could be described as the following three aspects:

First, the nature of science is the understanding of some aspects of *scientific knowledge*: facts, laws, concepts and theories about the natural world. Driver *et al.* (1996: 42-44) also suggested that the nature of science for students should be presented mainly 1) with the view of the purpose of scientific work – science aims to explain natural phenomena and 2) with the understanding of the nature and status of scientific knowledge.

Second, the nature of science is the understanding of the *scientific approach* to inquiry. This involves an epistemological consideration. The inquiry needs planning and carrying out within a framework of scientific conceptual and theoretical knowledge. The framework could be limited by different understandings of the role of observation, experiments and the relationship between evidence and theory.

Third, the nature of science is the understanding of *science as a social enterprise*. Science is expressed using an interpreted language which refers to the objects, phenomena and events of the natural world. Science operates in its social organization and its mechanisms for receiving, checking and validating knowledge claims. In addition, an awareness of the possible influence of social commitments, values, interpretation and culture that could affect the understanding of science is important.

Understanding the nature of science is also identified and presented in three main statements from McComas and Olson's (1998: 44-48) study of national science education standards documents as:

- Scientific knowledge is tentative
- Science relies on empirical evidence
- Science is an attempt to explain phenomena

- New knowledge must be reported clearly and openly
- Scientists make ethical decisions
- Scientists require: accurate record keeping, replicability and truthful reporting
- Scientists are creative
- Change in science occurs gradually

- Science has global implications
- Science is part of social tradition
- Scientific ideas are affected by their social and historical milieu.

In this study, the nature of science is the understandings of *why* scientists have to study scientific knowledge, *how* they study the knowledge and *how* they can develop the knowledge within a socio-culture. In other words, scientists study science because they aim to explain natural phenomena. The explanation developed stems

from process of inquiry such observation, planning and investigation which needs social acceptance.

2. The Value of the Nature of Science for Teaching and Learning Photosynthesis

Apparently science teachers often undervalue the nature of science. They focus on teaching scientific concepts rather than helping the students understand how science works and how science knowledge is created. Teaching without regarding the nature of science was shown to result in students holding significant misconceptions about photosynthesis (Smith and Anderson, 1984; Driver *et al.*, 1996).

Smith and Anderson (1984) studied the use of a life science unit of the Rand McNally SCIIS program to teach Grade 5 students about plant growth and photosynthesis. A female teacher was studied through the teaching-planning process using observation and video recording, as well as formal and informal interviews before and after her teaching in the classroom. Although student misconceptions about plant and photosynthesis were found during the unit, the teacher had attempted to solve this problem by herself. For example, she grew seeds in the germination systems without soil as evidence that plants do not need soil or fertilizer to grow. At the end of the unit, 80% of the students were aware that plants made food, while 20% of the students actually changed their conception about plants from ‘plants *take* food’ to ‘plants *make* food’ (Smith and Anderson, 1984: 695). These researchers thus indicated that the teacher’s belief about what is scientific knowledge and how students learn could significantly develop student learning about photosynthesis.

Including the nature of science as a goal of science teaching was suggested through the works of Driver *et al.* (1996), McComas, Clough and Almazroa (1998), and Robinson (1998a, 1998b). There are reasons which Driver *et al.* (1996: 16-23) gave for this suggestion. First, from a utilitarian view, students have to understand the nature of science because it could enable them to know the limitation of scientific knowledge and theories. This is needed to confidently make sense of the science and manage the technological objects and processes in everyday experiences. Second, a

democratic view, that the understanding is also needed for participation in the decision-making process of socio-scientific issues. The third and fourth rationales are concerned with cultural and moral views. The nature of science brings them an appreciation of science as a major achievement of culture, and to be aware of science particularly in norms of the scientific community respectively. The final rationale, a science learning view, is that the nature of science can support students' learning of scientific content. An additional suggestion of McComas, Clough and Almazroa (1998: 11-14) is that by teaching with a firm understanding of the nature of science, in particular, the process of historical scientific conceptual development might be a possible solution for the problem of resistance to conceptual changes in learning. Matthews (1997, 1998) argued that including the nature of science in science teaching should also recognize epistemological educational issues, e.g. the creation versus science debates, multicultural science, feminist critiques of contemporary science and feminist proposals for the reform of science programmes.

3. Students' Understanding of the Nature of Science

In 1991 – 1993, Driver *et al.* (1996) aimed to investigate students' ideas about the nature of science based on the Science National Curriculum for England and Wales, through an eleven-series research project, titled The Development of Pupils' Understanding of the Nature of Science. Here a cross-age study was designed using 9, 12 and 16 year-old student samples. The nature of science was characterized in three features: the purposes of scientific work, the nature of status of scientific knowledge, and science as a social enterprise. Stimulus materials and tasks related to the features were given and semi-structured interviews were used with pairs of the students to probe their ideas. In the case of the purpose of scientific work, the findings of Driver *et al.* showed that science was understood as providing solutions to technical problems rather than providing powerful explanation. Science was a physical and a biological phenomenon, not a social phenomenon. Younger students thought science in school was different from science in everyday life. The nature and status of scientific knowledge was viewed as complex that combines scientific inquiry, the status of theories and explanation, and coordination of explanation and

evidence. The students thought that scientific inquiry was a process of making observations. The explanation was connection between a cause and an outcome of an observation or an event. The students also thought that science work was an individual study – no process of checking or challenging within the scientific community. Some scientific conflicts came from their lack of sufficient data or personal bias. Scientists' society had a reduced influence on decisions about developing science.

From the studies of Moss, Abrams and Robb (2001) and Bell *et al.* (2003), also it was found that American students did not understand the key aspects of the nature of science. In a semi rural public school located in the northeast, Moss *et al.* used semi-structured interviews to investigate the understanding of five Grade 11 and 12 students. The findings indicated that the students fully understood the nature of scientific knowledge, but rarely understood the nature of scientific enterprise. Bell *et al.* used semi-structured interviews and a questionnaire to examine the understanding and scientific inquiry of ten Grade 10 and Grade 11 students in a science and engineering apprenticeship program at Northwest University. The results illustrated that the students understood the key aspects in different ways from the current science curriculum reform. These two studies also noted a problem of retaining the misunderstanding even after the course was over. In this case Bell *et al.* noted that students may have some belief and epistemology interrupting their understanding. Moss *et al.* thought that it might come from the lack of study of the nature of science. In addition, Smith and Anderson's (1984) study, argued that teachers' beliefs about the nature of science was an important factor influencing students' understanding of scientific knowledge, especially concerning photosynthesis. Therefore, overcoming misconception about the nature of science should be considered as a main aim of teaching science (Moss, Abrams and Robb, 2001; Bell *et al.*, 2003).

4. Summary: Integrating the Nature of Science for Teaching

Understanding the nature of science is important to developing science teaching. Teaching of concepts in science *without* addressing how science works and how science knowledge has been created and maintained could not actually lead students to understand science in its entirety. Students should be encouraged to understand the nature of science and recognize that *science* is a problematic issue which changes over time, that science is constructed through controlled experimental inquiry process, and that science is developed within social expectations, evaluations and constraints. In the case of this research study, the idea of *science as a social enterprise* was emphasized to support student learning about photosynthesis. It was hoped that the student would then comprehend the connection between scientific knowledge and the scientific method in the classroom and science concepts in society. Also they would understand that science actually has a social mechanism and needs approval by scientists in many fields around the world. With this understanding, the students might come to appreciate and be aware of scientific study and would more like fully understanding scientific concepts.

Teaching for Photosynthesis Understanding

1. Overview: Emerging Pedagogies

The misconceptions about photosynthesis have long been interesting as a factor influencing student learning in biology classrooms, so the development of teaching pedagogies which promote clearer understandings of the concepts has become an important goal of biology teaching (Amir and Tamir, 1984, 1994; Barker and Carr, 1989a, 1989b, 1989c; Anderson, Sheldon and Dubay, 1990; Eisen and Stavy, 1993; Hazel and Prosser, 1994; Lumpe and Staver, 1995 Lavoie, 1997; Brown, 2003; Ekborg, 2003). Three of the teaching strategies which have been developed are concept mapping, narrative technique and historical ideas, and integrating the nature of science. Firstly, *concept mapping* (Novak and Gowin, 1984; Hazel and Prosser, 1994; Lavoie, 1997; Kinchin, 2000b; Mintzes, Wandersee and Novak, 2001; Brown,

2003) was proposed to reveal misconceptions and promote conceptual understandings. Using only concept mapping, however, did not change persistent misconceptions. Secondly, a new teaching strategy based on *narrative technique and the history of ideas* was suggested in science education (Millar and Osborne, 1998 cited in Hipkins *et al.*, 2002; LaBoskey, 2002). Using everyday life stories (Kuhn and Hand, 1995) and even stories from the history of science (Barker, 1995, 1997; Allchin, *et al.*, 1999) enabled students to learn about, have a positive attitude towards, and understand the nature of science. Also, Gallas (1995) and Barker (1997) suggested that the technique should be utilized suitably with students' learning contexts. Thirdly, an additional strategy is *the integrated nature of science* (Bell, Lederman, and Abd-El-Khalick, 1998; Smith and Scharmann, 1999; Lin and Chen, 2002; Bell *et al.*, 2003). Lin and Chen (2002) suggested that teaching based on the aspect of science as a social enterprise could bring students to an understanding of the nature of science, which might then encourage them to improve their understanding of scientific concepts.

2. Concept Mapping

“A concept map is a two-dimensional node-link representation that depicts the most important concepts and relationships in a knowledge domain” (Mintzes, Wandersee and Novak, 2001: 119). The concept mapping technique illustrates the organization of conceptual ideas showing how major ideas are related to subordinate ideas and to associated ideas from other topic areas (Novak and Gowin, 1984; Kinchin, 2000b; Mintzes, Wandersee and Novak, 2001). This technique is very useful in diagnosing the errors in understanding of complex conceptual frameworks and revealing flawed reasoning.

Novak and Gowin (1984: 24-28) suggested that introducing concept mapping to senior high school students should follow three main steps; identification, organization, and presentation. Helping students to learn and acknowledge natural phenomena as concepts, in terms of words, is the first step which enables students to identify which concepts exist in their minds. The organisation process of the

relationship between one concept and another is the next step which they need to either separate or link concepts with appropriate words. The final step is students' visual presentation of the concepts through a concept map which shows detailed relationships and is easy to remember. Figure 2.1 illustrates a model of concept mapping.

Evaluating this mapping, Novak and Gowin (1984: 97-103) also suggested that a good structure should begin with a broad concept, called a hierarchy, some general concepts and then go through to more specific ideas. The mapping should present a continuous process of increasing new concepts and new linking words. The mapping should provide linking, called cross-links, between a set of concepts and another. In addition, Mintzes, Wandersee and Novak (2001) argued that the effectiveness of this technique depended on a teachers' critical appreciation of the importance of students' prior knowledge, the alternative concepts and the steps of learning.

Using the concept mapping technique to visualise how a student's photosynthesis knowledge was organized was also studied. Hazel and Prosser (1994) aiming to encourage general use of the technique explored changes of first-year undergraduate student understandings before and after studying photosynthesis. The students were given three weekly lectures, one laboratory and summary notes. Finally a 10 multiple-choice question examination was used to evaluate their achievement. Following the examination the students were given a pack of concept cards with which to construct a concept map of photosynthesis. Written sentences or a description of the relationships between the concepts were analyzed and scored using Novak's method, including counting the number of the concepts, links and cross-links between the concepts. The results, however, illustrated that the students had little change in their understandings of photosynthesis.

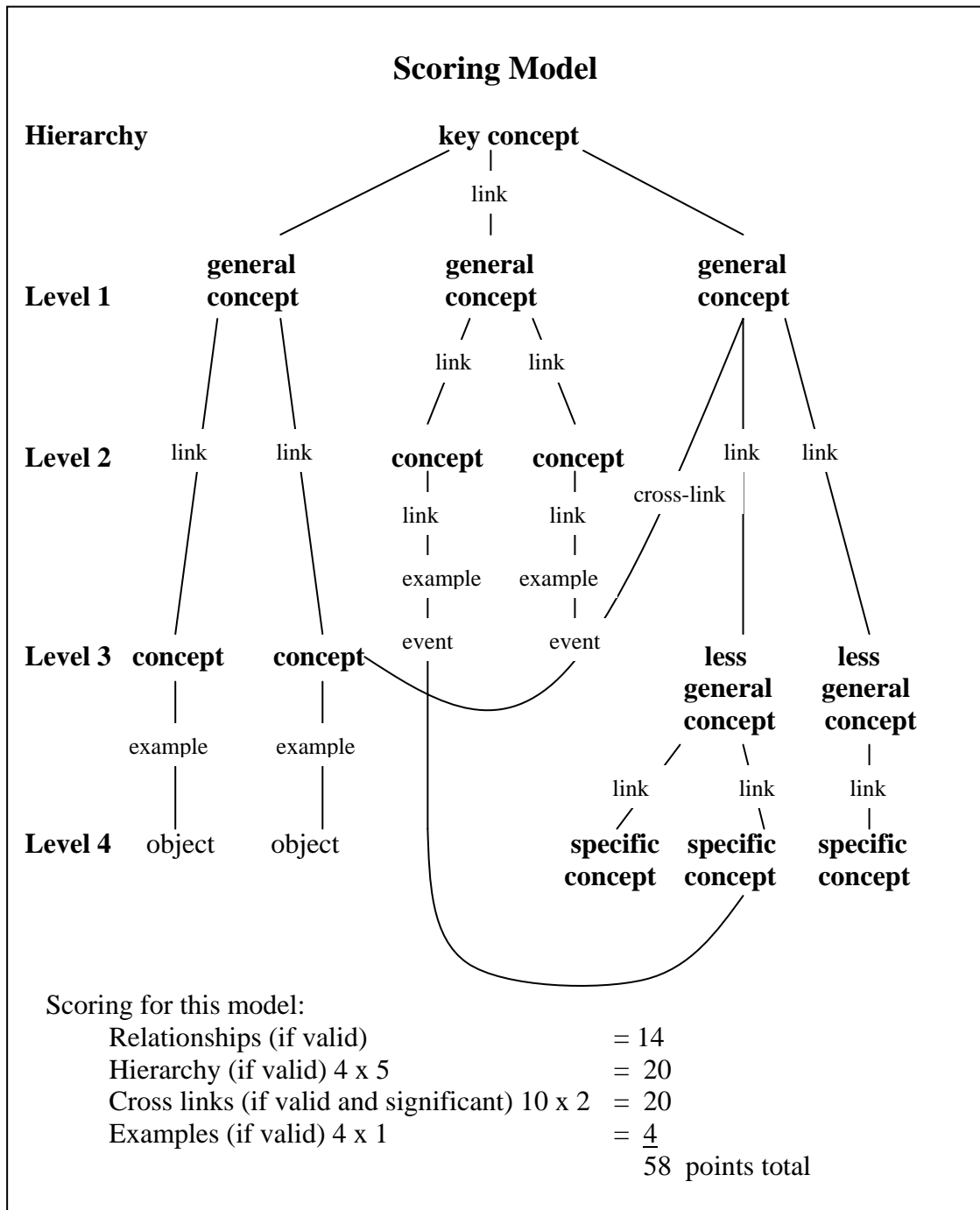


Figure 2.1 An Evaluating Model of Concept Mapping

Source: adapted from Novak and Gowin (1984: 37)

Brown (2003) used a combination of the concept mapping technique with collaborative learning while Lavoie (1997) used the technique with reflective writing to study student understandings about photosynthesis. The study of Brown used the combined strategy of concept mapping and collaborative learning in the teaching course at the Midwest suburban high school. The course concerned studying photosynthesis and cellular respiration. The students in experimental groups were organized working in small groups to create maps with collaboration within the final 15 minutes of each 50-minute biology class, while the students in a control group did not use this strategy. Achievement was assessed through Haslam and Treagust's (1987) two-tier test. The findings indicated meaningful learning by the experimental group of students. The post-test scores in both experimental groups had increased significantly more than the control group. However, Griffard and Wandersee (2001: 1049) argued that the findings which resulted from using the two-tier test might have no validity. Students could choose correct answers because they were familiar with the words addressed in the test. In addition, Lavoie argued the techniques without student explanation could not indicate what they actually understood about photosynthesis. The study of Lavoie suggested that the concept mapping technique including students' reflective narrative about their constructed maps would probe the understandings. The undergraduate students majoring in elementary education at the north central United States University were explored about their understandings of metabolism, respiration, photosynthesis and ecology. The results illustrated that this combined technique elicited what the students understood about the concepts.

Using the concept mapping technique integrated with descriptions of what students themselves understand about concepts is a better way to probe students' understanding. In this study, students were encouraged to produce their concept map of introductory photosynthesis which was then used for analysis of their prior knowledge. This can be used by the teacher to adapt teaching material.

3. Narrative Techniques and the History of Ideas

In 1998 a new teaching strategy called narrative or the story-telling technique, was suggested in science education by Millar and Osborne (Hipkins *et al.*, 2002: 191-192). The narrative technique uses explanation based on science's recognisable context. This has its characters, events and situations, which give logical direction to the context or the story. LaBoskey (2002: 34) explains that the story "...could be a retelling of something that actually happened ...or it could be fictional". It, however, should be presented, i.e. written or spoken, without the bias and judgement of the teller in order to present the discovery process of the people in the story. Historical ideas of science are powerful advocated and documented stories which should be recognized and used to promote student learning about science (Barker, 1997). "History [of science] can serve to [organize] the serial development of concepts, to reconstruct reasoning, to celebrate scientific discovery, or to bring anecdotal humour into a lecture" (Barker, 1997: 187-188). Telling the historical story of science also provides a cultural background of science which may lead students to better understand the nature of science, especially science as social enterprise. There are several studies which show the result of using the technique of narrative and/or historical ideas.

Successful use of the narrative technique has occurred in Australia (Kuhn and Hand, 1995), New Zealand (Matthews, 1994; Barker, 1995, 1997) and the United States (Allchin *et al.*, 1999). Kuhn and Hand (1995) used everyday life stories to challenge Australian junior high school students who were learning a new concept about geology. They were asked to write brochures and create their personal stories to illustrate their new learning of geological concepts for other people. The results showed the students' development in rethinking and learning the concepts.

In Barker's (1995) study, five historical stories about photosynthesis combined with a generative teaching model were used to develop 13-year-old New Zealand junior high school students while they were learning about photosynthesis.

Focusing on thinking and encouraging students' discussion was emphasized for his application of the model. The stories included Aristotle, Leonardo da Vinci, Jethro Tull, Joseph Priestley, and Erasmus Darwin. The results indicated that the students could describe photosynthesis relative to the learning achievement of the curriculum. In addition, Matthews (1994) supported the argument that using stories also enhanced students' understandings of the complexity and creativity of the original scientists' ideas. On the other hand, Irwin (2000) argued that using historical stories could not provide a positive effect on 14-year-old UK students' learning of the atomic theory. The students had less judgemental awareness of the complexity of this historical idea.

In addition, using an historical story of science in a lab course was successful in the study of Allchin *et al.* (1999). They found a problem with American non-science major students. They were unhappy about teaching and learning situations in a required science course. The problem was solved by the development of a new alternative lab courses which integrated historical ideas. Historical ideas about how science worked and how it developed were used as highlights in the outline of this course. Their team of faculty at the University of Texas at El Paso attempted to set labs based on human dimensions of science. These included motivation for studying science, attending labs and the scientific impact on everyday life. The histories of science and science-technology-society issues were introduced in the labs. There were students practicing organization and interpretation of the historical events e.g. distances to the moon (Greek) and the period of a pendulum (Galileo). Their explanations of the events and reflections of their own investigating processes were challenged. The results illustrated that students performed well, achieved good scores in the post-test and positively improved their attitude about science. Also, they thought that doing the labs enabled them to understand how science worked as an aspect of the nature of science. However, Gallas (1995) and Barker (1997) argued that using the technique would not be successful if the technique was developed inadequately with concerns of student learning contexts.

Narrative technique and historical ideas may be a way to develop students' full understandings of science. Nevertheless, this technique is still not used widely in

teaching photosynthesis. Therefore, this research would like to integrate the technique into the development of a teaching intervention. The historical story of photosynthesis would be used to challenge students regarding the importance of the study of photosynthesis. This challenge might encourage their interest in studying and fully understanding photosynthesis.

The importance of understanding the nature of science was also recognized for student effective learning. In this study, the nature of science is integrated with the teaching intervention within real contexts of teaching and learning.

4. Integrating with the Nature of Science

Student understandings of the nature of science; scientific knowledge, scientific inquiry, and scientific enterprise can not occur automatically without explicit teaching which provides a classroom environment or learning activities with current views of the nature of science (Bell, Lederman and Abd-El-Khalick, 1998; Smith and Scharmann, 1999; Bell *et al.*, 2003). There are common recommendations among science educators who have suggested ways to promote the understanding of the nature of science. Smith and Scharmann (1999: 496) suggested that the understanding of the characteristics of scientific knowledge should be aimed at as the most important learning outcome for the teaching of science. Students should be able to judge any argument about science by its characteristics. Bianchini and Colburn (2000) and Bell *et al.* (2003: 488) argued that doing or experiencing science with professional scientists could possibly lead to better understanding of the nature of science. They believed that teaching should focus on student awareness of scientific inquiry which then brings students to better understand the scientific content and the scientific enterprise. On the other hand, Driver *et al.* (1996) and Barker (1997) argued that emphasizing understandings the procedural development of scientific knowledge - how the knowledge was constructed and had been developed or science as a social enterprise - would promote successful understanding of the nature of science and therefore successful use of scientific knowledge in everyday life.

Which aspect of the nature of science should be emphasized as the better way to promote understanding of the nature of science was also studied. Bell *et al.* (2003) studied the impact of an eight-week apprenticeship teaching program which emphasized scientific inquiry using authentic science experiences to develop the students' understandings of the nature of science in a Pacific Northwest state, America. The ten volunteers of high-ability tenth and eleventh grade students were selected to participate in this program during the summer time. These students had to work actively with university scientists in a laboratory. They were required to participate in designing research, collecting and analyzing data. The results in the students' pre- and post- questionnaires, and semi-structured interviews; however, illustrated that their conceptions of the nature of scientific knowledge and scientific inquiry had changed very little. Their understanding of the nature of scientific enterprise had much improved. In discussion, Bell *et al.* claimed that the understandings of the nature of scientific enterprise were a spontaneous outcome of authentic science experiences such as in the laboratory, while changing the understandings of the knowledge and the inquiry depended on a student's epistemology and reflected on their own actions.

Teaching the nature of science which emphasized science as a historically social enterprise was promoted by Lin and Chen (2002). Their study was conducted using a quasi-experimental design with a group of trainee chemistry teachers, an experimental group of 33 senior students, and a control group of 30 junior students all from the National Kaohsiung Normal University of Taiwan. The experimental students were taught by using historical teaching materials which indicated how scientists developed their understandings of phenomena, namely scientists' original debates, discussions, and experiments. Group discussions, debates, teacher demonstrations, project-assignments, and hands-on experiments, were used to replicate historical scientists' work. The control group students did not take courses related to the history of science. Before and after the teaching, all student conceptions of the nature of science were assessed quantitatively with a modified version of VOSTS, a multiple-choice questionnaire (Aikenhead and Ryan, 1992). After they had completed the questionnaire, five students of the experimental group were selected

randomly to be interviewed for 30-45 minutes for qualitative probing on their belief about the nature of science. The results of covariance analysis showed that the experimental group had significantly better understandings of the nature of science than the control group. In addition, analysis of the interviews indicated that students gained better understandings from teaching with the historical teaching materials.

The socio-cultural perspective (discussed in pages 43-50) shows that society influences the teaching and learning of photosynthesis, so encouraging students to understand *science as social enterprise* may be a key concept for the integration of the nature of science in its teaching. Hopefully, students would see the power of the social organization influencing the interpretation and validation of scientific knowledge developed by scientists, and would realize that scientific knowledge was not easily established; it is developed with practical evidence and it is strongly socialized. Thus, it is necessary that they must understand scientists' ideas to gain a better understanding of scientific concepts. An additional recommendation by Smith and Scharmann (1999: 507) was that encouraging the teachers to understand the nature of science as well could support better understandings of the students. In the case of this study, a scientists' story of how they work for scientific knowledge would be given for classroom debate and discussion. The students would be encouraged to debate as scientists who would like the social acceptance of generated knowledge.

5. Summary: New Strategies for Teaching Photosynthesis

The attempt to identify the student misconceptions and to create strategies which develop their conceptual understandings about photosynthesis has continued, but has not yet been fully successful. The persistence of misconceptions reflects the limited success of the attempt. Concept mapping techniques were an example of one limitation, as it could provide teachers with understanding of what students actually understood about photosynthesis, but did not change the students' conception. Possibly, the reason for the limitation might have come from the teaching which particularly focused on student conceptual change where scientific knowledge was viewed and taught as an unproblematic story. If this is the case, the strategies for

teaching photosynthesis needs improvement and a new teaching strategy should be determined. One such strategy is using the narrative technique of telling historical ideas about science and the integrated nature of science focusing on the aspect of science as a social enterprise in relation to students' photosynthesis learning context. These strategies may encourage students to understand the uncertainty of science and that science is a problematic story which needs their inquiry and ability to think reasonably. Hopefully the understandings may then enable them to really understand and encourage them to improve their concept of photosynthesis.

Summary

In this chapter, purposes of science education which guided the way to reforming biology education in Thailand were discussed. Students were expected to learn biology for their everyday life. Research into the learning about biology, in particular, Thai students' learning about photosynthesis; however, showed that students were having difficulty in understanding photosynthesis. For example, photosynthesis was understood in isolation; its relationships with other plant processes, and the environment were not regarded. One solution to this problem is to improve teaching strategies about photosynthesis. This solution needs more attention, not only through a constructivist teaching perspective, but a consideration of the socio-cultural perspective. Thai students gain their identity from parents, family, or community. This may affect their ideas about photosynthesis through their living styles, their views about plants, the natural resources and environmental policies of Thailand, their educational values, and Thai school society. Some Thai students do not accept scientific ideas as their own, rather they learn only for the examinations. Challenging students to completely understand science also demands that they understand the nature of science – scientific knowledge as developed from practical evidences and its social organization. Also, scientific ideas should be considered by students, for self-improvement and learning. Therefore, this research study focuses on a teaching intervention which might offer a better understanding of photosynthesis. Three new teaching strategies including concept mapping, narrative techniques which is sometimes called story-telling, with historical ideas, and integrating with the nature

of science, as well as the socio-cultural influences on learning were considered for the intervention. The concept mapping would be used to explore students' existing ideas and/or the prior knowledge about photosynthesis before they would be challenged to study the new concepts. The story telling of historically scientific ideas would be used to challenge them for understanding the nature of science. The nature of science would promote student self-awareness of personal learning improvement for the understanding of photosynthesis concepts.

Up to this point this research has developed frameworks of developing teaching and learning about photosynthesis in Thailand.

1. Students' understanding of photosynthesis should be enhanced to fulfil the purposes of biology education based on the National Education Act and the National Science Curriculum of Thailand.

2. Photosynthesis should be applied in relation to plant processes in the environment. Separating photosynthesis knowledge from other processes might retain misconceptions about photosynthesis.

3. The understanding of the nature of science based on Thai science curriculum should be integrated with that of photosynthesis, because the nature of science addressed how scientists had strongly worked to develop photosynthesis, the understanding of nature of science might enable students to pay more attention and value photosynthesis study.

4. This research holds social constructivist beliefs of learning which holds that students must construct knowledge by themselves using their prior knowledge and interaction with people in society and culture. Thus,

- correcting students' misconceptions about prior/introductory concepts of photosynthesis should be done before attempting to enhancing the understanding of new/advanced concepts of photosynthesis and

– encouraging students to participate in classroom activities should be organized to launch interactions between teacher and student along with student and student interaction during photosynthesis study.

5. Thai students appeared to be familiar with Thai society and culture, correcting the misconception and encouraging participation should reflect well on Thai society and the culture involved while learning photosynthesis, such as Thai views about plants and educational value of biology.

Then, the researcher generated the following questions to detail what data should be collected to develop teaching and learning about photosynthesis.

1. How can the students' understanding of photosynthesis be enhanced through its relation to the environment and the nature of science?
 - 1.1) How should photosynthesis be taught for conceptual understanding?
 - 1.2) How should photosynthesis be taught for understanding relationships between photosynthesis and the environment?
 - 1.3) How should the nature of science be taught for the better understanding of photosynthesis?
 - 1.4) What should photosynthesis intervention be in regards of photosynthesis?

2. What is the impact of the teaching intervention on teachers and students?
 - 2.1) How far did teachers implement the intervention?
 - 2.2) How far did students progress from the introductory knowledge about photosynthesis to the advanced knowledge?
 - 2.3) What did students understand about the nature of science?

Next is Chapter III. The chapter describes the methodology used to develop and evaluate the teaching. Data collection and data analysis are also provided.

CHAPTER III

METHODOLOGY

This chapter reveals the research design including the overview, and the methodology and methods in the design. It also details how subjects were selected for participation in this study. There will also be details on the development of photosynthesis teaching intervention including photosynthesis lessons. This chapter also explains the ways of developing, implementing and evaluating the intervention. The instruments are then presented. Those instruments include two surveys, interviews and observations. This chapter also explains validity, reliability and triangulation. The data collection involves surveying, audio tape recordings, field noting and video recordings. Finally, this chapter describes the data analysis such as content analysis, interpretation, trustworthiness, reporting and ethical consideration.

Research Design

1. Overview of Methodology and Methods

The research belief is an important basic principle in inquiry and provides an explanation of the natural world. The belief shows what the researcher views and accepts about the world (Guba and Lincoln, 1998). This research study is based on an *interpretive methodology*. This methodology aims to understand meaning in regards to an individual who is learning within their social and culture organization (Erickson, 1986; Cohen, Manion and Morrison, 2000). Interpretive research also provides an understanding of “... the invisible situations of everyday life; ... specific understanding through documentation of concrete details of practice; ... local meaning; ... comparative understanding of different social settings; ... comparative understanding beyond the immediate circumstances of the local setting” (Erickson, 1986: 121-122).

The attempt to understand and interpret the world in terms of its actions mainly concerns observable phenomena. It uses the process of participant observational field work (Erickson, 1986; Denzin and Lincoln, 1994). This work, however, is guided by a set of beliefs and feelings held by the researcher about the world and how it should be understood and studied (Denzin and Lincoln, 1998). Erickson (1986) suggested that a basic assumption of this work is recognizing that people in everyday life take action together in terms of formal and informal status and roles e.g. the teacher-student role in a classroom.

The characteristics of interpretive research are identified by Cohen, Manion and Morrison (2000: 35). These include human actions which continuously recreate social life and the personal involvement of the researcher. The interpretive research is also interpreting the specific and understanding actions rather than causes, and practical interest. Guba and Lincoln (1998: 210-213) identify the research quality needed to show the trustworthiness, such as credibility, transferability, dependability, and conformability, and authenticity such as fairness, ontological authenticity and catalytic authenticity. Accomplishing interpretive research in context needs both useful qualitative and quantitative methods.

The interview is a research method which can be used in conjunction with other processes to help provide a wider meaning of actions (Cohen and Manion, 1994). Interpretation of people's conversations, initiated by the interviewer for the specific research purposes, may be used to clarify relationships of that action. Guba and Lincoln (1998) also suggested that research activities which are generated should pay careful attention to the communicative relationship that the researcher establishes with the participants.

Bogdan and Biklen (1982: 27-30) defined qualitative methods as those which 1) are carried out in the natural setting as the direct source of data with the researcher as the key instrument 2) are descriptive 3) are concerned with process rather than simply with outcomes or products 4) tend to analyze the data inductively and 5) are essentially concerned with "meaning" as interpreted by researchers. In education,

Erickson (2003: 1155) believed that the qualitative research involves detailing information about an everyday event and identifying the personal understandings of participants in the event. A necessary example of an event is the implementation of a teaching program, which can be studied by observing and documenting classroom discourse and pedagogy. In this case, identifying and revealing the students' meanings of school science and everyday science knowledge and the students' awareness of knowledge should be considered critically while investigating what students understand.

Quantitative methods are viewed as a tradition of emphasis on the measurement and analysis of fundamental relationships between research variables rather than the research inquiry process (Denzin and Lincoln, 1998: 8-9). The quantitative method could be used to provide good information for qualitative research, such as using computer assisted methods and low-level statistics to analyze frequency counts. Also, the statistical measures, methods, and documents could be used as a way of selecting a group of subjects from a larger population.

2. Methodology and Methods in Design of the Research

This research study used an interpretive methodology to develop a teaching intervention to promote the eleventh grade student understandings about photosynthesis in Thailand. Figure 3.1 shows developmental processes and evaluating processes of the intervention as a research design. The development process was concerned with the first research question, and evaluating process was concerned with the second research questions presented in Chapter 1.

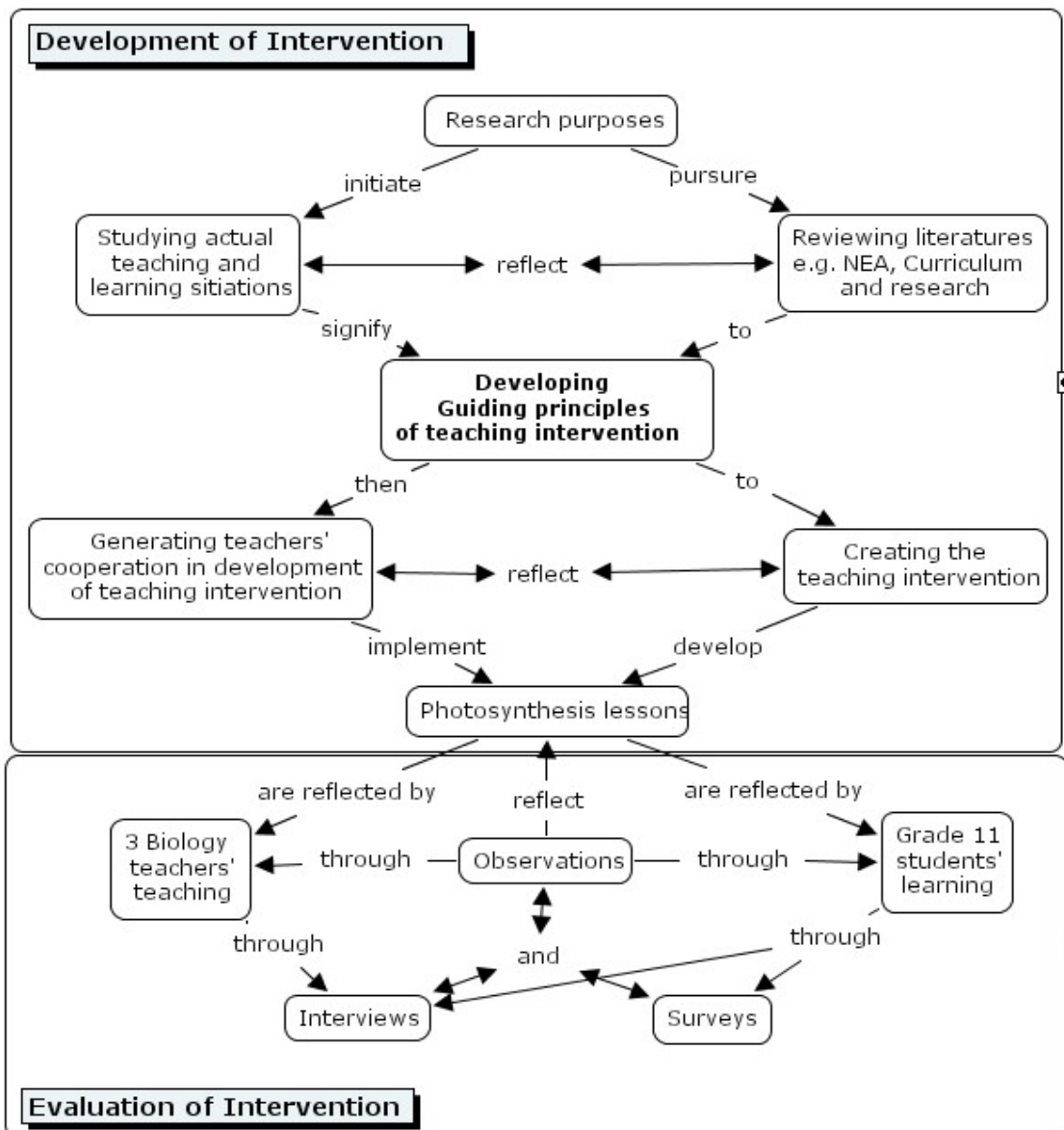


Figure 3.1 Research Design of the Teaching Intervention

The teaching intervention was developed through the prior study in 2002, analysis of the National Education Act of 1999, the National Science Curriculum (IPST, 2002), and the relevant literature discussed in Chapter 2. The analyzed information provided guiding principles for the developed intervention i.e. photosynthesis lessons. There were seven photosynthesis lessons developed with the cooperation of biology teachers who were going to implement the lessons. These lessons were used to teach three classes of Grade 11 students, for twelve 50-minute

teaching periods, covering a total of four weeks. The students were taught three periods per week.

The evaluation used three case studies which were concerned with one classroom in each of three schools. The researcher plays a role as a facilitator who cooperatively encourages practitioners i.e. three biology teachers trialing the new photosynthesis lessons to reflect on their own actions i.e. their teaching.

The impact of the photosynthesis lessons was monitored with observations, pre-and post-surveys, and interviews. The biology teachers and the Grade 11 students were observed during every teaching period. The three biology teachers were interviewed informally to reflect their own teaching after each observation. Pre- and post- surveys including unstructured interviews were used to review the students' understanding of photosynthesis. After the students responded completely, four students in each class, they were a total of twelve students in this research, were purposively selected to probe their understandings through the interviews.

The next section described the biology teachers and Grade 11 students as subjects in all three case studies.

Subjects

This study was conducted in the second semester of the 2004 academic year. The subjects consisted of three biology teachers and 118 students at the three public high schools in the Bangkok suburban area. The schools had student-teacher training in cooperation with the Faculty of Education, Kasetsart University, Bangkok, Thailand. School administration was organized to know the subject information and then selected the subjects using the following processes.

1. Informal interviews with the teachers indicated the interest of teaching development in biology education and the teacher background. The interest was a priority which had brought the three teachers to be selected. Then, the background

was considered to differentiate their teaching contexts from each other. For this study their pseudo-names were Mrs. Engka, Mr. Vyn and Mrs. Amp.

2. This study formally invited the teachers by asking the school head master. The school saves permission for the teachers to participate in the data collection processes.

3. The teachers' classrooms were approached to introduce the research study for the teachers' students and to make the students were familiar in the data collection processes, such as classroom observation and interviews.

4. Finally, the students' information was collected with their consideration. Four students from each teacher were purposively selected to be studied in depth. The selection was based on the gender, age, biology achievement, attitude towards biology and their family. Table 3.1 overviews the subjects of this study.

Table 3.1 Biology Teacher and Grade 11 Student Subjects in Three Case Studies

| Cases | Teachers | Students (total number of students) |
|----------------|------------|--|
| Border School | Mrs. Engka | S01, S02, S03, S04 and students in class. (41) |
| Market School | Mr. Vyn | S05, S06, S07, S08 and students in class. (40) |
| Babysat School | Mrs. Amp | S09, S10, S11, S12 and students in class. (37) |

Developing Photosynthesis Teaching Intervention

There was the photosynthesis teaching unit that was designed to provide the course descriptions, the unit objectives, the lists of concept proposition, the concept map, the lists of skills and attitude and the teaching sequence. The teaching unit was comprised seven lessons, detailed periods, behavioral objectives, concepts, learning activity, and materials and evaluation.

1. Developing Photosynthesis Lessons

These lessons were developed to enhance Grade 11 students' learning about photosynthesis. The analysis of the National Education Act of 1999, the National Science Curriculum (IPST, 2002) and the relevant literature, including a prior study of 2002 (Kijkuakul and Yutakom, 2004) provided the guiding principles to develop photosynthesis lessons for the intervention.

Then, the scope and sequence of the contents in each learning unit was organized. The teaching and learning activities, teaching materials and assessment were designed to facilitate individualized learning, such as hands-on/minds on activities, laboratory experiments, discussion, negotiation, problem solving, and teacher/student demonstration.

The photosynthesis lessons, then, were validated by the experts including four science educators and two scientists. In addition, these lessons were piloted with a group of the 11th grade students at a high school in cooperation with the Faculty of Education, Kasetsart University, in the first semester of the 2004 academic year. Later, the lessons were revised.

Finally, the biology teachers who would implement the photosynthesis lessons were invited to collaborate in revising these lessons. Their teaching contexts i.e. teaching and learning culture in the classroom were mainly recognized for the revision.

2. Implementing Photosynthesis Lessons

To support their effective implementation in the classroom, it was necessary for teachers to understand the theoretical background in the development of photosynthesis lessons. Teacher training for this understanding and suggestions for an understanding of the teachers' roles in the classroom were part of this study.

2.1) Teacher Preparation for Implementing Intervention

This concerns the development of teachers' profession, society, and personality (Bell and Gilbert, 1996; Bell, 1998; Marx *et al.*, 1998). A teacher should not only thoroughly understand the new teaching or learning activities integrated in the new intervention, but they should also be aware of how to share their views of how to be a biology teacher – this would change a teacher's beliefs about the relationship between the teacher and students. In addition, they should be aware of and accept the need for their professional growth. In this study, encouraging a teacher to reflect on these three developments was necessary in implementing the photosynthesis lessons. The approach for this training was that:

1. presenting teachers with empirical data of their students' conceptions about introductory photosynthesis,
2. giving teachers opportunities to think of their self-identity as a teacher of biology, how children construct knowledge – they construct by personal and social transformation, and their emotion when they have to do some thing new or different from what they are used to,
3. leading teachers to analyze the biology education goals based on the National Education Act of 1999 and the National Science Curriculum (IPST, 2002). This is for sharing ideas on how to enable students to achieve the goals and reconstructing the teacher's ideas about being a biology teacher and learning for students,
4. introducing information on the guiding principles, the structures, the application of the teaching intervention i.e. photosynthesis lessons. The teachers were then given opportunities to discuss these ideas and new teaching strategies,
5. helping teachers to plan and manage the photosynthesis lessons in relation to their situations e.g. student learning, culture and school policy. The

planning would support teachers' thorough understanding of the guiding principles and that of integrating new teaching strategies with teaching and learning activities,

6. encouraging teachers to think of a way to reflect their own teaching which would lead to improvement in their students' learning,

7. encouraging teachers to share their ideas in developing the intervention.

2.2) Teachers' Roles

Using socio-cultural perspectives that social interactions in the classroom are very important to support students' learning (Sawyer, 2004). Consideration of management for the interaction process, and the relationship between teacher and student and among peers were part of the implementation of the photosynthesis lessons. In implementing the lessons, each teacher had three roles:

1. considering how student groups learn and develop their conceptions, and trying to encourage students to learn as a whole group, not just as individual participants,

2. also facilitating group conversations or discussions that give students freedom to creatively express their ideas for the construction of their own knowledge, rather than asking known-answer questions and calling on specific students,

3. along with facilitating a collaborative management of discussion among students in whole class whenever different answers are proposed throughout the discussion, does not evaluate any given answer, but keeps the flow of the discussion.

3. Evaluating Impacts of Photosynthesis Lessons

3.1) Students' Understandings of Photosynthesis

The photosynthesis lessons and the teaching intervention were developed to enhance Grade 11 students' understanding of photosynthesis. Thus investigating students' development of photosynthesis conceptions was necessary in order to evaluate the impact of this intervention. During this study, both quantitative and qualitative methods were used for evaluation. Comparing students' understanding of each photosynthesis conception was illustrated through a specially designed pencil-and-paper pre-survey, taken two months before the intervention, and another post-survey administered one week after the intervention. The students' understanding of photosynthesis, the relationships between photosynthesis and environment and the nature of science were probed using the two surveys and interviews.

3.2) Teachers' Reflection to Their Teaching

This reflection concerns teachers' thinking about teaching practice and ideas while implementing an intervention. The reflection would help their professional, social and personal development. They would modify the ideas and beliefs about their teacher being, teaching of biology, learning, nature of science, their actions and roles in the classroom. The modification leads to student improvement in learning (Bell and Gilbert, 1996). In this study, the teachers' reflection was considered as an evaluation of the impact of the teaching intervention. An informal interview was used to capture the reflection.

Instruments

Surveys, interviews and observations were designed to evaluate the impact of the teaching intervention as follows.

1. Surveys

A survey study in terms of descriptive research is an explanation of the relationships among variables in a current situation and of the chronological changes happening in those relationships (Cohen, Manion, and Morrison, 2000). The survey could be furthered with large sample scales using simple or complex data-collecting techniques. In this study, surveys were chosen for research purposes which aimed to interpret students' prior/pre and post understandings about photosynthesis concepts, relationship between photosynthesis and the environment, the nature of science, and learning before and after implementation of the teaching intervention. The surveys that comprised multiple choices, open ended questions and explanation, could provide qualitative details of the understandings. Two special designed pre-and post-surveys were developed. For this research, the pre-survey used before and the post-survey used after the implementation were called the Introductory Photosynthesis Survey (IPS) and the Advanced Photosynthesis Survey (APS) respectively.

1.1) Introductory Photosynthesis Survey (IPS)

The survey was specially designed to investigate the eleventh grade students understanding of scientists' ideas in science. Here IPS was used prior to the implementation of the intervention. Developmental process is showed below.

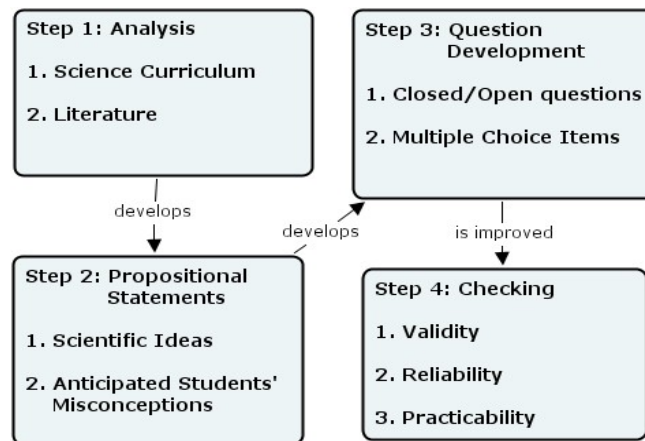


Figure 3.2 Survey Developmental Processes

There were four steps of the survey developmental processes.

1. It started with analyzing the goals of the Thai national science curriculum.
2. Identifying its propositional knowledge statements i.e. scientific ideas. The literature on students' learning about photosynthesis was reviewed; in particular the student misconceptions about photosynthesis were investigated to help to fulfill the statements.
3. The scientific statements were used to design the questions, and the anticipated students' misconceptions were used to develop multiple choice items of the questions. The concepts of chlorophylls, plant materials, plant food and energy, plant and light energy; simple photosynthesis process, and the relationship between photosynthesis and the environment (discussed in Chapter 2: Research into Student Learning about Photosynthesis) were included in this IPS. Also, the students' understandings of the ideas *about* science, i.e. the nature of science, specifically science as social enterprise were investigated (discussed in Chapter 2: The Nature of Science for Teaching and Learning about Photosynthesis). The survey contained both five closed and five open questions. The closed questions included multiple choice items with space given for their personal explanation of the selection. Basing on a

socio-cultural perspective (discussed in Chapter 2: Socio-cultural Influences on Teaching and Learning about Photosynthesis), student's information concerning themselves, their parents and the culture, they were also asked to identify their dependability in the culture. Table 3.2 shows correlation between introductory photosynthesis concepts and scientific statements.

4. The questions were checked for validity, reliability and practicability by co-operative experts from New Zealand and Thailand including three science educators, a secondary science teacher, and four scientists. Both Thai and English copies of the questions were produced for expert checking. Then, the questions were piloted by 34 tenth grade Bangkok area students. These students were selected on the basis of their school's cooperation with the Kasetsart University student teacher training program of the Faculty of Education. Finally, the questions were revised and used with the subject students.

Table 3.2 The Propositional Statements of the Introductory Photosynthesis Concepts

| Concepts | Propositional Statements |
|--|--|
| 1. Roles of Chlorophylls | Chlorophylls are used to make food. |
| 2. Plant Food | Carbohydrate is the food of plants. It provides energy for plant growth. |
| 3. Plant Materials | H ₂ O is required for plants' making food. CO ₂ is the major raw material plants use to make food. |
| 4. Plant and Light Energy | Light supplies energy for the photosynthesis. |
| 5. Simple Photosynthesis Equation | $\text{CO}_2 + \text{H}_2\text{O} \xrightarrow[\text{Light energy}]{\text{chlorophylls}} \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2$ |
| 6. Relationship between Photosynthesis and Environment | Photosynthesis reduces air pollution by increasing O ₂ and decreasing CO ₂ in the atmosphere. |
| 7. Nature of Science | Scientific ideas are subjected to change. Science demands evidence. Science is a complex social activity. |

1.2) Advanced Photosynthesis Survey (APS)

The survey was designed to investigate the eleventh grade students understanding and knowledge of photosynthesis after the implementation of the photosynthesis teaching intervention. The knowledge includes the concepts of pigments, light dependent reaction, light independent (dark) reaction, necessary factors of photosynthesis rate, the nature of science, and the relationship between photosynthesis and the environment (Table 3.3). The survey contains seven closed and eight open questions. The closed questions include multiple choice items with space given for their personal explanations of the selection. Development process of this survey is similar to the process of IPS.

Table 3.3 The Propositional Statements of the Advanced Photosynthesis Concepts

| Concepts | Propositional Statements |
|--|--|
| 1. Structures and Functions of Chloroplasts | Photosynthesis reactions takes place in chloroplasts which have pigments to be able to absorb the light energy. |
| 2. Light Dependent (light) Phase | Light energy absorbs and oxidizes H ₂ O to provide the primary electron and release O ₂ . |
| 3. Light Independent (dark) Phase | CO ₂ is fixed to produce carbohydrate which is the plant food. After the light reaction happen, the dark reaction can then happen without light energy. |
| 4. Necessary Factors Affecting Photosynthesis Rate | Humidity, light intensity, CO ₂ concentration, and numbers of leaves affect the photosynthesis rate. |
| 6. Relationship between Photosynthesis and Environment | Plant tissue difference affect CO ₂ fixation. Photosynthesis uses CO ₂ in atmosphere. It reduces green house affect. |
| 7. Nature of Science | Scientific ideas are subjected to change. Science demands evidence. Science is a complex social activity. |

Additional instruments and methods used to evaluate the impact of the teaching intervention were interviews and observations. Student interviews were used to gain more in-dept responses of the students' photosynthesis understanding, and

teacher interviews were used to illustrate teachers' ideas and emotions about the teaching in classroom. Observations were used to increase trustworthiness of the interview data showing disagreement to interviewing.

2. Interviews

An interview is a form of verbal questioning (Sarantakos, 1993). It could be considered as a purposed conversation (Lincoln and Guba, 1985). The interview provides external information of what people, interviewees, are thinking internally. Within a particular situation, the bias interviewing which is happening might be recognized and then controlled immediately (Cohen, Manion, and Morrison, 2000). There are many types of interviews based on the structure, purpose, and role of the interviewer e.g. unstructured, standardized, individual interviews.

In this study, the individual interview was chosen for students and teachers. The students' understandings of photosynthesis were questioned based on how they responded in the IPS and the APS. The teachers' reflection of their teaching intervention was the basis of their individual interviews. The unstructured interview was also chosen to combine with the individual interview for this study. Sarantakos (1993) suggested that the unstructured interview could provide qualitative data. The interview is conducted flexibly on the basis of certain research points i.e. the students' responses on the surveys. The researcher could ask a respondent, i.e. the teacher, direct or indirect questions (Sarantakos, 1993; Denscombe, 1998). In conclusion, one person was the respondent of the interview. They would be asked to grasping their ideas and emotions, and guiding how to implement the intervention through the interview. Also, sensitive asking and active listening according to the researcher's understandings of what was important to know about the situation and their experiences of people in that situation, should be needed for the interviews (Maykut and Morehouse, 1994).

These are the important ideas of developing interviewing tasks (Kahn and Cannell, 1983; Moser and Kalton, 1983 cited in May, 2001: 128-129):

1. *accessibility* – is enabling the interviewee to understand what the interviewer would like to ask, e.g. the questions which may need clarification,

2. *cognition* – is providing the interviewee with an understanding of what is expected of them in the role of interviewee i.e. ethical and theoretical consideration is needed during the interview,

3. *motivation* – is making the interviewee feel confident while being interviewed e.g. keeping the interviewer's interest on the answers and considering their action during the interviewing process are needed to gain confidence.

Relaxing and welcoming to listen to the interviewee's responses was also needed for interviewing although the interviewees sometimes did not directly reflect the interviewer's questions (Fontana and Frey, 1998). The listening helps maintaining the relationship between the interviewee and the interviewer. The interviewer then conducted new interviewing for receiving directive data.

In this study, it is possible that interviewee i.e. the teacher would ask or say something else e.g. consulting about the teaching implementation or not reflecting their teaching of the teaching intervention, so separating time between the consultation and the reflection was a concern during the conducted interviews.

3. Observations

Observation provides a chance to see what is going on independently in real situations. Other useful information unfortunately ignored from a data-collecting plan may be discovered with the observation (Patton, 1990). Also, it enables the researcher to understand environment, the interaction between teachers and students, and between students and students, and the pedagogical approach taken in the classroom, while the researcher is being a participant observer who hopes to unfold the complex story of the participants. The three styles of observation include

structured, semi-structured, and unstructured observations. Structured observation emphasizes testing a hypothesis, but the others emphasize generating hypotheses.

In this study, which needed an explanation of classroom situations rather than a decision whether or not the classrooms' organization was good, the semi-structured and unstructured observations were used. Field notes were used in the classroom to record situations of teaching and learning in each observation. The observational protocol consisted of four columns including time, a number for each new phase of the activity, descriptive notes, and comments. The time column was concerned with how long the classroom activities and interaction take. The descriptive notes described what was going on in the classroom i.e. activity, conversation, and other relevant information during the implementation of the teaching intervention. The comment column involved reflections about the situation – teachers, students, teaching, learning tasks and activities. This comment was noted while the researcher was observing the situations.

4. Validity, Reliability and Triangulation

In quantitative research, the worth of the research must be considered in terms of validity and reliability (Cohen, Manion, and Morrison, 2000). Validity represents which fact an instrument is supposed to measure. Reliability involves the ability of the instrument to produce consistent findings. In qualitative research, however, accomplishing validity and reliability is "...not through manipulation of variables, but rather through [the researcher's] orientation towards, and the study of, the empirical world" (Sarantakos, 1993: 76). Credibility and dependability are suggested as alternatives for those two terms respectively (Lincoln and Guba, 1985).

Credibility concerns the attempt to present several interested realities being focused on in the study. Lincoln and Guba (1985) suggest prolonged engagement, persistent observation, triangulation, and member checks as some techniques to increase the credibility. In this study, the engagement was produced by becoming more familiar with natural settings and participants in the classroom before

implementation of the teaching intervention. Good relationship building with these participants enabled them to put trust in the researcher. This trust in turn helped the researcher to identify unrepresentative information. Each classroom implementation was observed persistently. This observation allowed the interpretation of key elements of the data. Method triangulation was also used to collect qualitative data in this study. The eleventh grade students' understanding of photosynthesis was collected through the designed surveys and also collected through interviews and observations. The teachers' reflection of teaching implementation collected through interviews was also complied through the observations (see Figure 3.1, Evaluation). Finally, member checking involved critiques of the collected data by other people who participate in the studied situation. This checking helps the researcher to have less bias in the data and have a clearer view on reality of the data.

Dependability concerns interpretations of human behavior, but not forming a rule of the behavior. Dependability also needs clear descriptions of research methods used to collect data, and clear descriptions of studied contexts. Merriam (1988) suggested that a full description of the theory behind the study and the use of method triangulation of collecting and analyzing data could increase the dependability. This study which did not plan to gather the respective data, would attempt to fully describe the theory behind the study i.e. the six guiding principles of the developed teaching intervention as the basis for selecting participants, and the socio-cultural contexts of the collected data.

Transferability and confirmability are additional issues for the worth of research. The transferability concerns generalizability, application of the research findings in new studied situations. In the case of qualitative research, Lincoln and Guba (1985) suggested that providing more description about people was needed significantly to generalize the finding in others. Generalizability has become transferability which the readers have to consider the findings for their own context, not the researcher. In this study a description of students, teachers and school contexts, and that of collecting data were included to help the reader with transferability.

Confirmability concerns the power of a researcher describing the collected data. Even the researchers act as an instrument e.g. an observer and an interviewer, but they could not be defined absolutely as an object. They work with feeling and emotion. To increase confirmability, illustrations of clear data findings help the reader to understand the possible power of the researcher (Lincoln and Guba, 1985).

Data Collection

1. Surveys: IPS and APS

The Introductory Photosynthesis Survey (IPS) with ten questions was designed to investigate the students' prior understandings of photosynthesis. It was administered at each biology class of three schools i.e. Border, Market, and Babysat schools in the two month before the November – December 2004 implementation of the teaching intervention. A 50-minute-teaching period was used for the survey. The students' understandings were analyzed and used to select some of the students for interviews. There were twelve students (S01 – S12) invited for interviews two weeks later to triangulation the responses. The selection was based on students' answers in the survey, their interest in this study, on their personal information about the gender, the learning ability, the attitude towards science, and on their family background.

Then all students in each class were asked to respond to the Advanced Photosynthesis Survey (APS) or the post-survey, in December 2004, after the unit. All of the students received the 50-minute responding time, and the twelve students (S01 – S12) were interviewed again after the survey.

The data collection program including the survey is shown in Table 3.4.

Table 3.4 Data Collection Program

| School | Week | Aug-04 | | | | Sep-04 | | | | Oct-04 | | | | Nov-04 | | | | Dec-04 | | | | Jan-05 | | | | | | |
|-----------------------------|------|--------|---|---|---|--------|---|---|---|--------|----|----|----|--------|----|----|----|--------|----|----|----|--------|----|----|----|----|----|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | |
| 1 Border (Mrs.Engka) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| a. Pre-survey (IPS) | | ↔ | | | | | | | | | | | | | | | | | | | | | | | | | | |
| b. Pre-interviews | | | | | | | ↔ | | | | | | | | | | | | | | | | | | | | | |
| c. Teacher cooperation | | | | | | ↔ | | | | ↔ | | | | ↔ | | | | | | ↔ | | | | | | | | |
| d. Intervention | | | | | | | | | | | | | ↔ | ↔ | ↔ | ↔ | | | | | | | | | | | | |
| e. Observations | | | | | | | | | | | | | ↔ | ↔ | ↔ | ↔ | | | | | | | | | | | | |
| f. Teacher interviews | | | | | | | | | | | | | ↔ | ↔ | ↔ | ↔ | ↔ | | | | | | | | | | | |
| g. Post-survey (APS) | | | | | | | | | | | | | | | | | | | | ↔ | | | | | | | | |
| h. Post-interviews | | | | | | | | | | | | | | | | | | | | | | | | | | | | ↔ |
| 2 Market (Mr.Vyn) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| a. Pre-survey (IPS) | | ↔ | | | | | | | | | | | | | | | | | | | | | | | | | | |
| b. Pre-interviews | | | | | ↔ | | | | | | | | | | | | | | | | | | | | | | | |
| c. Teacher cooperation | | | | | | ↔ | | | | ↔ | | | | ↔ | | | | | | ↔ | | | | | | | | |
| d. Intervention | | | | | | | | | | | | | ↔ | ↔ | ↔ | | | | ↔ | | | | | | | | | |
| e. Observations | | | | | | | | | | | | | ↔ | ↔ | ↔ | | | | ↔ | | | | | | | | | |
| f. Teacher interviews | | | | | | | | | | | | | ↔ | ↔ | ↔ | | | ↔ | ↔ | | | | | | | | | |
| g. Post-survey (APS) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| h. Post-interviews | | | | | | | | | | | | | | | | | | | | | ↔ | | | | | | | ↔ |
| 3 Babasat (Mrs.Amp) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| a. Pre-survey (IPS) | | | ↔ | | | | | | | | | | | | | | | | | | | | | | | | | |
| b. Pre-interviews | | | | | ↔ | | | | | | | | | | | | | | | | | | | | | | | |
| c. Teacher cooperation | | | | | | ↔ | | | | ↔ | | | | ↔ | | | | | | ↔ | | | | | | | | |
| d. Intervention | | | | | | | | | | | | | ↔ | ↔ | | | | | ↔ | ↔ | | | | | | | | |
| e. Observations | | | | | | | | | | | | | ↔ | ↔ | | | | | ↔ | ↔ | | | | | | | | |
| f. Teacher interviews | | | | | | | | | | | | | ↔ | ↔ | | | | ↔ | ↔ | | | | | | | | | |
| g. Post-survey (APS) | | | | | | | | | | | | | | | | | | | | | | | | | | ↔ | | |
| h. Post-interviews | | | | | | | | | | | | | | | | | | | | | | | | | | | | ↔ |

2. Interviews: Audio Tape Recording

The twelve students ($S_1 - S_{12}$) were interviewed after their complete responding on the pre-survey (IPS) and the post-survey (APS) respectively (Table 3.4). Suitable out-of-class interview times for the students and the researcher were organized for the interview at their school. Before interviewing, the researcher discussed their roles and what was expected of them in this interview. Then the students' responses were recalled by their reading from what they had written in the survey. The students' responses to interview questions were transcribed and analyzed together with their responses in the survey.

The three biology teachers, Mrs. Amp, Mr. Vyn, and Mrs. Engka, were interviewed individually at the end of the observation to reflect their teaching as it concerned the impact of the intervention. In other words, the researcher conducted two interviews in each week, for five weeks, totaling 30 interviews. The suitable interview times were class-free times, lunchtimes, or after school. The semi-structured interviews conducted were audio taped and transcribed verbatim by the researcher and the transcript was given to the teachers for their approval.

3. Observations: Field Note and Video Recording

The three Grade 11 classrooms implementing the photosynthesis teaching intervention were observed for 5 weeks. The teachers were observed during their teaching period. Their photosynthesis lessons were taught twice a week, one in two 60-minute periods and another in one 60-minute period. There were, in total, 30 observational periods with the three teachers. The teaching and learning situations were recorded through field notes during the teaching periods. The focuses for the twelve students were: the discussion and negotiation of their ideas, for their accomplishments of learning tasks and everyday interactions with the teacher and others in a group and/or whole classroom along with the collaborative management of the discussions among the students. The focuses for the teachers were: their management of the classroom interaction process, and their relationship with their

students. The learning culture in the classroom was also described. Before and after each observation, the researcher had a conversation with the teacher and the students to build up good relationships and encourage.

Data Analysis

The impact of the teaching intervention was evaluated by the analysis of the data i.e. the eleventh grade students' understanding of photosynthesis and the teachers' reflection of their teaching. The data was collected, in the three cases i.e. Border, Market, and Babysat Schools, through the two surveys, called IPS and APS, the student and teacher interviews, and the classroom observations. In this study, each case study was analyzed. Then the three cases were cross-case analyzed to represent the whole results of this study. Figure 3.3 shows the framework of the data analysis.

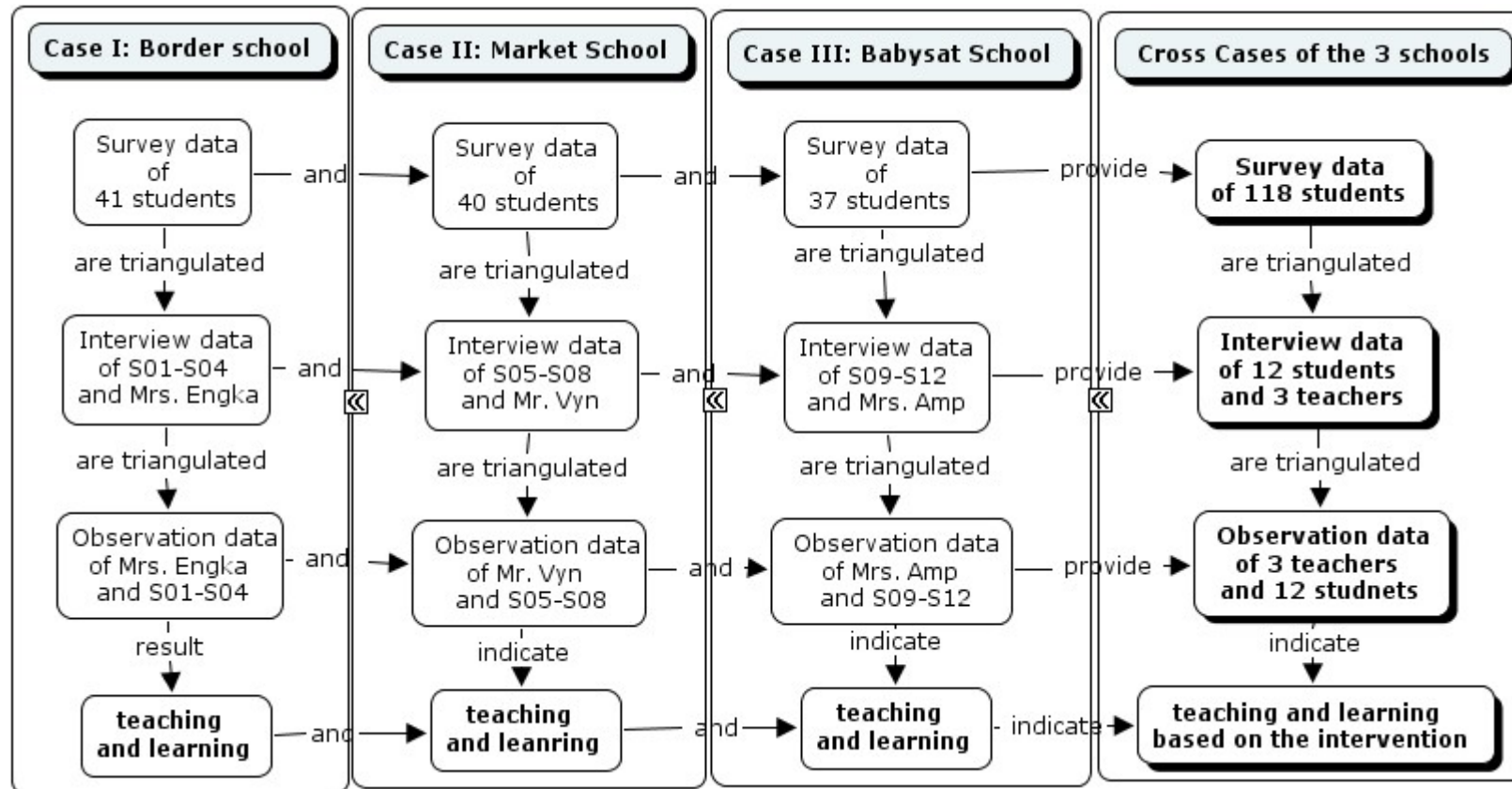


Figure 3.3 Three Cases Analysis and the Cross Case Study

1. Surveys: Content Analysis

Content analysis is the identification of people's communication which includes texts of books, transcripts of interviews and visual communication, through categorizing and coding (Patton, 1990; Sarantakos, 1993). In this study, content analysis was used to analyze the students' responses in the two surveys and interviews as reflection of the impact of the intervention. Categorization involves the selection and classification of the data appearing in the contexts i.e. the two surveys, IPS and APS. Goetz and LeCompte (1984) suggested that good categorizing recognized what the research would like to acquire as the research questions. Coding involves interpreting the categorized data and its frequency and then giving them a meaningful code such as a word, symbol, or character. Sarantakos (1993) suggested that good interpretation of the data depends on adequate skills and training of the researcher. In addition to the analysis, use of a cross-case study of participants or research methods in the same category (Glaser and Strauss, 1967), and member checking e.g. students and teachers (Lincoln and Guba, 1985) were suggested as techniques which might help the researcher establish a meaningful code.

The analysis of the students' written responses in the Introductory Photosynthesis Survey (IPS) and the Advanced Photosynthesis Survey (APS), began with 1) a description of student conceptions 2) categorization of the conceptions involved photosynthesis compared and contrasted with scientific conceptions 3) coding the conceptions by each photosynthesis topic e.g. roles of chlorophyll (see Table 3.2 and 3.3). The percentage of all class students' conceptions was calculated in the topic. There are five following categories of the students' conceptions.

1. Sound Understanding (SU) referred to the conceptions that fully/completely related to the scientific conceptions.

2. Partial Understanding (PU) referred to the conceptions that incompletely related to the scientific conceptions.

3. Partial Understanding with Misconceptions (PU+MU) referred to the conceptions related to the scientific conceptions but having some conceptions did not relate to the scientific conceptions.

4. Misunderstanding (MU) referred to the conceptions did not relate to the scientific conceptions.

5. In case of students who did not write their response on the survey, they were categorized in “No Answer” (NO).

In the case study analysis, the twelve student responses relating to each topic were read and interpreted in dependently. For example, the students’ responses to the IPS question number 1 and 4 were considered for individually determining what the students understood in the idea of chlorophyll. The responses were then interpreted, categorized, coded in a word and calculated for their frequency. Each category was described and concluded to evaluate what students understood before they came to study. The students were then interviewed and monitored in the observation for an in-depth case study of the development of their understanding of the advanced photosynthesis knowledge taught by their teacher who was implementing the intervention in their school.

2. Interviews: Transcribing and Interpretation and Trustworthiness

The student interviews of the understandings of photosynthesis were transcribed verbatim. Transcripts were checked by the researcher listening to the audio recording. The data was then analyzed thematically, after the survey responses. The important words or sentences were selected, highlighted and interpreted. Their personal understandings in each idea were described within case and cross case (Figure 3.3).

Teacher interviews as a basis of the teaching reflection were transcribed verbatim. The transcripts were revised by the researcher listening to the recordings.

They were confirmed by the teachers. The useful data of transcript were selected, quoted and acknowledged to support the findings of this study.

Trustworthiness is the level of honesty which the researcher provides to the readers encouraging them to agree with the research findings (Lincoln and Guba, 1985). The trustworthiness is increased by enhancing credibility, dependability and transferability (discussed in section of Validity, Reliability and Triangulation). In the case of interview, this study used method triangulation, member checking and thick descriptions increase the trustworthiness. The interview data also followed up the survey and the observational data.

3. Observations: Interpretation, Reporting and Ethical Consideration

The observational data collected was written into a readable form with time, descriptive, and comment columns. Whole reading of the three columns was used to establish the beginning ideas, questions and ideas about which data was useful for this study. Coding based on the researcher's interpretation of the teaching and learning situations was used to identify the key elements of the situations. An additional column of the analysis was generated to describe what the researcher thought of the coded situations in each study i.e. the three case studies, and then described the analysis of each case study.

After providing the three case descriptions, a cross-case study was initiated to find out the patterns of implementation of the intervention i.e. the lessons and what the impacts of the intervention towards the eleventh grade students' understandings of photosynthesis are (Figure 3.3).

Summary

Research methods were designed to respond to the research questions which were proposed to develop the teaching intervention and enhance the eleventh grade students' understanding of photosynthesis and evaluation of the impact of this

intervention. In the developmental process, the National Education Act, the National Science Curriculum and the relevant literature were analyzed to establish the guiding principles of the intervention. Then, the photosynthesis lessons were developed.

In evaluation process the following instruments were established in relation to the principles. First, the pre-and post- surveys were established and used to investigate the students' understanding about photosynthesis. The pre-survey, called IPS, was administered in three suburban schools in Bangkok, two months before implementation of the intervention while the post-survey, called APS, was administered one week after the implementation was finished. Second, the interviews were used to probe the students' ideas about photosynthesis. The pre-interviews were conducted two weeks after responding to the IPS survey, and the post-interviews were conducted one week after responding to the APS survey. The interview data was used to triangulate the survey data to get the students' understanding of photosynthesis. Teacher interviews were also conducted for the teachers' teaching reflection. They were interviewed at the end of their teaching period after every observation. Third, observations were used to collect data concerning actual teaching and learning practices in the three classrooms.

The data collected in these instruments were analyzed as a case study of each classroom i.e. three case studies. The students' understanding was categorized into five groups including SU, PU, PU+MU, MU and NO, and calculated the frequency showing the percentage in each photosynthesis concept. Then the development of their understanding of photosynthesis was described. The teaching reflection was analyzed thematically to give key elements of the successes and problems of the implementation of the intervention. In addition, these three cases were cross analyzed to describe the pattern of the development, that of the implementation, the success and the problems of the teaching intervention.

This study next reveals the findings based on the data collection and analysis in the Chapter IV the Photosynthesis Teaching Intervention and the Chapter V Implementation and Impacts of Photosynthesis Teaching Intervention.

CHAPTER IV

THE PHOTOSYNTHESIS TEACHING INTERVENTION

This chapter details the photosynthesis teaching intervention. The six guiding principles of the photosynthesis teaching intervention have been described to scope way of teaching about photosynthesis. The principles concern 1) correcting Grade 11 students' misconception about introductory photosynthesis; 2) enhancing Grade 11 students understanding about advanced photosynthesis concepts; 3) integrating nature of science into photosynthesis using historical narratives to illuminate the nature of science; 4) enabling students to relate photosynthesis knowledge to conserve the environment; 5) having regard to culture and society as socio-cultural perspectives on teaching and learning; and 6) encouraging students to participate in learning activities. Also, this chapter illustrates the photosynthesis teaching unit. This includes course description, course objectives, list of concept proposition, concept map, science process skills, scientific attitude, and lesson plans.

1. **Six Guiding Principles of Photosynthesis Teaching Intervention**

Guiding principles of the new teaching intervention had been developed to describe what introductory photosynthesis should be explicated and corrected to enhance Grade 11 students' understanding about advanced photosynthesis. Integrating the nature of science into photosynthesis teaching and enabling students to apply photosynthesis to conserve environment were also described to recommend learning activities for better students' learning about photosynthesis. Thai culture and society of teaching and learning were regarded for teaching based on constructivist approach in Thailand. Finally, the principles suggested encouraging students' participation in activities to support implementing the teaching intervention in classroom.

3.1) Correcting Grade 11 Students' Misconception about Introductory Photosynthesis

This principle aimed to deal with the students' pre-existing misconceptions which might come from their ideas from school and their own culture. Students' misconceptions would be reviewed, outlined and focused on in planning the photosynthesis lessons.

Because literature in Chapter II indicated that most students held misconceptions about introductory photosynthesis concepts e.g. plant food, they would be elicited and corrected the misconceptions using think pair share, think pair square, concept mapping and the post-box method called "Circus of misconceptions (True or False)". Also, the students' misconceptions about chlorophyll, plant materials, plant food and energy, plant and light energy, and simple photosynthesis process would be also corrected. Then, questioning, classroom discussion and game would be used to correct the students' misconceptions about role of chlorophyll, chemical structure and oxidation-reduction. After that, the unit would gradually challenge the students to learn the advanced photosynthesis based on the National Science Curriculum (IPST, 2002).

3.2) Enhancing Grade 11 Students' Understandings about Advanced Photosynthesis Concepts

According to the National Science Curriculum (IPST, 2002), in particular the relevant science content standards, this study developed the advanced photosynthesis knowledge propositions as biology educational goals of Grade 11 photosynthesis learning. Then, this study organized the relevant contents including the role of chloroplasts, the light dependent (light) and the light independent (dark) phases and the factors affecting photosynthesis rate.

Teaching the advanced photosynthesis concepts started with cooperative learning and experimenting through paper-chromatography. Understanding about the

structures and functions of chloroplast was expected. Questioning, discussing and concept mapping would be used to enhance the understanding about the light dependent (light) phase. Then, the light independent (dark) phases would be taught through role play, collaboration, classroom discussion and concept mapping. Problem solving, experimentation and group work were additional teaching approaches expected to enhance the understanding about the factors affecting photosynthesis rate.

As important as the understanding of advanced photosynthesis concepts, the understanding of nature of science was valued in science education of Thailand. This study additionally finds the teaching strategy to illuminate the nature of science.

3.3) Integrating Nature of Science into Photosynthesis and Using Historical Narratives to Illuminate the Nature of Science Based on the National Science Curriculum (IPST, 2002)

The nature of science integrated into photosynthesis teaching was expected to enable students to value studying science, in particular photosynthesis, in classroom. The integration associated the nature of science, involved photosynthesis knowledge and based on the National Science Curriculum (IPST, 2002). This study, thus, would illuminate the nature of science in three aspects that scientific ideas are subjected to change; that science demands evidence; and that science is a complex social activity.

Barker (1997) and Allchin *et al.* (1999) suggested use of the narrative technique or story to enhance the understanding about the nature of science. The stories were anticipated to provide a cultural background of science. The background might let the students valuing the three aspects of science. Also, Lin and Chen (2002) suggested an emphasis on science as a social enterprise to promote the understanding.

Therefore, this study addressed the nature of science in the teaching unit. The three aspects of science was initially discussed through reading historical story and playing game. '*Scientific ideas are subjected to change*' was theoretically

presented as science was problematic issue. The scientists in the history needed to argue with others for using word 'Photosynthesis'. The students would then discuss and play game to identify those three aspects.

Also, the three aspects would be discussed along teaching based on the unit. The scientists' stories of discovering evidences about the light and dark phases were questioned, analyzed and discussed. The discussion focused on how the scientists had cooperatively worked to each other including scientists' social expirations, evaluations and constraints.

Practically, '*science demands evidence*' and '*science is a complex social activity*' were focused on using the experimentation, problem solving and science project. Perhaps, the experiment in plant leaves enabled students to understand how scientists practiced inquiry about pigments in chloroplast, and the problem solving in studying the photosynthetic factors enabled the students themselves to demonstrate an evidence of photosynthesis. Also, the students' cooperation on a science project would tell them on how the scientists had cooperatively worked to develop the knowledge in society.

Not only integrating the nature of science but also integrating environmental education in photosynthesis was an additional way of developing student learning about photosynthesis.

3.4) Enabling Students to Relate Photosynthesis Knowledge to Conserve the Environment

A major problem found in the prior study of 2002 (Kijkuakul, 2002; Kijkuakul and Yutakom, 2004) was that traditional teaching had never given students enough opportunity to discuss their ideas about the relationship between photosynthesis and environment. Carlsson (2002) and Ekborg (2003) indicated that the traditional teaching might prevent development of students' understanding about photosynthesis, and students' awareness of using science in classroom for their live.

Therefore, this study focused on using science project to enable the students relating photosynthesis knowledge to conserve the environment. The science project integrating the nature of science in Principle III was also used. The project could be collection and experiment, survey and report, poster/display, model and demonstration or research project. It would be called “A campaign for photosynthesis and environment” that would come up with basic information for developing the students’ environment e.g. water, air and plants of school, house or community. The students were anticipated to use the accepted scientific ideas about photosynthesis to solve their environmental problems such as waste water in the community.

Because the students lived in the community, this study also recognized socio-cultural influences in their learning about photosynthesis. Next principle suggested how to teach the students based on the influences.

3.5) Having Regard to Culture and Society as Socio-Cultural Perspectives on Teaching and Learning

This study held that the students learn by individual and social transformations. The students assuming role of student have been born and have lives outside the classroom, so they also assume roles of social, family, community and political aspects (Packer and Goicoechea, 2000). Learning was perceived as functioning of a good citizen in the classroom and the society (Cobb, 1994). The learning could be occurred everywhere every time in the classroom and the society. Teaching needed to regard the society and culture influencing the students’ learning in the classroom.

Because of Thai living style (Srivichit, 2004), young students are seriously taught to respect their teacher, who had higher authority in the classroom. Arguing the teacher’s ideas or comments in classroom discussion might worry them about showing what they really think about photosynthesis. Therefore, teaching has to emphasize developing good relationship between teacher and student, and student and student in classroom. The teachers would not refuse to the students’ argument.

On the other hand, the teachers must continuously encourage and facilitate the student's group discussion or classroom discussion and then flow the entire discussion. The students were expected to become a citizen of the classroom society. They would then feel free to argue with the teacher for their better learning.

Also, teaching should relate Thai views about plants (Chapter 2). Before the students would be received formal teaching, the students' views about plants must be investigated and developed. The students were expected to regenerate own ideas and then link the ideas to the new concepts in the classroom. Also, they would be promoted to use the new concepts to conserve their environment based on the natural resources and environmental policy of Thailand (Chapter 2).

The educational values of some Thai students indicated that formal education system is being changed by the private tutorial system (Buranakarn, 2003). Some students learn biology for particular taking of the National Entrance Examination without really understanding about photosynthesis. So, teaching must build up the positive attitude towards learning in the classroom by developing assessment. This would concern student achievement in both conception and participation in classroom activities. Biology is not only useful for the examination but also for the living in classroom society. Students' own evaluation of learning would be additionally integrated in the teaching.

According to Thai school society (Chapter 2), the teaching was loaded by the teacher's extra work such as head of science department or head of the Scout Association. The teaching also was substituted by the school events or activities such as sport day. As well as, the teaching was required to change emphasis from teacher-centre of learning to student-centre of learning (ONEC, 1999). Thus, this teaching unit needed to be developed by the teachers' cooperation. The teachers were expected to implement the unit suitably, for the students in the school and the classroom.

Due to emergence of this socio-cultural perspective from the constructivist perspective (discussed in Chapter II), transmission of teaching approach

from constructivism to socio0culturalism was needed in this study. The generative learning model of teaching (Osborne and Freyberg, 1985) would thus used to promote the classroom learning. There were the three main steps:

1. *Focus* phase involves probing student existing ideas and prior knowledge about introductory photosynthesis based on Principle I;
2. *Challenge* phase involves encouraging students to learn new ideas. These are the current scientific ideas about photosynthesis (Principle II) and the nature of science (Principle III);
3. *Application* phase involves supporting students to use the knowledge taught to explore and develop their ideas about photosynthesis. This involved enabling students to apply/relate photosynthesis knowledge to conserve environment as Principle IV.

To support the teaching based on the previous five principles, the students would be expected to dynamically participate in learning activities. The students might be required to radically change their learning to new ways in contrast with their old tradition.

3.6) Encouraging Students to Participate in Learning Activities

This principle aimed to encourage students to thinking what to do, inside and outside teaching period, other than passively listening to teacher's lecture. Hopefully, the students would form a meaningful learning style to participate in learning activities. According to the National Education Act of 1999, the students should have opportunities to:

1. have a direct relationship with nature and the environment from which they draw authentic experience;

2. realize their own aptitude and work in scientific methods;
3. carry out activities in which knowledge and experience of members of the group are exchanged;
4. practice analytical and logical thinking in several ways in which imagination and creativity play an important role;
5. receive encouragement and be supported in finding answers to questions and problem solving;
6. practice in research, data collecting and constructing knowledge themselves;
7. select activities in line with their capabilities, aptitude and interests, which are carried out with happiness;
8. develop self-discipline and work responsibly;
9. develop self-improvement and acceptance of others as well as the interest and enthusiasm to seek knowledge on a continuous basis.

Those six principles were used as main ideas to develop the new teaching intervention. There was the new photosynthesis teaching unit including seven lessons.

2. Photosynthesis Teaching Unit

The photosynthesis teaching unit is developed for teaching advanced biology in Level 4, Grades 10-12, based on the National Science Curriculum of Thailand. There are four science sub-strands being integrated in the teaching unit:-

Sub-stand 1: Living Things and Living Processes

Standard Sc 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.

Sub-stand 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-stand 3: Matters and Properties of Matters

Standard Sc 3.1: Understand that matter possesses its own individual structure and properties.

Standard Sc 3.2: Understand that matter goes through physical and chemical changes.

Sub-stand 8: Nature of Science and Technology

Standard Sc 8.1: Understand the nature of science and nature of technology and appreciate the interaction between science, technology and society.

The photosynthesis teaching unit comprises of the course descriptions, the course objectives, the lists of concept proposition, the concept map, and the science process skills, attitude towards science and photosynthesis lessons.

5.1) **Course Description**

This photosynthesis teaching unit comprises the seven lessons for twelve 50-min periods. The unit initiates correcting students' misconception about introductory photosynthesis including plant food, roles of chlorophyll, plant materials,

plant and light energy, and simple photosynthesis process. Then, the understanding about advanced photosynthesis concepts integrated with nature of science is challenged. The students experiment, analyze, investigate and discuss about structures and functions of chloroplasts, light dependent (light) and light independent (dark) phase, and necessary factors affecting photosynthesis rate. In addition, they are encouraged to apply the photosynthesis knowledge to explore and analyze the situation of environment problem at local areas, make a plan and practice cooperatively with community in conserving the environment and solving the problem.

5.2) Course Objectives

The students would be able to:

1. Understand the advanced photosynthesis concepts including structures and functions of chloroplasts, light dependent (light) and light independent (dark) phase, and necessary factors affecting photosynthesis rate.
2. Use the accepted scientific ideas about photosynthesis to solve their problems relating to the environmental issue in community.
3. Understand the three aspects of the nature of science including that scientific ideas are subject to change; that science demands evidence; and that science is a complex social activity.
4. Use the scientific process skills and scientific attitude in investigation and solve problems in everyday living.

5.3) Lists of Concept Proposition

a) Structures and functions of chloroplasts

- Chloroplasts have internal membranes known as thylakoids.
- The region of the chloroplast outside the thylakoids is called stroma.
- Stack of thylakoids are known as granum which tacking is absent is known as stroma thylakoid. Stack building is grana.
- The pigments are located in thylakoid membrane. The pigments are the site of the light dependent reactions of photosynthesis. They absorb light energy.
- All plants and most alga have chloroplast containing photosynthetic pigments—chlorophyll, carotenoids, and phycobiliprotein.
- Some bacteria and blue-green algae (Cyanobacteria) have no chloroplasts, but have photosynthetic pigments which can photosynthesize.
- Blue green algae have chlorophyll, carotenoids, and phycobiliprotein, while bacteria have bacteriochlorophylls and/or carotenoids.
- The reaction centre chlorophylls in Photosystem I (PS-I) absorbs far-red light of the maximum wavelengths 700 nm. This is called P 700.
- The reaction centre chlorophylls in photosystem II (PS-II) absorbs red light of the maximum wavelengths 680 nm. This is called P 680.

b) Light dependent (light) phase

- Light dependent reactions occur in thylakoid membrane when light energy excites specialized chlorophyll from the ground electronic state to an excited electronic state.
- Primary photochemical event is the transfer of an electron from the excited state of chlorophyll in the reaction centre to an acceptor molecule.

- The oxidized reaction centre of the chlorophyll, that had donated an electron, is reduced by a secondary donor, which in turn is reduced by a tertiary donor.
- The water (H_2O) is oxidized by light (photolysis) to oxygen. The oxidation of water as the primary source of electrons. Protons also are released in the lumen by PS-II.
- The primary electron and proton are transferred from chlorophyll of the PS-II to chlorophyll of the PS-I that had donated the electron. This is called non-cyclic electron transfer.
- The electron in PS-I is transferred through electron protein carriers, and return to PS-I again. This is called cyclic electron transfer.
- Then, ATP is released into the stroma by proton (H^+) moving from the lumen to stroma.
- In plant, water (H_2O) is the ultimate electron donor, and NADP^+ is the ultimate electron acceptor. Moving electrons, electron flow, to synthesize ATP is called Z scheme.
- PS-II oxidizes water, while PS-I reduces NADP^+ .
- NADP^+ is reduced to NADPH on the stromal side of the membrane via the action of ferredoxin (Fd) and the flavoprotein ferredoxin-NADP reductase (FP).
- All the electron carriers are known to function in electron flow from water (H_2O) to NADP^+ .
- PS-II produces an oxidant that can oxidize the cytochrom b6f complex.
- The transfer of electrons (e^-) and protons (H^+) in thylakoid membrane is carried out by protein complexes--PS-II, the cytochrom b6f, PS-I, and the ATP synthase.

c) **Light independent (dark) phase**

- The light independent reaction occurs in stroma, and is carbon dioxide fixation (called Calvin cycle).
- The Calvin cycle is fixing CO₂, and using ATP and NADPH generated by the light dependent reactions, to produce carbohydrate e.g. starch, sugar.
- The Calvin cycle proceeds in 3 stages: 1) carboxylation of CO₂ acceptor, 2) reduction of PGA and 3) regeneration of the CO₂ receptor.
- Firstly, CO₂ and H₂O from environment are enzymatically combined with a five-carbon acceptor molecule (RuBP).
- RuBP generates two molecules of a three-carbon intermediate (PGA).
- Secondly, the intermediate (PGA) is reduced to carbohydrate (PGAL), sugar, a six-carbon molecule, by use of the ATP and NADPH generated photochemically.
- Thirdly, the CO₂ acceptor (RuBP) is regenerated from PGAL.
- C₃ plants include alga and most advanced angiosperm that have only one CO₂ fixation in mesophyll.
- C₄ plants have bundle sheath cell containing chloroplasts. The C₄ plants thus fix CO₂ both in mesophyll and bundle sheath cell.
- In mesophyll, PEP, a three-carbon molecule, combines with CO₂ to generate a four-carbon molecule, OAA.
- OAA is converted to malic acid and then move to bundle sheath cell.
- In bundle sheath cell, malic acid is changed. CO₂ is released for the second of CO₂ fixation.

d) Necessary factors affecting photosynthesis rate

- Humidity, light intensity, CO₂ concentration, and numbers of leaves affect the photosynthesis rate.
- The rate of photosynthesis increases when light intensity increases.
- Photosynthesis is a constructive process which may lead to increase in weight.
- Too low temperature and carbon dioxide effect on photosynthetic rate.
- Light and light intensity effects on photosynthetic rate.
- Light intensity, carbon dioxide concentration, oxygen concentration, temperatures and numbers of stroma are limiting factors which affect the rate of photosynthesis
- Photosynthesis essentially decreases CO₂ in atmosphere causing the green house affect resulting in higher temperature of the earth.
- Plant photosynthesis releases O₂ for respiration of all oxygenic living things.
- Photosynthesis acts as an intermediary which changes light energy to chemical energy, in terms of food for every living thing.

5.4) Concept Map

Figure 4.1 shows the map of photosynthesis concepts in the teaching unit.

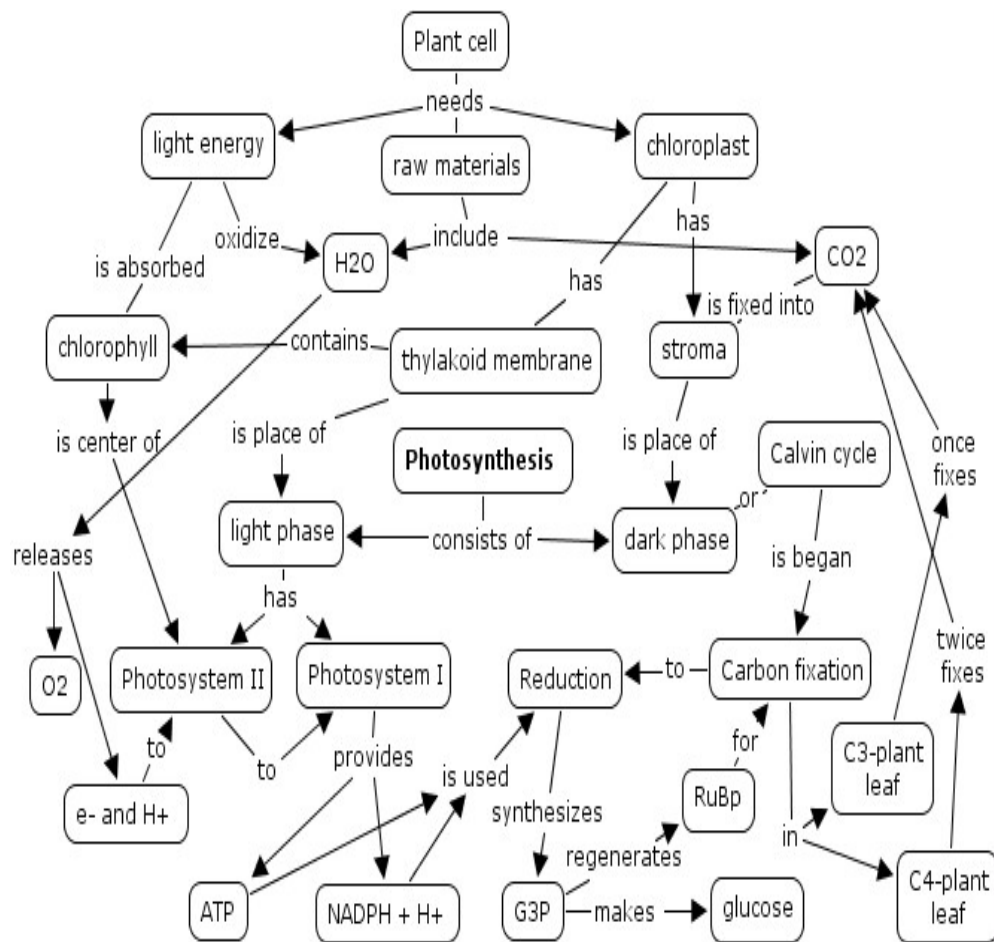


Figure 4.1 Photosynthesis Concept Map

5.5) Science Process Skills

The students would be able to:

1. ask questions based on the existing photosynthesis knowledge and understanding thoroughly and reliably,
2. experiment and interpret the results based on the paper-chromatography of the photosynthetic pigments of chloroplast,
3. state a hypothesis, design and conduct the experiment for their own demonstration of photosynthesis,

4. collect, record and explain the result of investigation reasonably,
5. exhibit result, writing report, and/or explain about concepts, processes, and result of scientific project or assignment to others.

5.6) Scientific Attitude

1. open mindedness in group discussion or classroom discussion, and accept that prior knowledge maybe changed when there are new added data and evidence,
2. have faith in developing the conceptions about photosynthesis, namely revising the concept mapping about light and dark phases,
3. have faith in problem solving and recognize self limitations,
4. be aware of the importance in involving students to take responsibility, explain, infer, and summaries science learning to present the public accurately.

5.7) Photosynthesis Lessons

There are the seven lesson plans including twelve 50-minute teaching periods. The seven lesson plans are called as following

- Plant food,
- The nature of science and historical ideas about photosynthesis,
- Structure and functions of chloroplasts,
- Light dependent (light) phase,
- Light independent (dark) phase,
- Students' own demonstration of photosynthesis, and
- A campaign: photosynthesis for environment

Lesson 1 '*Plant food*', aimed to elicit and to correct students' misconceptions about introductory photosynthesis. Through think/pair/share, students would pair up with someone sitting near them and verbally shared their answers "what is *plant food*?" in the worksheet. The students would then discuss "why do *plants make sugar*?" using the booklet. This was the mini-book illustrating the scientists' ideas about the concepts. Responding a question/a concept statement such as whether "*Light energy is plants' food.*" *Is true or not*, through the game: *Circus of misconceptions (True or False)* was designed for evaluating students' self concepts. The game was based on the post-box method. Ten introductory photosynthesis statements concerning chlorophylls, plant materials, plant food and energy, and plant and light energy stuck to the boxes around the classroom. There were some examples of the introductory photosynthesis statements:-

- Light energy is plants' food. (F)
- Photosynthesis is the production of energy. (F)
- Plant food is carbohydrate (T)
- Plants get food from water and nutrients in the soil. (F)
- Plants get food from CO₂ in the air. (F)

The students independently respond to the statement by putting their answer cards, **True** or **False**, in the boxes. The statement was then discussed in whole class. Teachers would randomly choose a few pairs to summarize the correct answers. Finally, the students would group their team including four students to do assignment. They would create the concept map to illustrate the understanding about plant food.

Lesson 2 '*The nature of science and historical ideas about photosynthesis*', this lesson aims to introduce the nature of science in the three aspects that scientific ideas are subjected to change; that science demands evidence; and that science is a complex social activity. The story of Charles Barnes who established the term 'Photosynthesis' was told, in the student booklet: *History of the word "Photosynthesis"*, to represent those three aspects. How scientists had worked to

develop photosynthesis knowledge would be emphasized in group and classroom discussion. The students were requested to answer all questions and play game in the booklet. The game presented thirteen historical statements of photosynthesis discovery. The students would categorize the statements into three aspects of science.

Lesson 3 '*Structures and functions of chloroplast*' aimed to introduce the importance of chloroplasts and photosynthetic pigments in photosynthesis, and to demonstrate how scientific knowledge had been established in the contexts of the scientists' society. Historical jigsaw game was used to introduce the chloroplast. Scientists' pictures and statements would be chosen and rearranged to complete all scientific ideas of simple photosynthesis process by the students. The historical discovery of T.W. Engelmann would present the scientist's data collection and interpretation of the chloroplasts and the pigments, in the student booklet: *Who had discovered the chloroplast?* Then, the students would be challenged to test pigments of green plant leaves using experimentation with discussion. The relationships between structures and functions of chloroplast would be summarized.

Lesson 4 '*Light dependent (light) phase*' aimed to illustrate historical change of scientific ideas of the light phase. Three pamphlets would tell the stories of Cornelius Van Neil, Daniel Arnon, and Robin Hill. The students would identify the products of the phase found by each scientist. The hypothesis, "whether free oxygen (O_2) came from water (H_2O) or not", was discussed using the story of Van Neil. Light phase centers and the synthesis of ATP were discussed using the story of Daniel Arnon. Water splitting, called photolysis and the Z-scheme producing NADPH was discussed using the story of Robin Hill. In addition, this lesson aimed to promote understanding of the current scientific view of the light phase (see Table 4.1). The students would interpret the diagram of electron flow in photosystems, describe the important roles of light, chlorophyll and water in the phase. Tenacity of working scientists would also be discussed. Group discussion and concept mapping would be used for the promotion of the scientific view.

Lesson 5 '*Light independent (dark) phase*' aimed to introduce changing the historical discovery of the dark phases and to promote an awareness of scientific knowledge as a complex social activity. The student booklet: *The Long journey of the dark phase* would display the stories of the American scientists. During 1937-1940, Samuel Ruben discovered radioactive carbon (C^{14}). In 1948, Andrew Benson and Melvin Calvin used the carbon for discovery of PGA in the C3 pathway of photosynthesis. In 1944, Constance Hartt alternatively discovered C4 pathway of photosynthesis. Also, the Asian scientist, Shinichi Kawaguchi, discovered enzyme phosphoenolpyruvate (PEP) carboxylase in the C-4 pathway. The booklet also emphasized the scientists' cooperation in developing knowledge of dark phase. Students' participation in the role play activity, called Act as scientists, was learning requirement. The students would be early asked to prepare the role play before the teaching period. They were expected to perform like they were the previous scientists who were working with each others in the society. In addition, the Lesson 5 aimed to promote understanding of the current scientific view of the dark phase process (see Table 4.1) through classroom discussion and concept mapping. The students could see the Calvin-Benson cycle in C3 and C4 plant leaf tissues presented in the multi-color transparencies. Classroom discussion would be launched. They would then map their conceptions about the dark phase. Their concept mapping would be assessed finally.

Lesson 6 '*Students' own demonstration of photosynthesis*' aimed to encourage students to be aware of using the accepted scientific ideas to solve a problem. The students would design and experiment for an evidence of photosynthesis, in particular the necessary factors affecting photosynthesis rate. Scientists' repeated experiments of light intensity, temperature affecting the production of oxygen in photosynthesis, and the requirement of light, carbon dioxide for photosynthesis were posed as the problem. The students would select, clarify and design the experiment in line with students' own capabilities, aptitude and interests based on the student booklet: *Experimentations of photosynthesis*, and the work sheet: *Experimental design*. The booklet showed demonstrating O_2 of photosynthesis; testing a leaf for sugar or starch; and requiring light and CO_2 for photosynthesis. The

work sheet illustrated blank blocks of group members, problems, theories, variables, chemicals, experimental process, results and discussion.

Lesson 7 '*A Campaign: photosynthesis for environment*' aimed to relate photosynthesis knowledge to conserve the students' environment using the science project. They would tell their personal stories about the environment and discuss what they found as the environmental issue of the family, school or community. Then, their group work would plan and design process of conserving the environment on the worksheet: *A campaign to conserve the environment by photosynthesis*. The worksheet showed blank blocks of group member, objectives, procedures, time and limitation. Then, the students proposed the worksheet for the teacher's approval. The students would operate their science project outside teaching periods and finally present the project for whole class discussion.

Consequently, Table 4.1 has summarized the seven lesson plans of the photosynthesis teaching unit. Each lesson plan displayed title and periods, learning outcomes, concepts, learning activity, and materials and assessment.

Table 4.1 Photosynthesis Lesson Plans

| Lesson | Periods (min) | Learning outcomes | Concepts | Learning Activities | Materials | Assessment |
|----------------|---------------|---|--|--|--|---|
| 1. Plant food. | 2 (100) | Students would be able to... 1. Elicit own existing ideas about plant food. 2. Develop the concept map about plant food. 3. Illustrate the ideas with each others. | 1. All organisms need to take food (matter containing nutrients) in order to respire, grow and reproduce. These nutrients are minerals, carbohydrates, proteins and fats. 2. Plants and some other organisms, such as algae, are able to use very simple molecules, like carbon dioxide and water, to produce their complex food materials through their photosynthesis process, which requires light energy especially from sunlight. 3. Plant cells have chloroplasts which contain chlorophylls. These green pigments, mostly located in the leaves and the stems, are the place of photosynthesis. 4. Food produced by the photosynthesis process is carbohydrate, in the form of sugar (glucose). Light energy, chlorophyll, and carbon dioxide, and water are necessary factors of the process. Water is absorbed through the roots. Carbon dioxide is taken in by the green leaf (or green stem) and then sugar and oxygen are produced during the photosynthesis. | 1. Think pair share 2. Think pair square 3. The post-box method called “circus of misconceptions (true or false)”. 4. Concept mapping | 1. The work sheet: <i>What is plant food?</i> 2. The student booklet: <i>Why do plants make sugar?</i> 3. The game: <i>the True or False</i> 4. The concept mapping | 1. Use the work sheet: <i>What is plant food?</i> to probe the students’ existing ideas. 2. Use the student booklet: <i>Why do plants make sugar?</i> to improve the students’ misconceptions. 3. Use <i>the True or False</i> for students’ own assessment of learning. 4. Use the concept mapping to evaluate development of the students’ learning. |

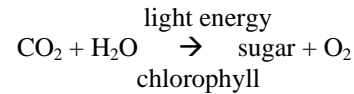


Table 4.1 Cont'd

| Lesson | Periods (min) | Learning outcomes | Concepts | Learning Activities | Materials | Assessment |
|--|---------------|--|---|--|--|--|
| | | | 5. The sugar molecules that are not used immediately form starch for storage in the plant cells. Starch is converted back to sugar to supply energy and materials for the plant's growth, etc. Starch shows yellow-brown colour when it is proved by iodine solution. | | | |
| 2. The nature of science and historical ideas of photo-synthesis | 0.5 (25) | Students would be able to... 1. Question about the nature of science. 2. Summarize how photosynthesis knowledge have been developed. 3. Give some examples representing the three aspects of the nature of science. | Three aspects of the nature of science 1. Scientific ideas are subject to change. 2. Science demands evidence. 3. Science is a complex social activity. | 1. Questioning 2. Story telling using the student booklet 3. Cooperative learning 4. Classroom discussion | 1. The student booklet: <i>History of word "photosynthesis"</i> 2. The work sheet: <i>Nature of science</i> | 1. Use the student booklet: <i>History of word "photosynthesis"</i> to probe the students' ideas about the nature of science. 2. Use the work sheet: <i>Nature of science</i> to evaluate the development of the students' ideas. |

Table 4.1 Cont'd

| Lesson | Periods (min) | Learning outcomes | Concepts | Learning Activities | Materials | Assessment |
|--|---------------|--|---|--|--|--|
| 3. Structure and functions of chloroplasts | 2 (100) | <ol style="list-style-type: none"> 1. Identify where photosynthesis take place. 2. Experiment to find out pigment taking place in plant leaves. 3. Interpret, analyze and describe the structure and function of chloroplast. 4. Give some examples of photosynthetic pigment 5. Explain how photosynthesis had been developed. | <ol style="list-style-type: none"> 1. Chloroplasts have internal membranes known as thylakoids. 2. The region of the chloroplast outside the thylakoids is called stroma. 3. Stack of thylakoids are known as granum which tacking is absent is known as stroma thylakoid. Stack building is grana. 4. The pigments are located in thylakoid membrane. The pigments are the site of the light dependent reactions of photosynthesis. They absorb light energy. 5. All plants and most alga have chloroplast containing photosynthetic pigments—chlorophyll, carotenoids, and phycobiliprotein. 6. Some bacteria and blue-green algae (Cyanobacteria) have no chloroplasts, but have photosynthetic pigments can photosynthesize. 7. Blue green algae have chlorophyll, caretenoids, and phycobiliprotein, while bacteria have bacteriochlorophylls and/or carotenoids. 8. The reaction centre chlorophylls in Photosystem I (PS-I) absorbs far-red light of the maximum wavelengths 700 nm. This is called P 700. 9. The reaction centre chlorophylls in photosystem II (PS-II) absorbs red light of the maximum wavelengths 680 nm. This is called P 680. | <ol style="list-style-type: none"> 1. Playing the game: Historical jigsaw 2. Cooperative learning using the student booklet 3. Story telling using the student booklet 4. Experimentation using paper-chromatography | <ol style="list-style-type: none"> 1. The game: Historical jigsaw 2. The student booklet: <i>Who had discovered the chloroplast?</i> 3. The lab direction: <i>Pigment</i> | <ol style="list-style-type: none"> 1. Use the game to probe the pre-conceptions about simple photosynthesis process. 2. Use the student booklet: <i>Who had discovered the chloroplast?</i> to discuss the importance of chloroplast 3. Use the lab direction: <i>Pigment</i> of the experimentation to discuss, practice and evaluate the students' conceptions about chloroplast. |

Table 4.1 Cont'd

| Lesson | Periods (min) | Learning outcomes | Concepts | Learning Activities | Materials | Assessment |
|----------------------------------|---------------|--|--|---|--|---|
| 4. Light dependent (light) phase | 1.5 (75) | Students would be able to... 1. Identify the products of the light phase. 2. Explain roles of light, pigment, water and electron transport system in the light phase. 3. Distinguish between the cyclic ETS and the non-cyclic ETS. 4. Tell the importance of changing development of the light phase. | 1. Light dependent reactions occur in thylakoid membrane when light energy excites specialized chlorophyll from the ground electronic state to an excited electronic state. 2. Primary photochemical event is the transfer of an electron from the excited state of chlorophyll in the reaction centre to an acceptor molecule. 3. The oxidized reaction centre of the chlorophyll, that had donated an electron, is reduced by a secondary donor, which in turn is reduced by a tertiary donor. 4. The water (H ₂ O) is oxidized by light (photolysis) to oxygen. The oxidation of water as the primary source of electrons. Protons also are released in the lumen by PS-II. 5. The primary electron and proton are transferred from chlorophyll of the PS-II to chlorophyll of the PS-I that had donated the electron. This is called non-cyclic electron transfer. 6. The electron in PS-I is transferred through electron protein carriers, and return to PS-I again. This is called cyclic electron transfer. 7. Then, ATP is released into the stroma by proton (H ⁺) moving from the lumen to stroma. 8. In plant, water (H ₂ O) is the ultimate electron donor, and NADP ⁺ is the ultimate electron acceptor. Moving electrons, electron flow, to synthesize ATP is called Z scheme. 9. PS-II oxidizes water, while PS-I reduces NADP ⁺ . | 1. Questioning 2. Cooperative learning 3. Story telling using pamphlet 4. Group discussion 5. Concept mapping | 1. The pamphlet: <i>Van Neil, Arnon and Hill</i> 2. The concept mapping | 1. Use the pamphlet: <i>Van Neil, Arnon and Hill</i> to probe the students' ideas about the light phase. 2. Use concept mapping to evaluate the students' conceptions about the light phase. |

Table 4.1 Cont'd

| Lesson | Periods (min) | Learning outcomes | Concepts | Learning Activities | Materials | Assessment |
|-----------------------------------|---------------|--|--|--|---|--|
| | | | <p>10.NADP+ is reduced to NADPH on the stromal side of the membrane via the action of ferredoxin (Fd) and the flavoprotein ferredoxin-NADP reductase (FP).</p> <p>11.All the electron carriers are known to function in electron flow from water (H₂O) to NADP+.</p> <p>12.PS-II produces an oxidant that can oxidize the cytochrom b6f complex.</p> <p>13.The transfer of electrons (e-) and protons (H+) in thylakoid membrane is carried out by protein complexes--PS-II, the cytochrom b6f, PS-I, and the ATP synthase.</p> | | | |
| 5. Light independent (dark) phase | 3 (150) | <p>Students would be able to...</p> <ol style="list-style-type: none"> 1. Explain how the scientists worked for photosynthesis. 2. Explain the process of the dark phase. 3. Distinguish between the dark phase of c3 plants and c4 plants. 4. Evaluate own learning about the dark phase. | <ol style="list-style-type: none"> 1. The light independent reaction occurs in stroma, and is carbon dioxide fixation (called Calvin cycle). 2. The Calvin cycle is fixing CO₂, and using ATP and NADPH generated by the light dependent reactions, to produce carbohydrate e.g. starch, sugar. 3. The Calvin cycle proceeds in 3 stages: 1) carboxylation of CO₂ acceptor, 2) reduction of PGA and 3) regeneration of the CO₂ receptor. 4. Firstly, CO₂ and H₂O from environment are enzymatically combined with a five-carbon acceptor molecule (RuBP). 5. RuBP generates two molecules of a three-carbon intermediate (PGA). 6. Secondly, the intermediate (PGA) is reduced to carbohydrate (PGAL), sugar, a six-carbon molecule, by use of the ATP and NADPH generated photochemically. | <ol style="list-style-type: none"> 1. Role play based on historical story 2. Cooperative learning 3. Classroom discussion 4. Concept mapping | <ol style="list-style-type: none"> 1. The dialogue of role play 2. The student booklet: <i>The long journey of the light independent phase</i> 3. The work sheet: <i>Photosynthesis of C3-and C4-plant</i> | <ol style="list-style-type: none"> 1. Use the role play to evaluate the students' ideas about nature of science as social enterprise. 2. Use the student booklet: <i>The long journey of the light independent phase</i> to probe the students' ideas about the phase. |

Table 4.1 Cont'd

| Lesson | Periods (min) | Learning outcomes | Concepts | Learning Activities | Materials | Assessment |
|--------|---------------|--|--|---------------------|--|--|
| | | 5. Interpret, analyze and develop a concept map of the dark phase. | <p>7. Thirdly, the CO₂ acceptor (RuBP) is regenerated from PGAL.</p> <p>8. C3 plants include alga and most advanced angiosperm that have only one CO₂ fixation in mesophyll.</p> <p>9. C4 plants have bundle sheath cell containing chloroplasts. The C4 plants thus fix CO₂ both in mesophyll and bundle sheath cell.</p> <p>10. In mesophyll, PEP, a three-carbon molecule, combines with CO₂ to generate a four-carbon molecule, OAA.</p> <p>11. OAA is converted to malic acid and then move to bundle sheath cell.</p> <p>12. In bundle sheath cell, malic acid is changed. CO₂ is released for the second of CO₂ fixation.</p> | | <p>4. The work sheet: <i>Matching me</i></p> <p>5. The concept mapping</p> | <p>3. Use the work sheet: <i>Photosynthesis of C3-and C4-plant</i></p> <p>4. Use the work sheet: <i>Matching me</i> to evaluate the understanding about the dark phase of the plants.</p> <p>5. Use the concept mapping to evaluate the students' conceptions about the phase.</p> |

Table 4.1 Cont'd

| Lesson | Periods (min) | Learning outcomes | Concepts | Learning Activities | Materials | Assessment |
|--|---------------|--|---|---|---|---|
| 6. Students' own demonstration of photosynthesis | 2 (100) | Students would be able to... 1. Theorize, plan and design the experiment for studying light intensity. 2. Collect, analyze and summarize the data. 3. Tell the advantage of the experimentation . | 1. Humidity, light intensity, CO ₂ concentration, and numbers of leaves affect the photosynthesis rate. 2. The rate of photosynthesis increases when light intensity increases. 3. Photosynthesis is a constructive process which may lead to increase in weight. 4. Too low temperature and carbon dioxide effect on photosynthetic rate. 5. Light and light intensity effects on photosynthetic rate. 6. Light intensity, carbon dioxide concentration, oxygen concentration, temperatures and numbers of stroma are limiting factors which affect the rate of photosynthesis | 1. Problem solving 2. Experimentation 3. Group work | 1. The student guide: <i>Experiments of photosynthesis</i> 2. The work sheet: <i>Experimental design</i> | 1. Use the student booklet: <i>Experiments of photosynthesis</i> for students' own evaluation about photosynthesis factors. 2. Use the work sheet: <i>Experimental design</i> to evaluate the students' understanding of photosynthesis factors. |

Table 4.1 Cont'd

| Lesson | Periods (min) | Learning outcomes | Concepts | Learning Activities | Materials | Assessment |
|---|-------------------------------------|--|---|---|---|--|
| 7. A campaign: photosynthesis for environment | 1 (50) plus Outside teaching period | Students would be able to... 1. tell the story of the relationship between photosynthesis and environment 2. apply photosynthesis knowledge to conserve the environmental issue in school or community. 3. explain the advantages of cooperative working. | 1. Photosynthesis essentially decreases CO ₂ in atmosphere causing the green house affect resulting in higher temperature of the earth. 2. Plant photosynthesis releases O ₂ for respiration of all oxygenic living things. 3. Photosynthesis acts as an intermediary which changes light energy to chemical energy, in terms of food for every living thing. | 1. Science project 2. Students' personal story telling 3. Group work 4. Classroom discussion | 1. The work sheet: <i>A campaign to conserve the environment by photosynthesis</i> 2. The presentation board in the discussion | 1. Use the work sheet: A campaign to conserve the environment by photosynthesis to evaluate the students' proposal about the science project 2. Use classroom discussion to evaluate the students' applying the photosynthesis knowledge to conserve the environment. |

After the researcher finished developing the photosynthesis teaching unit, three participant teachers were invited to participate in the meetings. Those aimed to introduce the teaching unit and its guiding principles to those teachers. Then, the teachers were challenged to recognize the students' misconception using empirical data of the Introductory Photosynthesis Survey (IPS). The survey showed their students' learning difficulties of photosynthesis. The teachers were expected to be able to adapt the unit for the student needs and the classroom society and culture.

Summary

The six guiding principles of the photosynthesis teaching intervention had been developed to scope for developing the photosynthesis teaching unit. This included seven lesson plans for twelve 50-minute teaching periods. The understandings of photosynthesis in its relation to nature of science and environment would be enhanced using the generative learning model of teaching. Teaching would focus on correcting the students' misconceptions about introductory photosynthesis using think pair share, game and discussion. Then, the students' understanding of photosynthesis integrated with nature of science teaching would be challenged using several learning activities such as experiment, concept mapping, cooperative learning, discussion and role play based on historical discovery of scientists. Also, teaching would promote students' application of photosynthesis knowledge. The students would relate the knowledge to conserve the environment through problem solving and science project. Along time of teaching, teachers should concern students' learning society and culture: living style, views about plants and educational value to adapt the teaching intervention for students' needs. Also, teachers should encourage students' participation in learning activities to facilitate teaching based on the intervention.

Next is Chapter V. The implementation and impact of the teaching intervention in the three biology teachers have been described as three case studies.

CHAPTER V

IMPLEMENTATION AND IMPACT OF PHOTOSYNTHESIS TEACHING INTERVENTION

This chapter illustrates biology teacher contexts, and teacher perceptions before, during and after implementing the intervention. Then, three case studies of three biology teachers, Mrs. Engka, Mr. Vyn and Mrs. Amp, have been described. The teacher's school contexts, background information, beliefs about teaching and learning and planning are initiated to discussion of teacher's implementation. The implementation is showed in terms of the teacher's practices in classroom, and in parallel with the impacts on the students' understanding. The discussion focuses on the expanded range of objectives of the intervention. The objectives based on the six principles: 1) correcting Grade 11 students' misconceptions about introductory photosynthesis, 2) enhancing Grade 11 understanding about advanced photosynthesis, 3) integrate nature of science into photosynthesis and using historical narratives to illuminate the nature of science based on the National Science Curriculum (IPST, 2002), 4) enhancing students to relate photosynthesis knowledge to conserve the environment, 5) having regard to culture and society as Socio-cultural perspectives on teaching and learning, and 6) encouraging students to learn photosynthesis actively.

The following is biology teacher contexts.

Thai Biology Teacher Contexts

As results of the educational reform, the National Science Curriculum (IPST, 2002) required the school to develop its own science curriculum. The school science curriculum organized teaching photosynthesis into the Grade 11 advanced biology subject. Teaching Photosynthesis had taken place in the beginning (Nov 2004) of the second semester or before the school midterm examination (the end of Dec 2004) of the schooling year of 2004. The teachers had different number of the teaching periods

per a week, namely two 60-min periods a week, three 60-min periods a week, or three 50-min periods a week.

Survey and interview data indicated that some teachers felt constrained by the reform. Some senior teachers could early retire and leave teaching loads for them. Also, they were nervous to prepare themselves for teaching evaluation based on the reform. Now a day, they had large number of students, 40-45 students, in their classroom. They thought that the classroom organization might be interrupted. In this second semester, there were a lot of school activities and long public holiday interrupting the periods.

Mrs. Engka, Mr. Vyn and Mrs. Amp were three Thai biology teachers participating in this research. They had personal background, belief of learning and teaching planning. Also, they had implemented the photosynthesis teaching unit in different schools: the Border School, the Market School and the Babysat School. The case study of Mrs. Engka, in the Border School has been initially described into this chapter.

The Case Study of the Border School

1. School Contexts

This first public high school was called the “Border School” because it was located near the boundary of the province, around Bangkok suburban area. This school was established in 1992 to celebrate the Queen of Thailand’s birthday. The school provides education for boys and girls around the community and the neighboring area. The entire population of the school was approximately 3,200 students and 131 -150 teachers. The school had twelve classrooms each in Level 3, Grades 7 – 9, and nine classrooms each in Level 4, Grades 10-12. Each Grades 7-9 classroom had 55 - 60 students, and each Grades 10 – 12 classroom had 40 - 45 students.

Every morning, 7.40 – 8.20 a.m., students and teachers began their day with singing the national anthem, and clasping their hands and giving thanks to the country, to Buddha and to the king, which upholds the Buddhist faith. In school, students wore the school uniforms, and had a teacher advisor. They spend twenty minutes before class, to meet the advisor. This meeting was called *home room*. The advisor announced school news and advised them on how to be a good student. Then, the teaching period started at 8.20 a.m. and finished at 15.20 p.m. There were seven one-hour teaching periods and one hour of lunchtime.

In the science department, there was Friday teaching meeting weekly. The head of the department informed all science teachers about news of science activities in the school, and launch discussion on what the teachers found interrupting their teaching. Then, they would seek a way of solving the interruption. The meeting sometimes was run informally. The head of the department would take responsibility to inform and solve the interruption.

2. Background Information about Mrs. Engka

2.1) Educational Background and Teaching Experience

Mrs. Engka was a beginning teacher in a rural province in 1984, before she moved to the Border school. She was now about forty three years old and taking charge of the head of the science department at the Border school. Her formal education was a Bachelor of Education, majoring in biology and minoring in nutrition. Her teaching experience on the advanced photosynthesis in Grade 11 was for approximately ten years. In this second semester, she had taught about the advanced biology, but had not taught about basic/introductory biology in Grade 11. She had also taught about science in Grade 9. Totally, she had sixteen teaching periods a week.

Because she preferred to study nature around her, she would like to teach about biology. She was enthusiastic about implementing the teaching unit. She

always asked what she really did not understand about the unit, in particular the scientific contents and the nature of science. However, she was not confident that she would successfully teach about the advanced photosynthesis.

2.2) Mrs. Engka's Students Information

Mrs. Engka's Grade 11 advanced biology class contained twelve boys and twenty nine girls who studied the biology two 60-min periods a week. Twenty six were aged sixteen, and fifteen were aged seven teen. She described the class as a great student. Most students in her class were above average (Table 5.1). Their biology achievement score was 3.61 averagely. Nobody studied biology with private tutorials. The students' opinion towards the biology learning varied considerably. Twenty nine would like to learn biology for their everyday life, nine would like to learn biology for the examination and graduation, but three students would not like to attend the biology classroom because they could read biology textbook by themselves.

Table 5.1 Biology Achievement of Mrs. Engka's Students

| Biology Achievement | Students (number) |
|---------------------|-------------------|
| (Score 4.0) | 19 |
| (Score 3.5) | 15 |
| (Score 3.0) | 4 |
| (Score 2.5) | 3 |
| (Score 2.0) | - |
| (Score 1.5) | - |
| (Score 1.0) | - |
| (Score 0) | - |

There were four students who were selected purposively to be studied in depth concerning their development of photosynthesis understanding. The selection was based on gender, age, biology achievement, and attitudes towards biology. Career of the parent was also considered to reveal the student's society at their place,

outside the classroom. The four students were called S01, S02, S03 and S04. Table 5.2 shows information of the students

Table 5.2 Mrs. Engka's Students Selected as Participants in the Case Study

| Categories | Students | | | |
|-------------------------------|---|---------------------|---|---|
| | S01 | S02 | S03 | S04 |
| Gender | Male | Male | Female | Female |
| Age | 16 | 16 | 17 | 16 |
| Biology Achievement | 3.0 | 3.5 | 3.5 | 3.5 |
| Attitudes Towards Biology | I sometimes was interested in biology. It depends on the topic. | I disliked biology. | I disliked biology because it needed too much memory. | I studied biology because I would like to be a dentist. |
| Parent Career (Father/Mother) | A small business owner/ Tailor | Lawyer/ Nurse | Labors | Engineer/ House wife |

S01 was sixteen years old boy. His mother was a tailor, and his father owned small private business. Outside formal schooling studying, S01 spent several hours in private tutorial institutions for enhancing his knowledge of Physics, Mathematics, Chemistry, and English language during school day and weekend. Even though he believed that studying biology was necessary for his everyday living, he was occasionally interested in that study. His biology learning achievement score was 3.0 and his GPA was 3.46.

S02 was also sixteen years old boy. His father was a lawyer, and his mother was a nurse. He disliked studying biology, but liked studying Math, Chemistry and Sport. However, he did not study in any private tutorial institute, his biology learning achievement score was 3.5 and his GPA was 3.63.

S03 was seventeen years old girl. She lived in Bangkok with her aunt while her parents were now labors living in another province. Outside formal

schooling studying, she studied Physics and Mathematics in the evening during school day. She did not quite like studying biology. “It needed too much memory”, she said. Finally, she suggested that receiving an opportunity for sharing ideas would be better way of the study, even though she had been unfamiliar with this way. Her biology learning achievement score was 3.5 and her GPA was 3.42.

S04 was sixteen years old girl. Her father was an engineer, and her mother was a housewife. S12 liked to share ideas with others, and would like to be a dentist. However, she thought that she had no enough ability to be the dentist. Outside formal schooling studying, she studied Physics, Chemistry, Mathematics and English language during the week and weekend. Her mother always picked her up from a private tutorial institute to another one during weekend. Her biology learning achievement score was 3.5 and her GPA was 3.36.

3. Mrs. Engka’s Beliefs about Teaching and Learning

According to the classroom observations and the discussion with Mrs. Engka during informal interviews throughout the study, Mrs. Engka believed that teaching by lecturing could not longer develop the students’ learning about biology. The interaction between students and their friends, and teachers’ suggestions would encourage the students to better learning.

Mrs. Engka was enthusiastic about the importance of students’ interactions in teaching activities and launching group discussion and classroom discussion. She would like the students to form their group independently and happily to participate in the activities and discussion. She noted that the students might not immediately change the way of learning from passive learning to active learning. The students in her classroom was still familiar with intently listening, copying what she said and wrote on the board, and completing activities from the worksheet.

Also, Mrs. Engka was critical of the approach used at the Border school where her great students were usually required to participate in a large number of school

events or activities. The students, thus, had got loads of work, but had not received much time to complete. Mrs. Engka hoped that there were more opportunities for the students to complete her teaching activities within class. She perceived her role in terms of monitoring student learning development, helping each student to learn by answering questions, and providing information as each student recognized the need.

4. Mrs. Engka's Planning

In Mrs. Engka's role as head of the science department, she had responsibility for coordinating the course, planning equipment needs and sequencing of topics throughout the second semester of the academic year 2004. So, she planned implementing the teaching unit systematically. Also, she anticipated the amount of time that she expected to assign and organize teaching and learning activities for most students.

In the daily planning, she always prepared equipment used and the content taught. In each activity, she examined the photosynthesis lesson in the teaching unit to see the information needed to complete each learning task or question in students' worksheet. The time schedule was reviewed on a weekly basis as students completed the activities.

However, Mrs. Engka accepted that she was not relaxed when she taught about chemical conceptions involved the light dependent phase. She was less successful for the students who tended to ask the complex questions. Also, she regarded her lack of content knowledge as particularly problematic.

By the findings, Mrs. Engka implemented the teaching unit for four weeks and began to implement the teaching unit on the 27th October 2004, in the laboratory which contained eight 100 x 200 x 80 cm. student tables, one 200 x 100 x 80 cm. teacher table, thirty eight stools, ten plastic chairs, six ceiling fans, six equipment cupboards, six electric light bulbs, an extractor hood, three sinks and an overhead projector. Figure 5.1 shows the classroom setting.

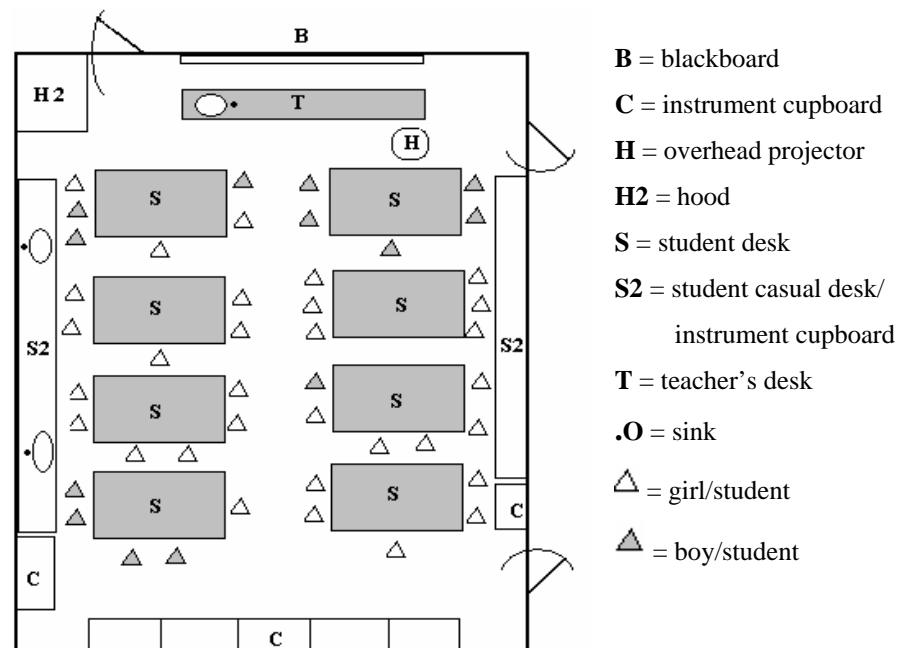


Figure 5.1 Mrs. Engka's Classroom Setting in the Border School

Implementing the teaching unit of Mrs. Engka has been described in terms of the teacher's practices in classroom and in parallel with the impacts on the students' understanding. Some students selected by purposive sampling at the Mrs. Engka classroom were studied in depth to reveal the development of the understanding. According to the unit developed basing on the six principles, describing focuses on the practices and the understanding involved the principles.

5. Mrs. Engka's implementation of the Intervention and the Students' Understanding Based on the Six Principles

5.1) Principle I: Correcting Grade 11 Students' Misconception about Introductory Photosynthesis

Before Mrs. Engka implemented the teaching unit, the findings of the Introductory Photosynthesis Survey (IPS) indicated that the students had held some misconceptions about the introductory photosynthesis. Most of forty one students

held misconceptions about plant food and partial understanding with misconceptions about plants and light energy, simple photosynthesis process and plant materials, but most of the students sound understood about role of chlorophyll. Here is briefly what the misconceptions early held by the students.

Almost all students (eighty five percentages) of Mrs. Engka's classroom misunderstood about *plant food*. They thought that external materials used to grow or used in photosynthesis were plant food such as water, fertilizer, air, light or chlorophyll. This misconception might come from their everyday experience (Wandersee, 1985; Kinchin, 2000). They pour water on and add fertilizer to plants and then the plants grow up, so they thought the water and the fertilizer were the plant food.

Eighty three percentages, almost all students, held partial understanding with misconceptions about *plant and light energy*. They understood that *sunlight* supplied *energy* for photosynthesis, but they were confused by role of plant materials, CO₂ and H₂O, role of chlorophyll in photosynthesis process and role of ATP in biology reactions. They misunderstood that CO₂, H₂O, chlorophyll and/or ATP also supplied the energy for photosynthesis and "photosynthesis needed light to transform both CO₂ and H₂O into starch."

About sixty six percentages, over half students, held partial understanding with misconceptions about *simple photosynthesis process and equation*. They attempted to recall the equation in the textbook, but they did not understand about the process. They perceived CO₂ and H₂O as substrates of photosynthesis process, but they did not understand role of chlorophyll and role of light energy. They alternatively thought that chlorophyll and/or light were also the substrates. In addition, their misconceptions about plant food confused them what substrates were. For the students, minerals which were misunderstood as plant food were also the substrates.

Forty nine percentages had partial understanding with misconceptions about *plant materials*, CO₂ and H₂O. They perceived plant materials as plant food, what the plants used to photosynthesize, but they held misconceptions about the plant food. So, sunlight, chlorophyll and minerals were also misunderstood as plant materials. Additional twenty percentages brightly misunderstood about the materials. They misinterpreted the wording “Photo” synthesis. They thought that plants did not need CO₂ and H₂O; plants used only sunlight as materials.

Seventy eight percentages had sound understanding about *role of chlorophyll* in plants. Plants having chlorophyll could photosynthesize. Only one student misunderstood about the chlorophyll, who thought that plants could photosynthesize when it was experimented.

Also, the students’ misconceptions were obviously found through Mrs. Engka’s classroom observation. Mrs. Engka investigated the students’ views and life experiences about plants before they received formal teaching, through discussion. The students presented their understanding that plant got the energy from their food. However, the students said that mineral, water and light were the plant food; peanut shell, egg shell and/or insects were also the plant food. For examples:-

A Student: (presenting in front of class)...food is what plants used for the growth. Plants will be died if they don’t have [food]... Food comprises both major and minor food. The major is water, sunlight, and air...containing carbon dioxide gas and nitrogen. The minor is mineral placing in both water and soil, and fertilizer such as N P K.

A Student: ...(presenting in front of class)...plant food is mineral used to grow. Sunlight helps plants’ photosynthesis. Fertilizer is minor food. Bean shell, egg shell [and] insects were [also] minor food...

The findings illustrated holding the misconceptions, in particular plant food. Teaching by an emphasis on correcting the misconceptions was initiated as a basis of developing the understanding about photosynthesis. A correcting way had been organized through Mrs. Engka's practices in the classroom.

5.1.1) Mrs. Engka's Practices on Principle I

Mrs. Engka's classroom observations and interviews strongly indicated that she consistently corrected the Grade 11 students' misconception about introductory photosynthesis including role of chlorophyll, plant food, plant materials, plants and light energy and simple photosynthesis process. She appeared confident to teach. She used the worksheet "what is plant food?" and the game "Circus of misconceptions (True or False)" to elicit the misconceptions. Her teaching focused on using the booklet "*Why do plants make sugar?*" as source of information to correct the misconceptions, and using classroom discussion and concept mapping to evaluate the conceptions. After Mrs. Engka's practices, most of students appeared to correct the misconceptions. Four students selected to in-depth study detailed the conceptual change.

5.1.2) Student Understanding about Introductory Photosynthesis

The surveys and interviews with student indicated that most of the students corrected the misconceptions, including plant food, plant and light energy, simple photosynthesis process and equation and plant materials.

Most of the students changed their conceptual from the misconceptions to the scientific conception. They fully understood that sugar was plant food. Only five percentages retained the misconceptions that water instead of sugar was the food.

It became more students who scientifically understood about plant and light energy. There was no student telling that chlorophyll supplied energy

for photosynthesis. Only seven percentages retained the misconception that CO_2 and H_2O supplied the energy for photosynthesis.

The misunderstanding about plant materials was overcome by the scientific understanding about simple photosynthesis process and equation. Most of the students used to recall the equation without the understanding, but they presently understood the equation and then could describe the substrate as plant materials, CO_2 and H_2O .

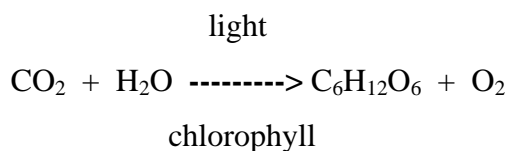
In addition to interviews with the four students on the Principle 1, S01 holding scientific concept about role of chlorophyll corrected the misconceptions about plant food and plant materials. His misconception; “mineral, fertilizer, water and air are plant food...” was correctly substituted by the scientific concept; “glucose was plant food.” Also, he now understood that plants used CO_2 and H_2O as the materials making the plant food. However, his conception about plant and light energy was confused with his conceptions about energy for respiration. In stead of sunlight, he misunderstood that glucose, the plant food, supplied the energy for photosynthesis.

The student, S02, who disliked biology and was holding only scientific concept about plant and light energy could complete the understanding about role of chlorophyll. S02 now understood that green substance was chlorophyll absorbing light energy. However, he could not obviously correct the misconceptions about plant food and plant materials. He mixed the experience in classroom with the experience outside classroom. He thought that $\text{C}_6\text{H}_{12}\text{O}_6$ was plant food, and H_2O used to water plants was also plant food. Light and CO_2 were plant materials because plants fixed CO_2 and also absorbed sunlight. “It’s called ‘photo’ synthesis, so [plants] also need light as well...”

S03 could correct the misconceptions about plant food and plant materials. Her misconception; “mineral, fertilizer, water carbon dioxide, light and chlorophyll are plant food...” was correctly substituted by the scientific concept;

“sugar was plant food.” Also, the scientific understanding about photosynthesis equation brought S03 to correcting the misconception about plant materials. She now understood that CO₂ and H₂O were plant materials.

S04 could correct the misconceptions about plant food and plant materials. Carbohydrate was plant food made from plant materials, CO₂ and H₂O. However, she still held some misconceptions about plant and light energy. She thought that chlorophyll also supplied energy for photosynthesis. S04 thought that ‘light’ and ‘chlorophyll’ presented on/under the arrow in the equation had similar function in the photosynthesis process:



Recalling the photosynthesis equation without really understanding the process might retain her misconception of the photosynthesis process.

Table 5.3 shows the four students’ conceptions about introductory photosynthesis.

Table 5.3 Correcting the Introductory Misconceptions of Mrs. Engka's Students Selected as Participants in the Case Study

| Concepts | | Students | | | |
|----------------------------------|--------|---|---|---|---|
| | | S01 | S02 | S03 | S04 |
| Role of Chlorophyll | Before | Green plants use chlorophyll to photosynthesize. (SU) ⁵ | Plants having green colour could photosynthesize. (PU) | Green plants use chlorophyll to photosynthesize. (SU) | Green plants use chlorophyll to photosynthesize. (SU) |
| | After | Chlorophyll is photosynthetic pigment. (SU) | Green substance, chlorophyll, absorbs light. (SU) | Pigments absorb light. (SU) | Pigments absorb light. (SU) |
| Plant Food | Before | Mineral, fertilizer, H ₂ O and air are plant food because plants use these to grow. (MU) | Mineral, fertilizer, H ₂ O and air are plant food because plants use these to grow. (MU) | Mineral, fertilizer, H ₂ O, CO ₂ , light and chlorophyll are plant food because these are used to photosynthesize. (MU) | Mineral, fertilizer, H ₂ O and air are plant food because plants use these to grow. (MU) |
| | After | Glucose is plant food. (SU) | C ₆ H ₁₂ O ₆ and H ₂ O are plant food. (PU+MU) | Sugar is plant food. (SU) | Carbohydrate is plant food. (SU) |
| Plant Materials | Before | (No answer) | (No answer) | Carbon dioxide and sunlight are used to photosynthesize. (PU+MU) | Water, sunlight and chlorophyll are used to photosynthesize. (PU+MU) |
| | After | Plants use H ₂ O and CO ₂ to make sugar and oxygen gas. (SU) | CO ₂ and sunlight are used to photosynthesize. (PU+MU) | Plants use H ₂ O and CO ₂ to make sugar and oxygen gas. (SU) | Plants use H ₂ O and CO ₂ to make sugar and oxygen gas. (SU) |
| Plants and Light Energy | Before | Light, H ₂ O, CO ₂ and chlorophyll supply the energy because plants use these to photosynthesize. (PU+MU) | Sunlight supplies energy for plant photosynthesis. (SU) | Sunlight supplies energy for plant photosynthesis. (SU) | Light and chlorophyll supply the energy and then change CO ₂ and H ₂ O into starch. (PU+MU) |
| | After | Sugar made supplies energy for photosynthesis. (PU+MU) | Sunlight supplies energy for plant photosynthesis. (SU) | Sunlight supplies energy for plant photosynthesis. (SU) | Light and chlorophyll supply energy for photosynthesis. (PU+MU) |
| Simple Photosynthesis is Process | Before | (No answer) | (No answer) | (No answer) | (No answer) |
| | After | $\text{H}_2\text{O} + \text{CO}_2 \xrightarrow{\text{light}} \text{Glucose} + \text{O}_2$ Chlorophyll (SU) | $\text{H}_2\text{O} + \text{CO}_2 \xrightarrow{\text{light}} \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2$ Chlorophyll (SU) | $\text{H}_2\text{O} + \text{CO}_2 \xrightarrow{\text{light}} \text{Sugar} + \text{O}_2$ Chlorophyll (SU) | $\text{H}_2\text{O} + \text{CO}_2 \xrightarrow{\text{light}} \text{Sugar} + \text{O}_2$ Chlorophyll (SU) |

⁵ SU = Sound Understanding, PU = Partial Understanding, PU+MU = Partial Understanding with Misconception and MU = Misunderstanding

After the students corrected their misconceptions about introductory photosynthesis concepts, teacher's practices were expected to enhance the understanding of advanced photosynthesis concepts based on the Thai National Science Content Standards.

5.2) Principle II: Enhancing Grade 11 Students' Understandings about Advanced Photosynthesis Concepts

5.2.1) Mrs. Engka's Practices on Principle II

This research found that Mrs. Engka had strongly attempted to enhance the understandings about advanced photosynthesis concepts. These included structures and functions of chloroplast, light dependent (light) phase, light independent (dark) phase and necessary factors affecting photosynthesis rate.

Mrs. Engka perceived her role as assisting students to learn. She appeared to introduce *chloroplast* to the students by questioning why plant leaves had different colors. Then, she launched classroom discussion about how to separate mixed pigments in chloroplast, in Lesson 3. She used paper chromatography to experiment the pigments. She moved around the classroom, worked with the students, and assisted them to discuss the experimental design, results and conclusion. This is an instance of discussion about the experimental design.

Mrs. Engka: ...some leaves have no green colour... Could do these leaves photosynthesize? (pause) How do we know green colour leaves have only the green one?

Students: (Quiet)

Mrs. Engka: (Look around the classroom) O.K. Let start again...

A student: Those leaves are [leaves of] cha-baa-dang (Thai local name).

Mrs. Engka: Right (confirmed). You used to study its starch when you were in Grade 7. What do you think about the plants? Do they have only green colour? (pause) how do you know?

Students: Separation...

Although Mrs. Engka had taught in a less confidence in the chemical knowledge involved photosynthesis, she attempted to investigate the students' pre-conceptions of oxidation-reduction involved *the light phase*. Some instances in an attempt at explaining the oxidation-reduction, she stated that "...that pigment is thylakoid...giving and taking the electron. The reaction was called...um...*I don't have strong content...*, but the oxidation and reduction would occur..."

In Lesson 5, Mrs. Engka would like to probe the students' understanding and assist the students to learn meaningfully about the dark phase. She linked the dark phase concepts to the light phase concepts using concept mapping. Also, she encouraged the students to evaluate and improve the concept mapping continuously. Usually, the interaction with students initially required the students to give their ideas before Mrs. Engka provided information. At the times, she spontaneously responded to the students' questions and difficulties. Then, her quality of explaining and questioning about the concept was found to be developed.

Perhaps, she was critical of the time spent on experimenting. Mrs. Engka appeared to avoid the laboratory activities involved Lesson 6: the *necessary factors affecting photosynthesis rate*. Also, she felt that some less able students would not be able to understand the factors within a two-hour period of the lesson. So, her teaching appeared to emphasize lecturing, in stead of experimenting about the factors in laboratory.

After Mrs. Engka practiced on the Principle II, the students' understandings about advanced photosynthesis concepts based on the National

Science Curriculum (IPST, 2002) were surveyed. The results showed the achievement described next.

5.2.2) Students' Understanding about Advanced Photosynthesis

The Survey (APS) and interviews with student also indicated that most of the students developed the understanding about advanced photosynthesis concepts. They achieved sound understanding about light independent (dark) phase, partial understanding about light dependent (light) phase, structures and functions of chloroplast and necessary factors affecting photosynthesis rate in terms of its relationships.

Probing and correcting the students' misconceptions about plant food and plant materials, and assisting the students to learn meaningfully resulted in a high percentage of the students' understanding about *the light independent (dark) phase*. There were eighty percentages that fully understand about the dark phase. Plants fixed CO₂ and used ATP and NADPH to produce plant food, sugar. Only ten percentages holding misconception about plant respiration misunderstood about the dark phase. "The dark phase was respiration of plants at night and it produced oxygen".

Teaching in a less confidence in oxidation-reaction might impact the understanding of *the light dependent (light) phase*. Lecturing with less identifying what the students really understood the concepts, might lead most of students to partial understanding of the light phase. Forty nine percentages forgot to explain about the water separation, but they could explain the electron transfer in the light phase. There were thirty seven percentages explaining all concepts about the light phase. Water was separated by light and then provided the prior electron transferred to produce ATP and NADPH.

Assisting students to learn about the structures of chloroplast using the experimentation without strong discussing the functions in relation to those

structures might be a metaphor of using hands-on without minds-on activity. This approach possibly brought half of students, fifty one percentages, to have partial understanding about *structures and functions of chloroplast*. Only twenty percentages had the sound understanding. Chloroplast significantly comprised two structures. Thylakoid containing chlorophyll functions as light absorbance. Stroma containing enzyme functions as CO₂ fixation. However, the misconception was not found.

Skipping the laboratory activities involved solving problem about the *necessary factors affecting photosynthesis rate* indicated a less percentage of the students' understanding about the relationships between numbers of chloroplast in C3- and C4- leaf tissues and CO₂ fixation. Only ten percentages had sound understanding. The fixation depended on number of chloroplast contained in mesophyll cell and bundle-sheath cell. The C4-plants containing both type of cell fixed CO₂ more time than the C3-plants containing only one type of cell. Most of students, fifty one percentages had just partial understanding about the relationships. Additional thirty percentages had misconceptions and fifteen percentages had no ideas about the relationships.

Also, the survey (APS) and the individual interviews with the students, S01, S02, S03 and S04, strongly supported that development of the understanding about photosynthesis. The students who could correct the misconceptions about introductory photosynthesis appeared to develop the understanding of advanced photosynthesis.

The best learning of the four students was the understanding about the light independent (dark) phase. They achieved the sound understanding that C atom of CO₂ was used to synthesize glucose in the dark phase.

The learning difficulties of chemical structure and oxidation-reaction had brought misconceptions about roles of H₂O and CO₂ in photosynthesis. This probably interrupted the students' sound understanding about the light dependent (light) phase. Oxygen atom of H₂O and CO₂ was misunderstood as the resource of

the electron in the light phase. Thus, S01 and S04 perceived that light energy separated both H₂O and CO₂ into the electron and then released the oxygen gas. S02 misunderstanding that H₂O was plant food perceived that CO₂ was the only one resource of the oxygen gas.

As same as most of students taught through the experiment without the strong discussion of relationship between the structures and the functions of chloroplast, the four students had just partial understanding about structures and functions of chloroplast. Light absorption was only one function of the chloroplast. S02 also misunderstood that the chloroplast particularly took place in stoma and size of the stoma limited fixing CO₂ in the dark phase.

Holding the misconceptions of S02 caused the misunderstanding about the necessary factors affecting photosynthesis rate after Mrs. Engka skipped the laboratory activities in the lesson. "Fixing CO₂ depended on size of the stoma." S01 and S03 who believed that chloroplast functioned as the light absorption only also misunderstood about the factors. S01 perceived that number of chloroplast did not affect the CO₂ fixation. S03 perceived that fixation depended on stored energy in vacuole. Table 5.4 shows the students' conceptions about advanced photosynthesis.

Table 5.4 Advanced Photosynthesis Concepts of Mrs. Engka's Students Selected as Participants in the Case Study

| Concepts | Students | | | |
|---|---|--|---|--|
| | S01 | S02 | S03 | S04 |
| Structures and Functions of Chloroplast | Chloroplast contains chlorophyll absorbing light. (PU) ⁶ | Chloroplast places in stoma fixing CO ₂ and absorbing light. (PU+MU) | Chloroplast contains green substance absorbing light. (PU) | Chloroplast contains chlorophyll absorbing light. (PU) |
| Light Dependent (Light) Phase | Light digests both CO ₂ and H ₂ O. Both provide O ₂ and e ⁻ . (PU+MU) | CO ₂ supplies O ₂ gas [because] H ₂ O is plant food. (MU) | Light activates electron transfer. (PU) | Light separates H ₂ O [and CO ₂] providing the e ⁻ . (PU+MU) |
| Light Independent (Dark) Phase | CO ₂ provides C-atom...used to synthesize glucose. (SU) | CO ₂ supplies C-atom...used to make sugar. (SU) | Plants fix CO ₂ to make food. This is sugar. (SU) | CO ₂ is separated into C-atom making food and O-atom making O ₂ gas. (PU+MU) |
| Necessary Factors Affecting Photosynthesis Rate | [CO ₂] doesn't affect the rate. All plants similarly fix CO ₂ . (PU+MU) | Size of stoma limits the CO ₂ fixation rate. (MU) | Fixing CO ₂ depends on an amount of energy stored in vacuole. (MU) | C3-plant has a less CO ₂ fixation than C4-plant. (PU) |

⁶ SU = Sound Understanding, PU = Partial Understanding,

PU+MU = Partial Understanding with Misconception and MU = Misunderstanding

5.3) Principle III: Integrating Nature of Science into Photosynthesis **Using Historical Narratives to Illuminate the Nature of Science (IPST, 2002)**

Understanding about nature of science was perceived as important as understanding of concepts by teaching and learning about photosynthesis. Use of historical narratives was theoretically chosen as a possible effect in achieving the nature of science. There were three aspects in nature of science integrated in photosynthesis using historical materials. The three aspects are that scientific ideas are subject to change; that science demands evidence; and that science is a complex social activity.

With the hope to result the fully understanding about the three aspects of science, Mrs. Engka practiced the learning activities suggested by the teaching unit.

5.3.1) Mrs. Engka's Practices on Principle III

Mrs. Engka often asked questions and used student observations to develop the fully understanding. The historical story of developing the word "photosynthesis" was initially discussed to present the three aspects of science explicitly, in Lesson 2. Also, the historical stories of previous scientists who discovered evidences about chloroplast, light and dark phases, in Lessons 3-5, were analyzed and discussed to support those three aspects. Before class, reading the booklets involved the historical stories was assigned to the students. Then, they were formally asked to participate in the discussion. This focused on the nature of science as social enterprise, how the scientists had cooperatively worked to develop the knowledge in society.

The students were also assigned to prepare the role play activity before class of Lesson 5. Ten students acted as the previous scientists who cooperatively discovered the dark phase and worked with others, in front of the class. Mrs. Engka, then, began the discussion by an emphasis on science as social enterprise.

In her planning for the nature of science, Mrs. Engka perceived the understanding as a product of scientific thought. She placed a relatively low priority on considering what scientific process used to promote the understanding in the teaching unit. For instance, her observation on the students, in Lesson 3, seldom emphasized on the students' carefully observing and interpreting the paper chromatography during the experimentation of pigments contained in plant leaves.

Consequently, as the hope of Mrs. Engka's practices, the survey and the interviews indicated which aspect perceived as science and what conceptions understood by the students.

5.3.2) Students' Understanding about the Nature of Science

The observation on Mrs. Engka's classroom and the survey indicated the developmental understanding about the nature of science. The understanding appeared in the students' assignment. They personally questioned about the two aspects of science – science is subjected to change and science demands evidences. The survey then indicated that a majority had gained the understanding of science that is subjected to change. Fifty nine percentages perceived that scientific theories and laws could be changed because the old theories and laws were disproved by scientists using new technology or improved instruments or detecting errors in the old one. However, twenty nine percentages did not understand about this aspect. They thought that laws could not be changed. A theory became a law after that theory had been proven true many times by scientists' experiments, so the law had never been changed.

Science demands evidence, was considered with three options, by the students. There were sixty three percentages, a majority, focusing on the scientific methods or scientific process of investigation for scientific evidence. They noted that "...observing, questioning, assuming, collecting, experimenting, analyzing and summarizing brought the supporting evidence of the knowledge..." A minority, thirty two percentages, referred to the evidence as a product of studying natural phenomena.

The study associated with discovering and searching for an explanation. Only five percentages differently believed that discovery of the evidence was accidentally made; no scientific method.

After Lesson 5 was finished, students additionally showed the developed understanding of science that is a complex social activity. Students' discussion in role play focused on sharing the scientists' ideas with others. The students understood that "...scientists worked by observing, hypothesizing, experimenting, summarizing, and *cooperating with others*... They needed to be patient doing many experiments with *loyalty*... The used scientific processes, *exchanged knowledge* to each other and did experiment"

The survey also indicated the understanding of science that is a complex social activity. Most of students, sixty six percentages, obviously understood that scientists could not work individually. For example, fourteen students noted that scientists published their discoveries to advance scientific knowledge by sharing ideas or results, and thirteen students noted that scientist's work was building up on each other's work. Additional seven percentages understood that it was matter that scientists' success must be caused with their honesty in finding the answer.

Interview with the students, S01, S02, S03 and S04, strongly supported the previous findings. S01 believed that science could be changed if that science could not explain the present natural phenomena. Also, he focused on using scientific process to search for the evidence of science: "the scientists had set the hypothesis, done the experiment and summarized the results to develop new theories..." Also, he believed that scientist's work was building up on previous scientists' work.

S02 and S04 believed that an old scientific theory could be changed by its error detection. Experimentation was used as proving ideas of individual scientists. The scientists would get credit from the proving. After

participating in role play discussion, however, both understood that scientists could not individually work for developing photosynthesis knowledge and they used the experimentation to evident the knowledge. S02 noted that "...the scientist would publish the discovery to advance the knowledge." S04 noted that "...the scientists continued the previous study and then found new substance involved photosynthesis..."

Scientists with curiosity had observed the world and then given its explanation, in terms of laws and theories, for application in every day life. This idea was held by S03 who ignored the idea of science was a complex social activity. Table 5.5 shows the students' conceptions about nature of science in three aspects.

Table 5.5 The Nature of Science of Mrs. Engka's Students Selected as Participants in the Case Study

| NOS Aspect (Questions) | Student Conceptions of the Nature of Science (NOS) | | | |
|--|---|---|--|--|
| | S01 | S02 | S03 | S04 |
| 1. Scientific ideas are subject to change. Q: Why had the scientific ideas been changed? | "The nature kept changing, so scientists discovered new knowledge... Any knowledge that could explain the present nature wouldn't be changed." | "New ideas had been developed, [because] the scientists wanted to remove old theories or to modify them to confirm their ideas." | "...because the scientists had curiosity..." | "...newer and better theories caused rejection of older ones. The scientists always wanted to construct new theories..." |
| 2. Science demands evidence. Q: Why did the scientists need to do the experiments? | "...to find the answers to the questions linking in their mind." | "If they didn't do the experiment, they wouldn't be able to produce new knowledge, new theories..., so they did either to discover new theories or to become famous." | "...to obtain more precise and deeper knowledge for application in everyday life." | "Because they wanted to find out more..., to answer the questions they encountered, to search for new knowledge and to prove their ideas" |
| 3. Science is a complex social activity. Q: How did the scientific knowledge come about? | "They might cooperate with others. The information was then noted for us..." | "...from the experimental results obtained, they tested the existing theories, verified and modified systematically until they were certain that the theories were correct." | "...from the experiments and research findings, they collected the information available and set up laws and theories ..." | "...experimentation had brought about the discovery of new more precise theories but research cooperation among scientists might not be relevant." |
| The summary of ideas about the nature of science. Q: How had the photosynthesis knowledge been developed? | "...The scientists had set the hypothesis, done the experiment and summarized the results to develop new theories. The scientists also used results of old scientists to develop the theories..." | "...observation, ...cooperation,... and...curiosity of the scientists had brought development of photosynthesis knowledge. The scientist would publish the discovery to advance the knowledge." | "...the observation had reached them to the knowledge finding." | "...the scientist had observed, experimented and investigated until he found the water...a next [scientist] continued the study and then found new substance involved photosynthesis..." |

5.4) Principle IV: Enabling Students to Relate Photosynthesis Knowledge to Conserve the Environment

5.4.1) Mrs. Engka's Practices on Principle IV

Relating photosynthesis knowledge to conserve the environment was found in Mrs. Engka's classroom practice. At the very beginning of Lesson 7, the students were asked to tell their own stories about environmental situations around their places, school and community. Then, they independently formed their own group members, five to six peoples, to discuss what the environmental issue they would solve and develop the environmental project. The project could be collection and experiment, survey and report, poster/display, model and demonstration or research project, and provide basic information for the environmental development.

Also, Mrs. Engka formally asked the students to operate the project as an assignment. The students would propose the design of the project in the worksheet: A Campaign to Conserve the Environment by Photosynthesis. The project needed to be approved by the teacher. Also, the students' tasks for operating the project would be reported to the teacher.

5.4.2) Students' Ability to Relate Photosynthesis Knowledge to Conserve the Environment

Applying the accepted scientific knowledge about photosynthesis to conserve the environment was found through interview with students and their reports. Individual interview with S04 provided an example of the story which strongly supported the finding. She told that the canal in community was covered with water plants, called bhuk-tobe-cha-waa (Thai local name). Algae in the canal could not absorb light functioning as an electron activator in photosynthesis. So, algae could not release oxygen, as by-product, from photosynthesis. The plants might cause dirty water and a lower quantity of dissolved oxygen. Her group decided to do the campaign to decrease water pollution in January 2005. The plants were taken out

from the canal. The water was three week monitored. Her group observed the color and smell of the water once a week. They finally found that the smell of water got better. In the report, the group additionally told that they would need higher quality of equipments, e.g. an oxygen detector and longer sticks for keeping the plants. Also, they needed cooperation with the environmental health office for better doing and developing the project.

5.5) Principle V: Having Regard to Culture and Society as Socio-Cultural Perspectives on Teaching and Learning

Because the students assume roles of student, family and society in the classroom and the learning was perceived as functioning of a good citizen in the classroom (Cobb, 1994; Packer and Goicoechea, 2000), the students' living style, views about plants, educational value and school society influencing the learning were regarded for new teaching about photosynthesis. Mrs. Engka considered this teaching to make biology more enjoyable for her students.

5.5.1) Mrs. Engka's Practices on Principle V

Mrs. Engka also perceived investigating the students' views about plants as a basis of correcting her student misconceptions basing on Principle I. She appeared to drag the students' views about the plant to classroom discussion. In the very beginning of Lesson 1, Mrs. Engka firstly came to class with a plant having leaves with stem which was growing in soil. The lesson was introduced by questioning the students what they think about the plant. The students thought in pair and exchanged their ideas about the plant.

The interaction between teacher and student e.g. discussion was improved to support students' classroom participation. As Thai living style, Thai students were unfamiliar with direct discussion with their teacher. Mrs. Engka appeared to improve her interaction with students. "I'm going to improve launching discussion..." she said. She often conducted friendly conversations with the students

inside and outside teaching period. The students were allowed to independently forming the member of group, having a bit of noise for group discussion, walking around group desk for discussion. These performances had mechanically taken place through Lessons 3-7.

Mrs. Engka expected that the formative assessment might bring more students to prefer classroom study. Up to twenty two percentages of all students obviously wanted to learn biology for particular taking of the National Entrance Examination. Seven percentages did not need to study the biology in classroom. She appeared to use formative assessment to promote the biology study. She set up an excellent condition of gaining high level of biology achievement. The students would receive the extra score, if they formally participated in learning activities; or continued to improve their concept mapping.

Mrs. Engka taking charge of head of science department was situated within a set of relation in her school society. She was concerned with maintaining standards and credibility of teaching science. Although she faced on time limitation based on the school events such as sport day, she could actively manage the teaching suitably with the school schedule. Observation and interview indicated that she could adaptively finish all activities before the school midterm examination.

The friendly interactions between teacher and student, formative assessment and maintaining standards and credibility of teaching might enable students to think and develop the understanding about photosynthesis (section 5.2.1 and 5.2.2). Also, they appeared to learn photosynthesis based on their society and culture in classroom. Next section reveals the students' learning.

5.5.2) Students' Learning Based on Thai Society and Culture

Classroom observation of Mrs. Engka investigating the students' views about plants indicated that the students used their perceptions about plants to participate in classroom discussion. The students perceived plants as a resource of

food, air, medicine, place, and cloth. The perceptions were used to discuss the ideas about plant food. The students in think pair square presented their understanding that plant got the energy from their food. However, most of the students held misconceptions that mineral, water and light were the plant food. "...water, light and air are the major food, and fertilizer and mineral in water and soil is the minor food." Additionally, it appeared that students used their everyday experience in the discussion. They believed that peanut shell, egg shell and/or insects were also the plant food. "...the shell provides nitrogen...and some plants need insects for growth... They were the minor food." As the results of the investigation, the students were then corrected the misconception based on Principle I.

The serious respect on the teacher was adapted by the friendly relationship between students and the teacher. The observation and interview with student indicated that they were more familiar to direct discussion with the teacher. The students were appreciated to begin discussing with the in-closed friend and then proposed the ideas to the teacher. Also, the student with friends informally asked the teacher again if they really did not understand the concepts. Sometimes, the students were found to discuss their developed knowledge to each other in their group. Also, they moved to the front of classroom and sat on floor to look at the teacher's transparencies when they hardly saw the transparencies at the back of classroom.

Students' positive attitude towards learning in the classroom was found after Mrs. Engka's biology assessment was changed. The students received the extra score from participating in learning activities. The score could be counted as doing the concept test of the biology subject. Interview with S03 was strongly evident the attitude. The students appeared to enjoy the group cooperation for participating in classroom discussion. "...Our group set up the group representative to present the group ideas answering the teacher's questioning during the discussion. Being the group representative was turned to each member in the group. This was for our opportunities to the discussion."

5.6) Principle VI: Encouraging Students to Participate in Learning Activities

Students' engaging in thinking what to do, inside and outside period, rather than students' passively listening to teachers was hoped by this research. The students were expected to form a meaningful learning style of classroom studying. What the teacher had done basing on this principle is described below.

5.6.1) Mrs. Engka's Practices on Principle VI

Mrs. Engka appeared to use small group discussion for the large number of students in her classroom. She challenged the students to make a decision or answer question through small group discussion. The students would pair up with someone sitting near them, verbally shared their answers and worked together to create a final answer. Mrs. Engka randomly chose a few pairs to summarize answers.

Mrs. Engka appeared to develop the students' perspective on what learning belief values in studying science. The students were expected to have better sense of what they needed to do and what they needed to learn in classroom. She told that "I improved the launching strategy..., [because the students] were unconvinced by classroom discussion...they were convinced of listening and taking note rather than talking with me..." The students frequently asked her to give them a lecture as usual, but in spite of that, she kept on answering them "the discussion would help you lot better of learning..."

5.6.2) Students' Participation

The students' enthusiasm in participation was considered to support implementing the teaching unit. Some examples of observation illustrated that they continued to read the booklets and revise the concept map. They themselves were willing to organize the group work to prepare learning materials and group

responsibility to participate in classroom activity. For example, they made drawings of a shirt, a skirt, or a car to participate in the role play.

Interviews with students also indicated that participating in learning activities was valued for better learning in classroom study. For example,

Researcher: What else would you like to say [about the teaching]?

S01: Initially, I don't much understand the content. There was only doing an activity...until the time was gone I could understand...

Researcher: Did you think this teaching differs from usual?

S01: Yes, I did.

Researcher: How was the difference?

S01: ...um...I would like it if there was less homework such as worksheets and activities, but I knew this wasn't really a good thing (laugh). The discussing activities had brought thinking..., cheerfully brought us sharing our ideas, being enthusiastic, and convincingly participating in...

S02 also noted that he got enough chance to share the ideas with others questioning the class and then was not sleepy as ever. S01 also noted that his learning performance was changed. He initially did not prefer the new learning way which he had to do a large number of activities, but he now felt satisfied. Mrs. Engka then supported that the students often participate in group discussion, and "...they more often came and asked me whenever they struck with their photosynthesis ideas."

It seemed to this study that Mrs. Engka adhered strongly to practice ideas of the six principles of the intervention. The summary of the practices and the impacts on the students' learning in the context of this study is noted next.

6. Summary of the Border School

In this case study, the teacher's belief of how students learned, content knowledge and formative assessment impacted to the teaching and the learning about photosynthesis. Although the teacher was not confident in her chemical knowledge involved photosynthesis, the teacher believed that teaching by an emphasis on lecturing could not longer develop the students' learning about photosynthesis. Also, the teacher was interested in student-teacher interactions for better learning and happiness in classroom study. Then, the teacher appeared to use several learning activities, e.g. think pair share, classroom discussion, game, cooperative learning, concept mapping, experimentation, historical narratives, role play and science project. The findings showed the students' enhanced understanding of photosynthesis and its relation in environment, and nature of science. After the students could correct misconceptions, such as plant food and plant materials, they developed the understanding of advanced photosynthesis concepts, in particular dark phase. As well as, they could apply photosynthesis knowledge to relate environmental conservation. The understanding of nature of science was fully addressed. The majority of the students understood that scientific idea is subjected to change, that science demands evidence and that science is a complex social activity. However, the students were found to have some difficulties of understanding chemical concepts involved the light phase and the necessary factors affecting photosynthesis rate.

In addition, the teacher appeared to regard on students' view about plant, friendly interactions and attitudes towards biology study, and to emphasize formative assessment. Those might bring some confidence in classroom participation to the students. They were more enthusiastic to participate in group work and learning activities.

Next, the case study of the Market School has been described.

The Case Study of the Market School

1. School Contexts

This second public high school was called the “Market School”. It was located near the boundary of the province, around Bangkok suburban area. The school was established in 1904, and located within a market area and local bus station. The school aimed to be a top ten of school learning resources and develop student learning potential, morals and ethic. The entire population of the school was approximately 3,200 students and 141 teachers. The school had twelve classrooms each in Level 3, Grades 7 – 9, and ten classrooms each in Level 4, Grades 10 - 12. Each Grades 7 – 9 classroom had 55-60 students, and each Grades 10 - 12 classroom had 40-45 students.

During 7.40 – 8.20 a.m. students and teachers began their day with singing the national anthem, and clasping their hands and giving thanks to the country, to Buddha and to the king, which upholds the Buddhist faith. On Friday morning, they had special events such as the school leader gave a speech to students and the sport day preparation was operated. In school, students wore the school uniforms. Then, the teaching period started at 8.10 a.m. and finished at 16.10 p.m. There were seven one-hour teaching periods and one hour of lunchtime.

In the science department, most of teachers worked together in the room of the science department, but the participant teacher, Mr. Vyn, worked at the room of Scout Association. Occasionally, Mr. Vyn met all teachers in the department. The head of the science department would contact Mr. Vyn by visiting his teaching class periodically.

2. Background Information about Mr. Vyn

2.1) Educational Background and Teaching Experience

In 1978, Mr. Vyn was a beginning teacher, a senior high school biology teacher, at the Market School. He was now forty nine years old, and had taught about advanced photosynthesis in Grade 11 for twenty six years. He graduated with a Bachelor of Education (Biology Teaching) degree and a Master of Science (Botany) degree. In this semester, he was going to teach about Grade 11 advanced biology, but was not going to teach about Grade 11 basic/introductory biology. Mr. Vyn also taught about science in Grade 7 and scout association in Grades 7 through 9. Totally, Mr. Vyn had twenty one periods a week.

Mr. Vyn would like to teach biology because he preferred to study living things, nature and environment. Mr. Vyn perceived understanding of nature of science as understanding of natural laws of science, and was confident in his strong content knowledge in biology. He adopted a self style of presenting biology contents by rearranging the contents order and using transparency to support his lecture. However, he felt constrained by the school policy which assigned teachers to teach in too many periods a week in the school and a large number of students in the classroom.

2.2) Mr. Vyn's Students Information

There were forty Grade 11 students, thirteen boys and twenty seven girls, in Mr. Vyn's three periods on Monday and Friday. Twenty one were aged sixteen, sixteen were aged seventeen, two were aged eighteen and one was aged fifteen. Mr. Vyn described the class as a high competent student. They had highest average of all class in Grade 11. Most of his students were above average. Their biology achievement score was 2.90 averagely (Table 5.6). Nobody studied biology with private tutorials. The students' opinion towards the biology learning varied considerably. Nineteen would like to learn biology for their everyday life, nine would

like to learn the biology for the examination and graduation, four would like to learn biology for developing their world understanding, but seven students did not like to attend the biology classroom because they thought they could read the biology textbook by themselves, one student had no ideas about learning biology.

Table 5.6 Biology Achievement of Mr. Vyn's Students

| Biology Achievement | Students (number) |
|---------------------|-------------------|
| (Score 4.0) | 5 |
| (Score 3.5) | 4 |
| (Score 3.0) | 19 |
| (Score 2.5) | 6 |
| (Score 2.0) | 5 |
| (Score 1.5) | - |
| (Score 1.0) | - |
| (Score 0) | 1 |

There were four students who were selected purposively to be studied in depth concerning their development of photosynthesis understanding. The selection was based on gender, age, biology achievement, and attitudes towards biology. Career of the parent was also considered to reveal the student's society at their place, outside the classroom. The four students were called S05, S06, S07 and S08. Table 5.7 shows information of the students

S05 was eighteen years old, and desired to move in the school for better study than his old school. His mother was a teacher and his father was a retirement. He individually lived at his aunt place near by the school. Outside formal schooling studying, S05 seriously studied biology by himself, did not study biology with any private tutor. He learned biology to support his future career, doctor. He thought that teaching by lecturing was boring for him, and he liked teaching based on discussion and problem solving. His biology learning achievement score was 4.0 and GPA was 3.84.

Table 5.7 Mr. Vyn's Students Selected as Participants in the Case Study

| Categories | Students | | | |
|-------------------------------|---|---|--------------------------------------|---|
| | S05 | S06 | S07 | S08 |
| Gender | Male | Male | Female | Female |
| Age | 18 | 16 | 16 | 16 |
| Biology Achievement | 4.0 | 4.0 | 3.5 | 3.0 |
| Attitudes Towards Biology | I like to study biology...b/s I wants to be a doctor. | Biology is necessary for living...even I wants to be an engineer. | I learn biology for everyday living. | Biology was too difficult for understanding ...it had too much information. |
| Parent Career (Father/Mother) | Retirement/Teacher | Irrigation officer/Employee | Army officer/Banking officer | Industrial / government employee |

S06 was sixteen years old, had a twin brother studying biology in the class and lived with the parents. His father was an officer in irrigation department, and his mother was an employee. He thought that biology was necessary for his living even his requirement of being an engineer unexpected the biology from him. He usually studied biology by himself. His biology achievement was 4.0 and GPA was 3.95.

S07 was sixteen years old, and lived with the parents. Her mother was a banking officer, and her father was an army officer. She was only a girl in the class who believed in Islam. She would like to learn biology for her everyday living. Her interest in biology depended on how teacher teach biology. *"I like participating in the activities rather than listening to a lecture."* She was quite familiar with Mr. Vyn, and often was asked to participate in the teaching. Her biology learning achievement score was 3.5 and her GPA was 3.92.

S08 was sixteen years old, very shy and lived with the parents. Her father was an industrial employee, and her mother was a government employee. Her

biology learning focused on attempting to remember all content of biology. *“Biology was so difficult to understand...I couldn’t remember all content...it had too much information.”* However, she disliked the teaching emphasized lecture, and believed that teacher had never known what she had learned in the class. *“I don’t think he knew what I learned...he just kept talking on and on...and did not answer when he was asked [by the student].”* Her biology learning achievement score was 3.0 and her GPA was 3.81.

3. Mr. Vyn’s Beliefs about Teaching and Learning

According to the classroom observations and the discussion with Mr. Vyn during informal interviews throughout the study, his tradition of teaching was found as lecturing. The students independently noted whatever they wanted and talked to each other during his lecture. Mr. Vyn perceived that students could not learn without directly telling all concepts in/about science. *“They must learn from teachers who gave them advice...they could then be further critical thinking and inquiry by themselves”*, he said.

Mr. Vyn was not enthusiastic about the importance of students’ interactions in learning activities, but was critical of the time which students spent discussing during his periods. He believed that interactions had not brought better learning to students and that forming members of students’ group discussion was a waste of time. He believed that *“whenever the students talked with friend for sharing ideas, they would just put the ideas on and on...there was neither the summary nor the critique...”*

In accordance with the belief, Mr. Vyn had not perceived role of teaching as monitoring student progress, assessing learning, providing learning resources and assisting students to find out results of investigations. He often unfortunately provided students with worksheets or paper learning tasks. The students needed to do the tasks while he was lecturing. As the results, Mr. Vyn sometimes preferred to avoid whole class activity. Interacting with students who were not ready for the teacher was perceived as stopping the flow of the lecture.

Mr. Vyn had his own style of teaching that emphasized remembering abstract photosynthesis concepts, definitions and formulas. He always short noted his lecture and students' assignment on the board and used abbreviation, a short form of word to represent the concept. In some instances, he noted 'LR' and 'DR' to represent the meaning of 'light phase' and 'dark phase' respectively. In addition to the lecture, this was shaped by his experience in learning biology based on his old textbook. For example, he used RuDP, old abbreviation for Ribulose Bisphosphate, instead of RuBP, new abbreviation.

4. Mr. Vyn's Planning

In the role as head of Scout Association in the school, Mr. Vyn's priority was to plan for teaching Scout Association in Grades 7-9. In informal interviews, Mr. Vyn noted that he did not plan for teaching about photosynthesis. Frequently, he was found leaving the classroom during periods to collect equipment, students' worksheet or teaching materials. In terms of content planning, he typically used transparencies to introduce specific content in a lecture.

Because of experiencing in Botany, Mr. Vyn's science content knowledge was strong. He could concentrate on probing students' conception for management of learning activities. However, the probing which took account of students' difficulty to learn photosynthesis concepts did not appear in his planning. Some teaching activities such as discussion and concept mapping based on the unit were considered as a supplementary teaching for students' positive attitude towards learning biology. The activities were not used to overcome the difficulty. He yet taught about the concepts using his lecture as usual.

Mr. Vyn addressed that he could not conduct students' group activity because the teaching room was not belonging to the science department. He was not allowed to reset positions of students' tables and stools even though there was available back space in the classroom. So, his classroom setting organization was limited. He, then, could not walk into center of the room for monitoring the group learning.

Figure 5.2 shows the teaching room setting. There were six 100 x 200 x 80 cm. and nine 60 x 120 x 80 cm. student tables, one 200 x 100 x 80 cm. and two 80 x 100 x 80 cm. teacher table, forty seven stools, four ceiling fans, six electric light bulbs, four cabinets, a television, two sinks and an overhead projector.

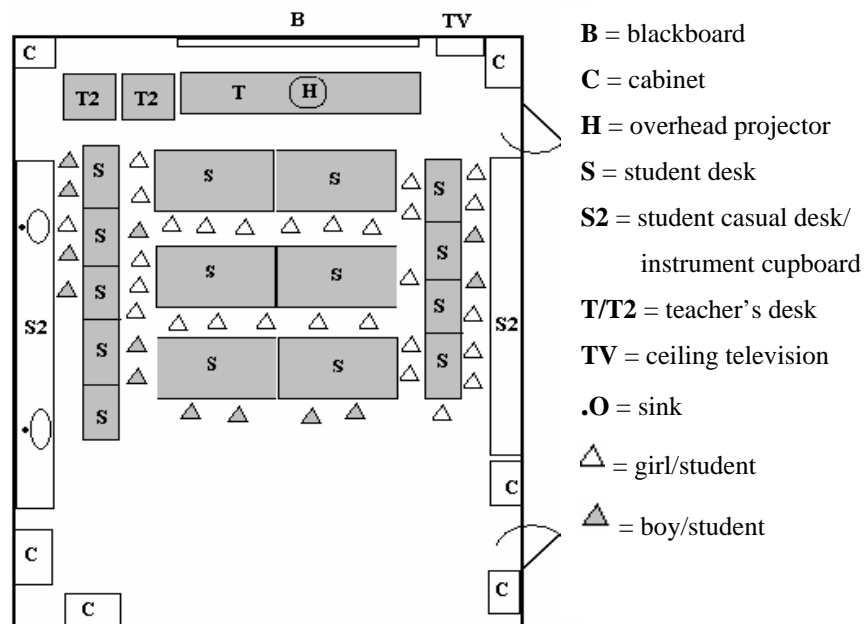


Figure 5.2 Mr. Vyn's Classroom Setting in the Market School

Mr. Vyn implemented the teaching unit for four weeks. He began the implementation on the 29th October 2004. This study has described the implementation in terms of Mr. Vyn's practices in classroom. Surveys, classroom observations and interviews were used to indicate the students' understanding as the impacts of the implementation. Because the teaching unit was developed basing on the six principles, describing focused on the practices and the understanding involved the principles. Then, this study also reveals the progress of some students who were purposively selected to study in depth.

5. Mr. Vyn's Implementation of the Intervention and the Students' Understanding Based on the Six Principles

5.1) Principle I: Correcting Grade 11 Students' Misconception about Introductory Photosynthesis

Before Mr. Vyn implemented the teaching unit, the findings of the Introductory Photosynthesis Survey (IPS) illustrated that his students held misconceptions about the introductory photosynthesis concepts. Half of students held misconceptions about plant food and partial understanding with misconceptions about plants and light energy and plant materials. Almost half of students had no ideas about simple photosynthesis processes and equations. However, they sound understood about role of chlorophyll. Here is briefly what the misconceptions early held by the students.

There were fifty percentages holding misconceptions about *plant food*. They thought that mineral, fertilizer and water were plant food because plants used those to grow; mineral, fertilizer, H₂O, CO₂, light and chlorophyll were plant food because plants used these to photosynthesize and/or to grow. Also, forty percentages were holding partial understanding with misconception about plant food. They understood that sugar was plant food, but thought that mineral was also plant food.

Partial understanding with misconception about *plant and light energy* was held by fifty percentages. They perceived plant materials, such as CO₂, as an energy supply of photosynthesis. Not only light but also CO₂ were addressed as the energy supply by the students. However, there were thirty seven percentages holding scientific ideas about plant and light energy. They understood that sunlight supplied the energy. The results also indicated that students who misunderstood that chlorophyll was the plant materials thought that chlorophyll also supplied the energy.

Fifty percentages held partial understanding with misconception about *plant materials*. They perceived sunlight, chlorophyll and CO₂ as plant materials used

to photosynthesize. Additional twenty eight percentages held scientific understanding that CO_2 and H_2O were materials of photosynthesis.

Forty eight percentages, almost half students, had no ideas about simple photosynthesis processes and equations. A student noted that “I could not remember its equation.” Additional twenty five percentages were holding partial understanding with misconception. They learned to recall all substances involved photosynthesis to draw the equation. Not only plant materials, CO_2 and H_2O , but also light and chlorophyll were perceived as substrates of photosynthesis process.

Almost all students had scientific understanding about *role of chlorophyll* in plants. Ninety percentages understood that green plants used chlorophyll to photosynthesize.

Holding the introductory misconceptions might be a weak point of developing the students’ understanding about photosynthesis. Mr.Vyn’s practice involved correcting the misconceptions, thus, was considered in this study.

5.1.1) Mr. Vyn’s Practices on Principle I

Classroom observations and the interviews indicated that Mr. Vyn consistently corrected the Grade 11 students’ misconception about introductory photosynthesis. He appeared confident to elicit students’ misconception using the game “Circus of misconceptions (True or False) in Lesson 1. All students in pair would be expected to discuss the introductory statements struck on the wall. They independently made decision whether the statements were true. However, Mr. Vyn perceived himself as a major resource of the science content. He also appeared to adapt the way of playing the game. He wrote the statements on the board, and questioned whole class students for making decision on the statements. Then, he directly justified the decision. There was no students’ discussion and students’ self evaluation using the worksheet “what is plant food?”

Mr. Vyn: ...No. 4...mineral is plant food, isn't it?

Students: Yes.../No...(noisy)

Mr. Vyn: it must be 'no'...plants use mineral as catalyst or enzyme...so, it isn't plant food...

The survey and interviews with student consequently indicated some alternative change of students' conceptions. This study explains overview of the change of whole class students and then details the conceptual change of four students studied in depth.

5.1.2) Students' Understanding about Introductory Photosynthesis

According to whole class students, the surveys indicated that students incompletely corrected the misconceptions. Although most of students understood plant food, the misconceptions about plant and light energy and plant materials were found.

Twenty three percentages strongly retained holding misconception about plant food. They understood that $C_6H_{12}O_6$, in terms of monosaccharide, was plant food, but they retained that H_2O was also plant food.

Light was not recognized as energy resource of photosynthesis. Eighteen percentages broadly addressed that plants needed light to photosynthesize, but they could obviously not identify roles of light which supplied energy for photosynthesis.

The survey did not indicated students' conceptual change about plant materials. However, holding new misconception about plant materials was found obviously. The students' misconception that 'light was plant materials' were substituted with the new misconception that 'light activated enzyme to absorb light...' The new misconception indicated mixing the misconception between light energy and plant materials.

In addition to observation and individual interview with four students, the finding supported that the students incompletely corrected the misconceptions. The correcting possibly depended on students' opportunities for participating in discussion and evaluation. S07, the girl who often was asked to participate in the practices could correct her misconceptions about plant food. The misconception that "... mineral and fertilizer were plant food..." was not longer found. She now understood that plants produced $C_6H_{12}O_6$ as carbohydrate, this was plant food. Plants use H_2O and CO_2 as two materials of photosynthesis. However, this study found that some misconception was limited by holding of some misconception unorganized in the teaching unit. For example, the conceptions of light that supplied energy for photosynthesis, was confused with the conceptions about energy for respiration. She appeared to hold misconception that light *indirectly* supplied the energy for photosynthesis. She thought that plant food, which supplied energy for respiration, directly supplied the energy for photosynthesis;

In addition to S06 and S08, the students who received less opportunities in the teaching participation, incompletely corrected the misconceptions. S06, who studied biology for everyday living, still had difficulty to understand plant food. Although his misconception that soil was plant food because it provided mineral for plants, was corrected, he unclearly understood where the food came from. S06 thought that $C_6H_{12}O_6$ was plant food, but perceived that C atom of $C_6H_{12}O_6$ was mineral that plants sucked from atmosphere. Also, new misconception about plant material was found. He understood that CO_2 and H_2O were materials of plant photosynthesis, but he thought that plants did not need H_2O when photosynthesis took place in dark. In addition to plant and light energy concept, his scientific conception was changed into misconceptions. He thought that sunlight supplied heat, in stead of energy, for photosynthesis.

S08, the student who disliked lecturing but believed that learning biology was remembering all content of biology, incompletely corrected the misconception about plant food, plant material and plant and light energy. S08 understood that sugar was plant food; H_2O , O_2 , mineral, fertilizer and CO_2 were not.

The misconception that CO₂, mineral and chlorophyll were supplying energy for photosynthesis was not longer found. However, S08 perceived that sunlight was an unnecessary factor of photosynthesis because plants could photosynthesize in dark. Also, S08 perceived that plants did not need H₂O when the plants photosynthesized in dark.

In case of S05, who was aged 18 and seriously studied of biology by himself, he could completely correct the misconception even his opportunity to discussion was not obviously found. His misconception about plant food – water, mineral, and CO₂ are plant food..., was correctly substituted by the scientific concept – glucose was plant food. His scientific understanding about plant and light energy, plant material and role of chlorophyll were continued along the teaching unit.

Table 5.8 shows the four students' conceptions about introductory photosynthesis before/after teaching.

Although the students incompletely corrected the introductory misconceptions, the students were needed to understand the advanced photosynthesis based on Thai National Science Content Standards.

5.2) Principle II: Enhancing Grade 11 Students' Understandings about Advanced Photosynthesis Concepts

5.2.1) Mr. Vyn's Practices on Principle II

Mr. Vyn believed that students must learn from teachers. Also, he perceived his role of teaching as covering the photosynthesis contents for the end-of-topic examination. Enhancing the understanding about advanced photosynthesis concepts appeared to be focused on lecturing. Observation and interview indicated that he often lectured all advanced photosynthesis concepts before he implemented learning activities of the teaching unit. Also, he personally reorganized the teaching sequence in the unit.

Mr. Vyn firstly described processes of the light dependent phase before he taught the structure and functions of chloroplast using closed-end questions and experiment. There was no prior discussion about problems or experimental design. Also, observations indicated that Mr. Vyn sometimes avoided discussion based on students' answers or questions.

Mr. Vyn: ...where does the photosynthesis equation take place?

Students: Leaves.

Mr. Vyn: Everything's taking place in chloroplast...and where does the chloroplast take place?

Students: Leaves.

Mr. Vyn: Leaves or other parts [of plants]?, however it's mostly in leaves...you [must chronologically remember] that photosynthesis is in chloroplast, chloroplast is in cell, and cell is in leaves...what we learn is in an organelle

which functioning photosynthesis. In your study in Grade 10, what's the chloroplast looked like?

Students: Bean.

Mr. Vyn: Really? (Mr. Vyn did not discuss this point)...What is in the chloroplast?

Students: Chlorophyll.

Mr. Vyn: the chloroplast contains pigments called chlorophyll...and [the chloroplast] contains other pigments in red, yellow, and orange colors...

Teaching about the light phase in Lesson 4 and the dark phase in Lesson 5 focused on presenting the concepts in an abbreviation form (see Figure 5.3). Teaching did not appear to focus on what and how students learn. The students were not asked to listen, copy and note the lecture intently. On the other hand, they were asked to complete the worksheets of game, cooperative learning, and group discussion while the teacher was lecturing about oxidation-reduction, endergonic and exergonic reactions, photosystem, light and dark reactions and C3-, C4- and CAM-plants.

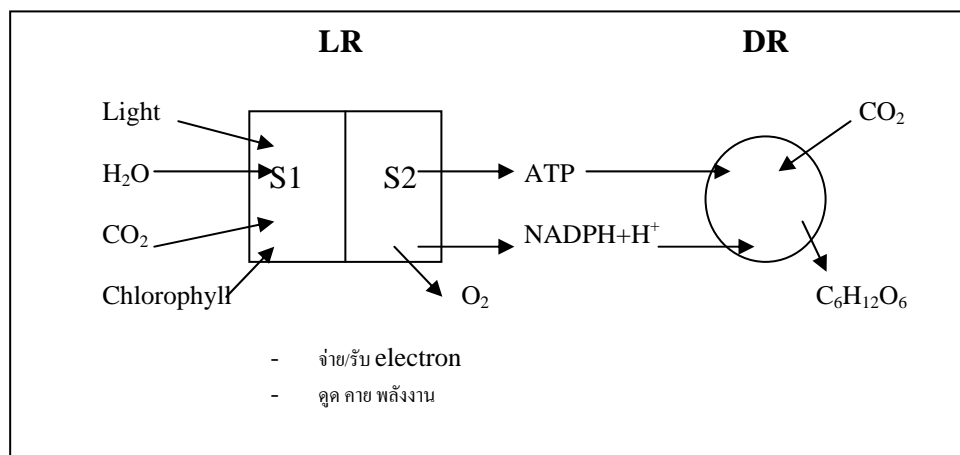


Figure 5.3 Mr. Vyn's Lecture about Photosynthesis in Classroom

Mr. Vyn appeared to avoid the laboratory activities involved solving problem about the *necessary factors affecting photosynthesis rate* in Lesson 6 by lecturing. The students were unpredictably asked to produce a three dimensional

model of chloroplast structure based on Lesson 3. Observation did not indicate that they had discussion about relationships between the structure and the functions of chloroplast in classroom. On the other hand, the teacher additionally lectured about photorespiration and plant translocation based on own teaching organization.

As results of Mr. Vyn's practices, observation and survey indicated that students could not follow all concepts of his lecture. Half students were doing assignments of English subject during the lecture. The study also found that the students held misconception about advanced photosynthesis concepts.

5.2.2) Students' Understanding about Advanced Photosynthesis

The survey and observation indicated that most of Mr. Vyn's students developed the understanding about light independent (dark) phase. However, less than half of the students developed the sound understanding about the dark phase. Most of the students had partial understanding about light dependent (light) phase and chloroplast structures and functions and necessary factors affecting photosynthesis rate in terms of its relationships.

Less than half students, there were forty three percentages, developed sound understanding about *Light independent (dark) phase*. Plants use CO₂ to produce plant food. Also, holding various misconceptions about the dark phase was found through thirty eight percentages. The survey and interview with students also indicated that photorespiration personally taught by Mr. Vyn confused the students' distinguishing between photosynthesis and respiration. The students thought that the dark phase was the respiration or was photosynthesis in night. For instance, the dark phase was respiration of plants, used O₂ and released CO₂, produced ATP, absorbed light for respiration, and produced O₂ for respiration. Haslam and Treagust (1987); Songer and Mintzes (1994); Kijkuakual and Yutakom (2002) supported that teaching about respiration in parallel with photosynthesis without carefully organizing concept order might cause of holding the misconceptions. The students only perceived the respiration and the photosynthesis in

terms of gas exchange. There was unawareness of energy conversion in photosynthesis and metabolism in respiration.

Observation and interview indicated that the understanding of *light dependent (light) phase* might be prevented by Mr. Vyn's belief of teaching role. Student-teacher interaction did not appear to be conducted enough for monitoring the students' progress and assessing the students' learning. "I don't think the teacher knew what I learn..." A student noted. The students could not immediately evaluate themselves what they really learned and should improve to develop the understanding. Therefore, it appeared that most students, sixty three percentages, had just partial understanding about the concept. Ten percentages had the sound understanding that light separated water to produce the primary electron. Up to eighteen percentages had no ideas about the concept. They just broadly explained that light was a factor of producing food.

Also, teaching emphasizing on lecture might bring nobody (0%) to understanding of *structures and functions of chloroplast*. Thylakoid membrane is absorbing light energy, and stroma is fixing CO₂. Hands-on activities, e.g. experimenting pigment of chloroplast and additionally producing a three dimensional model were used. However, minds-on activities, e.g. discussing about relationships between the structure and the functions of chloroplast did not appear to support the hands-on activities. The survey indicated that sixty three percentages, over half students, had just partial understanding about chloroplast. They thought that chloroplast had only one function i.e. light absorbing. Also, twenty five percentages believed that chlorophyll on the membrane was fixing CO₂.

It did not appear to this study that lecturing with skipping the laboratory activities promoted the understanding of *the necessary factors affecting photosynthesis rate*. The survey indicated that a majority of students, forty five percentages, had partial understanding. They understood that type of enzyme and number of leaf limited CO₂ fixation, but they could not describe the relationship between type of plant leaf tissue and the fixation. C₄ plant tissue has mesophyll and

bundle-sheath cells. Both cells contain chloroplast fixing CO_2 . C3 plant tissue contains just mesophyll cell. C3 plants less fixed CO_2 than C4 plants. Eighteen percentages did not concern to the relationship: “ CO_2 was fixed in the light phase more than the dark phase.”

Interviews with the students, S05, S06, S07 and S08 also indicated that the understanding of advanced photosynthesis concepts was not fully developed based on the students’ learning potential.

S05 holding scientific concept about introductory concepts and seriously studying biology could develop only sound understanding about dark phase. Also, he just held partial conceptions about structure and functions of chloroplast and necessary factors affecting photosynthesis rate. He held some misconception about light phase. The key idea of those concepts was often missed. Some instances in chloroplast concept, he noted to chlorophyll and stroma of the chloroplast, but he did not describe function of the stroma. His extent was only in function of the chlorophyll.

S06 who incompletely corrected the introductory misconceptions could not fully understand about the advanced concepts. S06 understood entire processes of light and dark phases, but misunderstood about relationship between the two phases. He perceived that plants had two types of photosynthesis separately. First type was ‘photosynthesis’ in day time, called LR or light reaction, and second type was ‘photosynthesis’ in dark area, called DR or dark reaction. The two types individually required materials and synthesized products.

S07 certainly correcting the introductory misconceptions and often having chances of the classroom participation developed sound understanding about dark phase and necessary factors affecting photosynthesis rate. S07 understood that plants used enzyme to fix CO_2 in dark phase and to make $\text{C}_6\text{H}_{12}\text{O}_6$. She also understood that C3- and C4- plants differently fixed CO_2 . However, her misconception about the light phase involved oxidation-reduction was found. She

perceived oxidation number of O-atom which was two minus (O^{2-}) as the symbol of electron. So, she thought that electron in photosynthesis came from O-atom of H_2O , not came from H-atom.

In addition to S08 who disliked the teaching and incompletely corrected the introductory misconception, she held some misconceptions about all concepts of advanced photosynthesis. For example, S08 thought that chlorophyll in chloroplast was fixing CO_2 , not absorbing light. O-atom of H_2O and CO_2 was perceived as symbol of electron. She thought that both H_2O and CO_2 released electron and oxygen gas in photosynthesis.

Table 5.9 shows the students' conceptions about advanced photosynthesis.

Table 5.9 Advanced Photosynthesis Concepts of Mr. Vyn's Students Selected as Participants in the Case Study

| Concepts | Students | | | |
|---|---|---|--|--|
| | S05 | S06 | S07 | S08 |
| Structures and Functions of Chloroplast | Chloroplast contains pigment absorbing light and stroma placing in photosynthesis (PU) ⁸ | Chloroplast contains chlorophyll absorbing light and fixing CO ₂ . (PU+MU) | Chloroplast contains chlorophyll for photosynthesis. (PU) | Chloroplast absorbs light to activate chlorophyll. (PU+MU) |
| Light Dependent (Light) Phase | H ₂ O is material for producing oxygen,... and the oxygen releases e ⁻ . Light initiates transfer of e ⁻ . (PU+MU) | Light causes of heat that separates H ₂ O to provide the electron and O ₂ . The light phase takes place only in day time. (PU+MU) | H ₂ O is separated to produce ½ O. This O then releases e ⁻ . (PU+MU) | H ₂ O and CO ₂ transfer e ⁻ . H ₂ O is source of sugar, O ₂ and electron. H ₂ +O ₂ ²⁻ → H ₂ O (PU+MU) |
| Light Independent (Dark) Phase | CO ₂ is material providing C-atom...for C ₆ H ₁₂ O ₆ , plant food. (SU) | CO ₂ is changed to C ₆ H ₁₂ O ₆ , plant food. The dark phase takes place only in night time. (PU+MU) | ...enzyme catches CO ₂ ...to make C ₆ H ₁₂ O ₆ , carbohydrate. (SU) | CO ₂ is reduced to sugar, plant food. O-atom in CO ₂ also provides O ₂ gas.(PU+MU) |
| Necessary Factors Affecting Photosynthesis Rate | Number of leaf and amount of stoma affect the rate. High number and amount causes high rate. (PU) | High number of chloroplast causes high CO ₂ fixation rate. (SU) | C3-plants and C4-plants have different enzyme fixing CO ₂ , so their photosynthesis rate is different too. (SU) | Each plant has different amount of chlorophyll fixing CO ₂ , so the rate is different. (PU+MU) |

⁸ SU = Sound Understanding, PU = Partial Understanding, PU+MU = Partial Understanding with Misconception and MU = Misunderstanding

5.3) Principle III: Integrating Nature of Science into Photosynthesis Using Historical Narratives to Illuminate the Nature of Science (IPST, 2002)

Understanding the nature of science based on the National Science Curriculum (IPST, 2002) was perceived as important as understanding the photosynthesis concepts based on the teaching unit. Historical narrative was theoretically chosen as an effective way to illuminate the nature of science. Three aspects in science integrated in the concepts are that scientific ideas are subjected to change; that science demands evidence; and that science is a complex social activity.

5.3.1) Mr. Vyn's Practices on Principle III

Mr. Vyn perceived understanding of nature of science as understanding of natural laws of science. He appeared to lecture all ideas about the three aspects of science on board. There was no discussion between the teacher and students in the classroom. Historical discoveries of chloroplast and light and dark phases were assigned as reading homework. Figure 5.4 shows the lecture about the nature of science.

| <u>Nature of Science</u> | <u>Inquiry</u> | <u>Scientists</u> |
|--|-----------------------|--------------------------|
| - changeable by evidence and reason slowly | - experimentation | - systemic |
| - explainable/ confirmable | - fossil | - ethic/moral |
| - can not provide all answers | - evidence | - observe |
| | | - no bias |

Figure 5.4 Mr.Vyn's Lecture about Nature of Science in Classroom

Also, Mr. Vyn appeared to use historical narrative a supplementary learning activity for positive attitude towards learning biology. The students were asked to prepare role play activity, called 'Act as scientists' after he finished all lecture about the nature of science. Here the students independently played the roles in the school conference room, not in the lecture room as usual.

However, there was no discussion about a complex social activity of science based on the teaching unit.

After Mr. Vyn's practices, the survey and the interviews were used to indicate students' varied understanding about the nature of science in the three aspects including scientific ideas were subjected to change; that science demanded evidence; and that science was a complex social activity.

5.3.2) Students' Understanding about the Nature of Science

The survey indicated that students were ambiguous in understanding the nature of science. Most students understood way of finding scientific evidence demanded for supporting scientific ideas. Half students did not believe that scientific ideas could be changed. Half students believed that scientists cooperatively developed the ideas.

A majority did not gain the understanding of the aspect that scientific ideas are subjected to change. Although forty eight percentages understood that disproved or detected error theories and laws of previous scientists could be substituted by new theories and laws. The rest of the students, fifty two percentages, thought that the previous theories and laws had not been changed. For example, they believed that change appeared in term of application of previous knowledge; previous knowledge was not changed actually. Scientific theories which were proved true many times by correctly experiments and then became a law would not be changed.

All students perceived the aspect of science that scientists demanded evidence to support their ideas in/about science, but they held varied conceptions about ways of finding the evidence. Ten percentages focused on process or method of science as the way of finding the evidence. Fifty five percentages perceived that scientists used investigating, searching and experimenting to find out an acceptable explanation, the evidence of science. A minority, twenty percentages,

however, perceived science as body of thought. There was no practicing on science. Scientific knowledge particularly came from scientists' thinking.

About half students, fifty three percentages, obviously understood that science is a complex social activity. The students noted that scientists had not worked individually. The present scientists' discovery is being built up on previous scientists' discovery. The scientists in many fields share their ideas or their results to advance scientific knowledge. Arguments among scientists have brought development of scientific knowledge.

The survey, observation and interview with the students indicated that the lecturing could not fully illuminate the understanding of nature of science in three aspects. The students' understanding about the nature of science possibly depended on the enough opportunities to participate in learning activities especially discussion and role play.

S05, who seriously studied biology by himself, but had fewer opportunities to participate in the learning activities, did not perceive that scientific ideas were subjected to change. Also, he did not think that scientists needed to cooperate with others for development of the ideas and knowledge. He just understood that scientists demanded evidence to support their ideas. "...They used different types of experiments and different techniques..."to acquire the evidence.

S06 who studied biology by himself and had opportunities to act as a scientist in the role play activity, understood that scientific ideas could be changed and that scientific ideas was developed by several scientists. The scientists observed, questioned, experimented, searched for new knowledge and discussed the ideas to each other.

It was not obvious to S07 that scientific ideas were subjected to change and that science was a complex social activity. She appeared to repeat Mr.Vyn's lecture with unclear understanding. S07 thought that science appeared to

change in term of application of old knowledge; old knowledge was not actually changed. The scientists individually experimented and developed the knowledge.

S08, who disliked studying biology but had opportunities to act as a scientist in the role play activity, obviously understood that scientists worked with others. “[Scientists] find out something that could be compared by others. If these things agree with their ideas, a new theory could be constructed...” she noted. However, S08 perceived that correct experiment done by scientists yielded unchangeable ideas of science. Science appeared to be changed because the application of the old ideas.

Table 5.10 shows the students’ conceptions about nature of science in its three aspects.

Table 5.10 The Nature of Science of Mr. Vyn’s Students Selected as Participants in the Case Study

| NOS Aspect (Questions) | Student Conceptions of the Nature of Science (NOS) | | | |
|--|--|---|--|--|
| | S05 | S06 | S07 | S08 |
| 1. Scientific ideas are subjected to change. Q: Why had the scientific ideas been changed? | “...knowledge accumulated from research and teaching experiences urged them to try new experiments using new methods which might produce new findings, new knowledge.” | “In the past, scientists might have poor quality equipments and might indicate the results without experiments ... ” | “...because of the accumulated experiences and inquisitive nature of human beings together with scientific habits.” | “...they adapted old concepts for present utilization.” |
| 2. Science demands evidence. Q: Why did the scientists need to do the experiments? | “...to uncover the hidden truth unknown by others to provide support...” | “...to obtain a more concrete conclusion.” | “...to answer their questions through experiments.” | “...to find out about something that could be compared by others. If these agree with their ideas, a new theory could be constructed...” |
| 3. Science is a complex social activity. Q: How did the scientific knowledge come about? | “...they used different types of experiments and different techniques...” | “...they observed, questioned, experimented and searched for new knowledge to discuss ideas of the others...” | “...they thought, observed, experimented and were aware of their questioning. | “...they questioned...and then tested... The results needed critiqued by the others. |
| The summary of ideas about the nature of science. Q: How had the photosynthesis knowledge been developed? | “...photosynthesis was developed by previous scientists...using scientific process...and attempts...” | “Photosynthesis was developed by the cooperation between scientists such as Calvin and Benson...then new scientists experimented and searched for new knowledge.” | “...human observed, questioned natural phenomena ...and tried to find out the answer through experiment. They continuously thought to add more information about the knowledge.” | “...the development came from scientific habit of minds. People who were really interested in photosynthesis could develop the knowledge...” |

5.4) Principle IV: Enabling Students to Relate Photosynthesis Knowledge to Conserve the Environment

5.4.1) Mr. Vyn's Practices on Principle IV

Mr. Vyn believed that classroom discussion consumed time of teaching. Classroom discussion about the students' personal environmental stories did not appear to initiate the science project. The teacher originally offered his environmental stories for students. They were asked to apply photosynthesis knowledge for environment in the school and the community e.g. developing water quality of the pond in the school and distributing photosynthesis knowledge.

5.4.2) Students' Ability to Relate Photosynthesis Knowledge to Conserve the Environment

Observation and interviews indicated that students attempted to operate the science project based on Mr. Vyn's offering. S08 supported that *"...there was no discussion on the origin of doing the science project...the teacher just asked [the students] to operate the proposal soon after [the students] finished the school midterm examination."* S05 told that his group developed the brochure to illustrate knowledge of photosynthesis. His group expected that the brochure would persuade people to grow plants in the school. His group now finished publishing the brochure and was going to distribute the brochure. In case of S07, her group would like to develop the water quality in a pond. She was going to prove color of the water. *"...time and equipment were limited...the teacher told that I would not be able to test the dissolved oxygen chemically...I [then] needed to test it physically"*, S07 said.

Although it appeared that the students practiced the scientific project, the interview indicated that students' learning potential of the practice was limited by Mr. Vyn's practices. The students had done the project for particular taking the assignment. There was no valuing use of photosynthesis knowledge to conserve their environment.

5.5) Principle V: Having Regard to Culture and Society as Socio-Cultural Perspectives on Teaching and Learning

Because the students assume roles of learner, family and society in the classroom and the learning was perceived as functioning of a good citizen in the classroom (Cobb, 1994; Packer and Goicoechea, 2000), the students' living style, views about plants, educational value and school society influencing the learning were regarded for practice on teaching photosynthesis.

5.5.1) Mr. Vyn's Practices on Principle V

In spite of the ideas above, Mr. Vyn appeared to emphasize teaching for taking of the National Entrance Examination. The teaching focused on abstract concepts, definitions and formulas. Also, the teaching was less emphasis on discussion, game, cooperation or problem solving. Observation and interview also indicated that even he attempted to discuss about plants, he regularly discussed by himself. Because the students were "*...in culture of big city where they had not easily found plants, forest, and garden..., [so] they might not appreciate to study photosynthesis ...and the parents [then] had no time to help them...*" Therefore, there was the teacher's duty "*...to develop [the students'] discipline, royalty, and responsibility on the study...*" Mr. Vyn explained.

5.5.2) Students' Learning Based on Thai Society and Culture

Follow on the Mr. Vyn's practices, this study found that students still were unfamiliar with the practices. They still were not confident to participate in the learning activities. The student who seriously studied biology by himself, S05, supported that "*...in classroom, thinking and sharing ideas was rarely found...the teacher rarely launched the classroom discussion...he usually asked the [favorite] students individually...I rarely had chance to participate in the discussion.*" S06, the student who also studied biology by himself, supportively noted that he was not confident to argue the teacher's ideas even though he would like to participate in the

discussion. *“The teacher always described everything...and I tried to follow him by [silently] answering his questions in my mind..., I sometimes taught my friends if they could not follow him or didn’t understand...and I attempted to seek out the [other] textbooks for developing the understanding by myself.”*

The observation and interviews also indicated that the students seriously respected to higher authority i.e. the teacher. They did not appear to be convinced to share their ideas without teacher’s facilitation. What they appeared to do was silently questioning in mind and observing what was going on in the classroom.

5.6) Principle VI: Encouraging Students to Participate in Learning Activities

Students’ engaging in thinking what to do, inside and outside period, other than students’ passively listening to teacher’s lecture was expected by this study. The students were also expected to form a meaningful learning of studying photosynthesis in classroom. What the teacher had done basing on this principle was described.

5.6.1) Mr. Vyn’s Practices on Principle VI

Mr. Vyn had much business of teaching other subjects e.g. Grade 7 science and the Scout Association (see Section 1.5). Observation and interview indicated that his teaching appeared to emphasize lecturing. This was expected to cover teaching all photosynthesis concepts before the school mid-term examination started. Encouraging students’ participation in biology learning activities was rarely found in the classroom. He accepted that his teaching might less encourage the participation because the school events forced him to finish teaching about photosynthesis rapidly.

5.6.2) Students' Participation

Observations did not indicate that students received more chances of participating in learning activities. Some students appeared to listen to the lecturer while other students were talking with their friends, or doing assignments of other subjects. Individual interview supported that students was not basically changed their learning style from usual. *“It seemed to me that no problem solving in our class...there was just studying death knowledge...I needed teaching by an emphasis on thinking rather than lecturing”*, S05 addressed.

Up to this point, the findings indicated that Mr. Vyn adapted the teaching unit based on his teaching contexts. His practices on the six principles of the intervention were different from other two participant teachers. His case study has been summarized as follow.

6. Summary of the Market School

In this case study, the teacher's content knowledge and beliefs of student learning and teacher responsibility impacted to the teacher's teaching and the students' learning about photosynthesis. The teacher had strong content knowledge and believed that students learned by his transmission, appeared to implement the teaching unit by an emphasis on lecturing. It was consistently used to correct the misconceptions about introductory photosynthesis, to enhance the understanding about advanced photosynthesis, to illuminate the understanding about the nature of science. Even though scientific project was used to relate photosynthesis knowledge to conserve the environment, it was passively used in the classroom. The findings indicated that the students incompletely developed the understanding of photosynthesis and its relationship with environment, and the understanding of nature of science. Even though the students corrected some misconceptions about introductory photosynthesis, new misconceptions were found. For example, they corrected the misconception of plant food, but held new misconceptions of plant material. Less than half students developed fully understanding about advanced

photosynthesis e.g. dark phase. Also, they passively applied photosynthesis knowledge to related environmental conservation. The findings also indicated that the students did not fully understand three aspects of science. They understood that scientists cooperatively developed scientific ideas, and the scientists demanded evidences for supporting the ideas. However, half students perceived that scientific ideas would not be changed if the ideas were many proved true by scientists.

In addition, the teacher did not appear to regard on students' view about plant, friendly interactions, attitudes towards biology study and formative assessment. Teaching was expected for particular taking the National Entrance Examination. Encouraging students' participation in learning activities was limited by the business of the Scout Association and the school events. The students did not appear to appreciate the teaching. On the other hand, the findings indicated that they still needed to receive more chances of the participation in classroom study.

Next, the case study of the Babysat School has been described.

The Case Study of the Babysat School

1. School Contexts

The third suburban public high school was located in a residential area, and established in 1978 with helps from a closely associated popular Bangkok girl school. This school, thus, was called the “Babysat School” for this research. The school aimed to develop students’ technology knowledge and skill, moral, ethic and happily cooperative working for the community. The entire population of the school was approximately 2,800 students and 120 teachers. The school had twelve classrooms each in Level 3, Grades 7 – 9, and ten classrooms each in Level 4, Grades 10 - 12. Each Grades 7 – 9 classroom had 45-50 students, and each Grades 10 – 12 classroom had 40-45 students.

In school, students wore the school uniforms. Students and teachers began their day with singing the national anthem, and clasping their hands and giving thanks to the country, to Buddha and to the king, which upholds the Buddhist faith, during 7.30 – 8.30 a.m. On Thursday morning, they were needed to participate in special events such as school sport day and ‘School Loving Day. The participation was often over 8.30 a.m. If the school had no special events, students spend twenty minutes before class, to meet the advisor in home room period. Usually, the teaching period then started at 8.30 a.m. and finished at 15.10 p.m. There were eight fifty-minute teaching periods and one period of lunchtime.

Most of science teachers sat together in the room of the science department, but the participant teacher, Mrs. Amp, sat with her friends in the department of Mathematic. Science teachers rarely met all in the department.

2. Background Information about Mrs. Amp

2.1) Educational Background and Teaching Experience

Mrs. Amp was a beginning teacher in 1974 before she moved to the Babysat School. She was now fifty one years old, a member of student affair committees, and a senior biology teacher. She had taught about photosynthesis in Grade 11 for twenty years. Her formal qualification was a Bachelor of Education, majoring in biology and minoring in chemistry. In this second semester, Mrs. Amp was going to teach about Grade 11 basic and advanced biology subjects and Grade 9 science subject. Totally, Mrs. Amp had seventeen periods a week.

Mrs. Amp liked to teach biology because she graduated in biology teaching. She perceived nature of science as a general knowledge for everyday living, and thought that lecture and experiment were two teaching strategies promoting the students' understanding of biology especially photosynthesis. She was worried about implementing the teaching unit and was not confident in her content knowledge of science. Also, she felt constrained by the educational policy of the government which expected Thai teachers to change teaching tradition from teacher-centered approach to student-centered approach.

2.2) Mrs. Amp's Student Information

Thirty seven students, twenty nine girls and eight boys, studied advanced biology on Monday and Thursday classes of Mrs. Amp. There were three fifty-minute periods a week of photosynthesis teaching. Mrs. Amp described the class as a great student. Twenty nine were aged sixteen, seven were aged seventeen and one was aged eighteen. Most of students believed in Buddhism, and two girls believed in Islam. The biology learning achievement score was 3.42 averagely (see Table 5.11). Only one student additionally studied biology with private tutorials. Twenty five students would like to learn biology because it was necessary for their everyday life, seven students would like to learn for the examination and graduation and one student

would like to learn for developing the understanding about biology. However, three students did not like to study biology in classroom. I could read the biology textbook by myself, they thought. In addition, one student had no ideas why studying biology.

Table 5.11 Biology Achievement of Mrs. Amp’s Students

| Biology Achievement | Students (number) |
|---------------------|-------------------|
| (Score 4.0) | 16 |
| (Score 3.5) | 9 |
| (Score 3.0) | 4 |
| (Score 2.5) | 6 |
| (Score 2.0) | 2 |
| (Score 1.5) | - |
| (Score 1.0) | - |
| (Score 0) | - |

In Mrs. Amp’s classroom, there were four students who were selected purposively to be studied in depth concerning their development of photosynthesis understanding. The selection was based on gender, age, biology achievement, and attitudes towards biology. Career of the parent was also considered to reveal the student’s society at their place, outside the classroom. The four students were called S09, S10, S11 and S12. Table 5.12 shows information of the students

S09 was sixteen years old, and was the student head of the school. His parent owned small private business. He neither much preferred rote learning in biology in classroom nor studied biology in private tutorial institutes. *“I sometimes leaved the biology class because I needed to participate in the school conferences... In my opinion, I [really] like hands-on activities such as concept mapping...rather than lecturing [in classroom].”* His biology achievement was 2.0 and his GPA was 3.10.

Table 5.12 Mrs. Amp's Students Selected as Participants in the Case Study

| Categories | Students | | | |
|-------------------------------|---|--|--|--|
| | S09 | S10 | S11 | S12 |
| Gender | Male | Male | Female | Female |
| Age | 16 | 17 | 16 | 16 |
| Biology Achievement | 2.0 | 3.5 | 4.0 | 4.0 |
| Attitudes Towards Biology | I don't much prefer biology which teaching by an emphasis on lecturing. | Biology is necessary for taking the National Entrance Examination. | I usually studied biology by myself...when I'm going to have the test. | I'm not interested in study [biology] by my self, but I tried to concentrate the study in class. |
| Parent Career (Father/Mother) | Private business | Private business/ Language teacher | Engineer/ Housewife | Office worker/ Government officer |

S10 was seventeen years old. His mother was a language teacher and his father owned a small private business. He aimed to study for particular taking the university entrance examination and surviving in everyday life. *"I'm not much interested in studying biology because I'm unfamiliar with [teaching] in this subject... whenever I don't understand the contents I would ask/consult my friends..."* His biology learning achievement was 3.5 and his GPA was 3.55.

S11 was aged sixteen, and lived in Bangkok with her aunt while her parents were now employees living in other province. Her father was an engineer, and her mother was a housewife. She had studied biology for everyday living by herself. *"Even though the teacher repeated her explanations on photosynthesis, I don't understand...so, I attempted to sort out other textbook to develop my understanding."* Her biology learning achievement was 4.0 and her GPA was 3.63.

S12 was sixteen years old, and was not confident to express her thought. She often addressed that *"Am I stupid to say...?"* Her father was an office worker, and her mother was a government officer. She expected to study biology for

everyday living and taking the National Entrance Examination, but she thought that teaching biology inside the school could not help her for the expectation. *“When the school events came, the teacher missed the class or I don’t understand the contents, I’ve studied biology by myself and consult my friends...now I’m going to study biology with the private tutorial.* Her biology learning achievement was 4.0 and her GPA was 3.85.

3. Mrs. Amp’s Beliefs about Teaching and Learning

According to the classroom observations and informal interviews throughout the study, Mrs. Amp perceived role of teaching as assessing students’ work responsibility. Her teaching, thus, was strongly emphasized students’ good discipline in classroom learning. Students should be quiet and be dependently moved. Sending all assignments was often asked to receive her briefly comments and the scores. Mrs. Amp would rarely appreciate students’ argument to the order of the teacher and the school. She believed that students would learn if they often wrote all concepts/ words/statements on their notebooks.

Also, Mrs. Amp was critical of the school policy which did not allow her to fail students in any examination involved GPA of the students. The policy was for helping the students to succeed in the National Entrance Examination which was counting GPA as a part of taking the Examination. So, she perceived the policy as the teaching interruption. She thought that students would not longer regard her orders and then her implementing the new teaching unit would hardly be succeeded. However, she addressed that it was necessary to help students for taking the Examination by over up grading the students’ biology learning achievement, GPA.

Mrs. Amp regarded her lack of content knowledge as particular problematic issue of teaching photosynthesis, and was very nervous to changing the teaching tradition from teacher-centered approach to student-centered approach. *“I’ m fear to teach with the new teaching style.”* she said sincerely in the final interview. Her teaching had appeared to avoid new teaching activities, in particular discussion,

laboratory activities and concept mapping. The learning step was locked into reading papers which were copied from teacher's transparencies and students' worksheets based on the teaching unit. Finally, the students' learning was found as repeating the concepts written in the papers and the worksheets unit they could remember for the examination.

4. Mrs. Amp's Planning

Mrs. Amp early prepared students' worksheets based on the unit at the beginning of the implementation. The worksheets were copies as much as the number of her students in Grade 11, and were disciplinarily distributed to the students page by page in the classroom.

Mrs. Amp commented that she was necessary to leave photosynthesis teaching because the school special events, e.g. school sport day and 'School Loving Day', and her special work such as welcoming school visitors to evaluate the school quality and attending conferences outside the school. Then, she asked the students to read the worksheets during her leave and then gave a lecture at the end of implementing the unit.

Mrs. Amp implemented the teaching unit for four weeks and began the implementation on the 1st November 2004. Figure 5.5 shows the teaching room setting. There were twenty 60 x 120 x 80 cm. student tables, one 200 x 100 x 80 cm. teacher table, forty five stools, three ceiling fans, seven cabinets and six shelves, one television and one refrigerator, two computers, two sinks and six electric light bulbs.

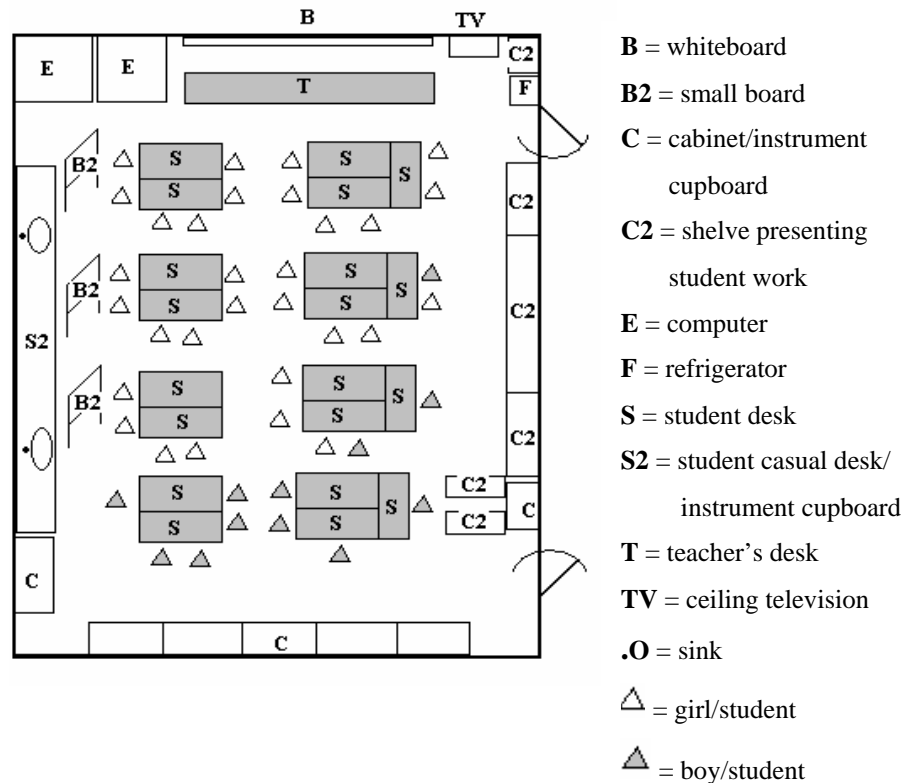


Figure 5.5 Mrs. Amp's Classroom Setting in the Babysat School

Follow on Mrs. Amp's personal background, beliefs and planning, her practices on implementing the photosynthesis teaching unit based on the six principles have been described. This study, then, outlined the photosynthesis understanding of the students and also detailed the understanding of S09-S12, the four students who were purposively selected to study in depth, based on the six principles.

5. Mrs. Amp's implementation of the Intervention and the Students' Understanding Based on the Six Principles

5.1) Principle I: Correcting Grade 11 Students' Misconception about Introductory Photosynthesis

Before Mrs. Amp implemented the teaching unit, the findings of the Introductory Photosynthesis Survey (IPS) illustrated that her students held misconceptions about the introductory photosynthesis. Most of students held

misconceptions about plant food, partial understanding with misconceptions about plants and light energy, and had no ideas about plant materials and simple photosynthesis processes and equations. However, almost all students held sound understanding about roles of chlorophyll.

Over half students, fifty four percentages, misunderstood about *plant food*. They thought that H₂O, fertilizer, CO₂, light and chlorophyll were plant food because plants used those substances for photosynthesis or for growth. Also, thirty eight percentages were holding partial understanding with misconception about plant food. Not only sugar/starch but also those substances were perceived as the plant food.

Almost all students held partial understanding with misconceptions about *plant and light energy*. Seventy three percentages thought that not only sunlight but also sun heat, chlorophyll, CO₂, H₂O, O₂ and glucose supplied energy for photosynthesis. This was because plants used those substances in photosynthesis and respiration.

Twenty two percentages held partial understanding with misconceptions about *plant materials*. They thought that not only CO₂ and H₂O but also chlorophyll, O₂, glucose and starch were the material. Fourteen percentages strongly misunderstood that CO₂ was toxic to plants; that CO₂ was protein; and that CO₂ was used for plants' breathing. Fourteen percentages had no ideas about plant materials.

Almost all students, seventy three percentages, had no ideas about *simple photosynthesis processes and equations*. However, eighty one percentages had scientific ideas about *roles of chlorophyll*. They understood that green plants used chlorophyll to photosynthesize.

Holding the misconceptions found before teaching was expected to be correct to further the understanding about photosynthesis. What the teacher, then, practiced to correct the misconception has been described below.

5.1.1) Mrs. Amp's Practices on Principle I

Classroom observations and the interviews indicated that Mrs. Amp inconsistently corrected the misconception about introductory photosynthesis. She appeared confident to elicit students' misconception: asking students in pair to do the worksheet 'what is plant food?' and to read the booklet 'why do plants make sugar?'. The students were asked to send the worksheets to her individually, formally and quietly. She corrected the misconceptions, gave her brief comments and mark scores on the worksheet, after teaching period. In the classroom, the misconceptions, however, were not obviously discussed and evaluated using concept mapping and game "Circus of misconceptions (True or False).

Subsequently through the survey and interviews with student, this study found that the students incompletely corrected the misconception about introductory photosynthesis. The findings are illustrated below.

5.1.2) Students' Understanding about Introductory Photosynthesis

According to whole class students, the Survey (APS) indicated that students uncertainly corrected the misconceptions. Less than half students corrected the misconception about plant food. They retained the misconceptions about plant and light energy and plant materials. They still had no ideas about simple photosynthesis processes and equations even though they held scientific conception about roles of chlorophyll.

Thirty five percentages misunderstood about plant food. Two students thought that H_2O was plant food. Four students held new misconceptions: CO_2 and H_2O were digested into sugar; plants used CO_2 to fix the food; and plants used O_2 and C atom of CO_2 to produce the food. Seven students misunderstood that plants could produce the food without light.

The misconceptions about plant and light energy had been held by thirty two percentages. Four students became more confused and misunderstood that sun supplied its heat for photosynthesis. Two students thought that plants used light to produce energy or to fix CO_2 . Six students were unconvinced that light supplied energy for photosynthesis. They broadly recognized the light as a factor of photosynthesis.

The misconceptions about plant materials were incompletely corrected. Even nobody retained the misconception, but twenty two percentages held new misconceptions that plants used CO_2 to produce not only sugar but also O_2 and O_3 .

Observation and interview with S09-S12 supported that the students incompletely corrected the misconceptions. Correcting the misconceptions appeared to be depended on the students' aims and attitude towards studying biology.

S09, the student who did not prefer biology teaching and occasionally leaved the class for the school conference, incompletely corrected the misconceptions. The misconception about plant food that mineral, fertilizer and water were plant food was not longer held, but new misconception was found. He thought that CO_2 was plant food. His scientific understanding about plant and light energy, and roles of chlorophyll was changed into misunderstanding and partial understanding respectively. For example, he believed that sun supplied its heat for photosynthesis.

Also, S12, the student who was not interested in biology teaching even she would like to study biology for taking the examination, incompletely corrected the misconception. She thought that plants could photosynthesize without light, at night. She also misunderstood that plants use O_2 as material of day-photosynthesis; and plants use CO_2 as material of night-photosynthesis. In addition, she still had no ideas about simple photosynthesis processes.

S10 and S11, who personally studied biology for taking the examination, corrected the misconception about plant food, plant material and simple photosynthesis processes. However, S10 retained the misconception about plant food. He thought that H₂O was also plant food.

Table 5.13 shows the students' conceptions about introductory photosynthesis before/after teaching.

As well as, this study found that enhancing the understanding of advanced photosynthesis, discussed in section 5.2, might be interrupted with holding the misconceptions of introductory photosynthesis.

Table 5.13 Correcting the Introductory Misconceptions of Mrs. Amp’s Students Selected as Participants in the Case Study

| Concepts | | Students | | | |
|----------------------------------|--------|---|---|---|--|
| | | S09 | S10 | S11 | S12 |
| Roles of Chlorophyll | Before | Green plants use chlorophyll to photosynthesize. (SU) ⁹ | Green plants use chlorophyll to photosynthesize. (SU) | Plants having chlorophyll could photosynthesize. (SU) | Plants having green color of chlorophyll photosynthesize. (SU) |
| | After | All plants could photosynthesize. (PU) | Plants having green color of chlorophyll photosynthesize. (SU) | Chloroplast of plants contains chlorophyll for photosynthesis. (SU) | Green plants use chlorophyll to photosynthesize. (SU) |
| Plant Food | Before | Mineral, fertilizer and water are plant food because plants use these to grow. (MU) | Water, mineral, fertilizer, and starch were plant food used for plants’ growth. (PU+MU) | Water, mineral, fertilizer, sugar and starch were plant food used for plants’ growth. (PU+MU) | H ₂ O, mineral and fertilizer are plant food used for growth and respiration. (MU) |
| | After | CO ₂ are plant food because it is a part of glucose. (MU) | Starch, water and mineral were plant food used for plants’ growth. (PU+MU) | Plants use CO ₂ to produce carbohydrate. (SU) | Plants use CO ₂ to produce carbohydrate. (SU) |
| Plant Materials | Before | H ₂ O and CO ₂ are materials of plant photosynthesis. (SU) | H ₂ O, CO ₂ and starch are materials of photosynthesis. (PU+MU) | Carbohydrate and CO ₂ are the materials b/s plants used them to produce food. (PU+MU) | Chlorophyll, CO ₂ and light are the materials of photosynthesis. (PU+MU) |
| | After | H ₂ O and CO ₂ are materials of plant photosynthesis. (SU) | H ₂ O and CO ₂ are materials of plant photosynthesis. (SU) | Plants use H ₂ O and CO ₂ as material of photosynthesis. (SU) | In day, plants use O ₂ as material, but in night, plants use CO ₂ as material. (PU+MU) |
| Plants and Light Energy | Before | Sunlight supplies energy for plant photosynthesis. (SU) | Light, H ₂ O, CO ₂ and glucose supply energy for photosynthesis. (PU+MU) | Sun heat supplies energy for photosynthesis. (MU) | Sunlight supplies energy for plant photosynthesis. (SU) |
| | After | Sun heat supplies energy for photosynthesis and are resource of O ₂ (MU) | Plants use sunlight to activate energy transfer in photosynthesis (SU) | Plants use light energy to produce food. (SU) | In night, plants could photosynthesize without light. (MU) |
| Simple Photo-synthesis Processes | Before | $\begin{matrix} \text{light} \\ \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{glucose} + \text{H}_2\text{O} + \text{O}_2 \\ \text{Chl} \end{matrix} \quad (\text{SU})$ | $\begin{matrix} \text{light} \\ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \\ \text{Chl} \end{matrix} \quad (\text{SU})$ | (No answer) | (No answer) |
| | After | $\begin{matrix} \text{light} \\ \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{glucose} + \text{H}_2\text{O} + \text{O}_2 \\ \text{Chl} \end{matrix} \quad (\text{SU})$ | $\begin{matrix} \text{light} \\ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \\ \text{Chl} \end{matrix} \quad (\text{SU})$ | $\begin{matrix} \text{light} \\ \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \\ \text{Chl} \end{matrix} \quad (\text{SU})$ | (No answer) |

⁹ SU = Sound Understanding, PU = Partial Understanding, PU+MU = Partial Understanding with Misconception and MU = Misunderstanding

5.2) Principle II: Enhancing Grade 11 Students' Understandings about Advanced Photosynthesis Concepts

5.2.1) Mrs. Amp's Practices on Principle II

Mrs. Amp was not confident in her content knowledge. Also, the school events and public holiday took over the teaching periods from her. She appeared to use reading homework to enhance the understanding of advanced photosynthesis. She neatly distributed all worksheets and all copies of the teaching transparencies to the students. Also, she spent the final two periods for formal lecturing all concepts about photosynthesis. There was no discussion, concept mapping, game, experimentation, cooperative learning and problem solving in the classroom. S09, S10, S11 and S12 obviously supported that "...*the teacher usually told the concepts to us...and the students followed her by writing.*" "*There had not much activity.*"

The findings indicated that the teaching weakly enhanced the understanding of advanced photosynthesis.

5.2.2) Students' Understanding about Advanced Photosynthesis

The survey indicated that a majority held partial understanding with misconceptions about the dark phase. Also, they held partial understanding about the light phase and structures and functions of chloroplast. As well as, they had no ideas about the necessary factors affecting photosynthesis rate.

Only twenty four percentages, one quarter students, fully understood about *light independent (dark) phase*. Plants fix CO_2 to produce food. On the other hand, a majority, thirty two percentages, held partial understanding with misconception. They thought that the dark phase was particular process of producing food in night; that the dark phase was producing $\text{C}_6\text{H}_{12}\text{O}_6$, O_2 and O_3 ; and that the dark phase took place after ATP was used to produce O_2 and sugar. Eleven

percentages misunderstood that the dark phase was plants' respiration releasing CO₂. Also, twenty three percentages had no idea about the dark phase.

A majority, fifty percentages, held partial understanding about *light dependent (light) phase*. They understood that light supplied energy to activate electron, but they forgot to describe photolysis of water. Nobody had full understanding. A minority, thirty three percentages used the misconception about light energy to describe the light phase. They thought that sunlight supplied its heat to separate water and electron.

Nobody developed sound understanding (SU) about *structures and functions of chloroplast*. Forty nine percentages, a majority, held partial understanding that chloroplast had only chlorophyll. A minority, thirty five percentages had partial understanding with misconception that chloroplast could directly absorb light without chlorophyll.

In terms of the relationships between the *necessary factors affecting photosynthesis rate*, only five percentages had full understanding. They understood that numbers of chloroplast and type of plant leaf tissues affected to photosynthesis rate. However, forty one percentages, a majority, had no advanced ideas about the relationships. They broadly described that different type of plants differently fixed CO₂. A minority, thirty percentages had just partial understanding that CO₂ fixation of C₃ plants was different from C₄ plants, but they could not describe what the difference was.

The survey, observations and individual interviews with students, S09, S10, S11 and S12, did not indicate that the students developed the understanding. They appeared to hold some misconception, after teaching.

S09 who disliked teaching by rote learning could not develop scientific understanding about photosynthesis. The misconceptions about structures and functions of chloroplast, light phase, dark phase and necessary factor affecting

photosynthesis rate were found. He perceived chloroplast as solar cells absorbing and storing light energy. He thought the dark phase was photosynthesis without light. He also thought that the light phase took place only in daytime and produced sugar as same as the dark phase; and light absorption of pigments differed CO₂ fixation of one plant to another plant.

Also, S10 who personally studied biology for taking the examination and had no high biology achievement uncertainly developed the understanding. He perceived chloroplast as chlorophyll. Although he understood that plants fixed CO₂ to produce plant food, he thought that CO₂ also provided O₂ as by-product. The product was released in the dark phase. He retained misconceptions about plant food. He thought that “H₂O...was plant food in the light phase.” He could not give reasons why C3-plants and C4-plants fixed CO₂ differently. He also thought that number of leaves did not affect photosynthesis rate.

S11 and S12, the students who got high biology achievement and usually studied biology by themselves, could develop scientific understanding about light and dark phases. They understood that plants fixed CO₂ to produce plant food, carbohydrate, and that H₂O was separated into H⁺, electron and O₂ by light energy. However, they believed that chloroplast had only one function for photosynthesis. The function involved absorbing light. There was no CO₂ fixation in stroma of chloroplast. S11 also misunderstood that pigments were fixing CO₂. S12 were not convinced to describe why C3-plants and C4-plants fixed CO₂ differently.

Table 5.14 shows the students' conceptions about advanced photosynthesis.

Table 5.14 Advanced Photosynthesis Concepts of Mrs. Amp's Students Selected as Participants in the Case Study

| Concepts | Students | | | |
|---|--|--|---|---|
| | S09 | S10 | S11 | S12 |
| Structures and Functions of Chloroplast | Chloroplast is pigment absorbing light as solar cell. It supplied energy for photosynthesis without light. (MU) ¹⁰ | Chloroplast is chlorophyll absorbing light. (PU+MU) | Chloroplast contains pigment for photosynthesis. (PU) | Chloroplast contains green substances to absorb light. (PU) |
| Light Dependent (Light) Phase | It is photosynthesis in daylight, and provides sugar which supplied energy for the dark phase. (MU) | H ₂ O is separated into the electron ..., and is plant food. (PU+MU) | Light separates H ₂ O into H ⁺ and O ₂ and induces electron transfer. (SU) | H ₂ O provides e ⁻ and is separated into H ⁺ and O ₂ . (SU) |
| Light Independent (Dark) Phase | It is photosynthesis without light. It uses energy stored in pigments, and helps producing plant food. (MU) | Plants fix CO ₂ to produce food, and are resource of O ₂ . (PU+MU) | Plants fix CO ₂ to produce food. (SU) | Plants fix CO ₂ to produce food, sugar, carbohydrate. (SU) |
| Necessary Factors Affecting Photosynthesis Rate | Number of leaf and did not affect photosynthesis rate, but type of pigment differently caused rate of CO ₂ fixation. (MU) | Number of leaf and did not affect photosynthesis rate. (MU) | Type of pigment differently case rate of CO ₂ fixation. (MU) | No answer |

5.3) Principle III: Integrating Nature of Science into Photosynthesis Using Historical Narratives to Illuminate the Nature of Science (IPST, 2002)

Understanding the nature of science was perceived as important as understanding the photosynthesis concepts based on the teaching unit. Historical narrative was theoretically chosen as an effective way to illuminate the nature of science. Three aspects in science integrated in the concepts are that scientific ideas are subjected to change; that science demands evidence; and that science is a complex social activity.

¹⁰ SU = Sound Understanding, PU = Partial Understanding, PU+MU = Partial Understanding with Misconception and MU = Misunderstanding

5.3.1) Mrs. Amp's Practices on Principle III

Mrs. Amp perceived nature of science as a general knowledge for everyday living. She also believed that lecturing and experimenting were the best way of teaching. Her teaching appeared to illuminate the nature of science using reading assignments and guided inquiry. The students were formally asked to read and then complete all questions in the students' booklets and brochures. Those described the scientists' historical discoveries of chloroplast and the light and dark phases. There were no role play activity supported the illuminating. Also, the students were guided to experiment pigments of chloroplast without prior discussion about the experimental design and objectives. They, then, were asked to operate the experiment by themselves outside teaching periods.

Following Mrs. Amp's practices, the survey and the interviews indicated that students did not fully understand about the nature of science.

5.3.2) Students' Understanding about the Nature of Science

The survey indicated that students were ambiguous in understanding the nature of science. Most of students perceived science as a social complex society, but they believed that scientific knowledge did not change. Also, they appeared to less regard on scientific processes and methods.

Thirty five percentages, a majority, did not gain the understanding that scientific ideas were subjected to change. They believed that old knowledge did not change. Because new scientists found out new knowledge, that was more update and had never been known. So, scientific theories and laws *appeared* to change by adding the new knowledge on to the old knowledge. Nineteen percentages thought that the theories could be changed, but they thought that the laws could not be changed. Twenty seven percentages, however, understood that scientific knowledge changed because the old theories and laws were disproved and detected error by new scientists.

One conception about science demanded evidence was mainly perceived by most of students. Eighty one percentages thought that scientists tried to investigate, search and experiment for an explanation of science, the evidence of science. There was no student focusing on process or method of science as the way of finding the evidence.

However, two third students, sixty two percentages, understood that scientists had not worked individually; science was a complex social activity. Thirteen students noted that present scientists' discovery was building up on previous scientists' discovery. Ten students believed that scientists in many fields shared ideas or results to advance scientific knowledge.

The survey, observation and interview with students indicated that the students did not fully understand the nature of science in the three aspects. The understanding of the nature of science sometimes appeared to relate with the students' personal behaviors in studying biology.

The student, S09, who liked doing hands-on activity and had no chance to participate in learning activities, believed that scientists used the experiments to find out knowledge. Science could be changed by different experiments of scientists. However, he did not seem to be aware of scientific methods scientists' cooperation in the experiments.

S10, who liked to cooperate with friends in biology study, understood that the new knowledge, such as new theories, were accepted through [many] scientists' argument and conclusion. Scientific knowledge could be changed because the old knowledge was reinterpreted by using different method and new techniques. However, he did not appear to focus on using scientific method to find out the new knowledge.

S11, the student who usually studied biology by herself and seriously respected to the teacher, thought that knowledge would not be changed if it

had been proved true many times. However, she understood that scientific knowledge was developed through scientists' observation and experiment.

S12, who believed that biology in classroom could not complete her expectation of taking the National Entrance Examination and then she needed to studied biology by herself, believed that new knowledge was unknown ideas which nobody had ever known. So, the ideas appeared to change by adding new knowledge on to the old knowledge. However, she understood that scientists used scientific method to prove the scientific ideas.

Table 5.15 shows the students' conceptions about nature of science in three aspects.

Table 5.15 The Nature of Science of Mrs. Amp’s Students Selected as Participants in the Case Study

| NOS Aspect (Questions) | Student Conceptions of the Nature of Science (NOS) | | | |
|--|---|---|---|--|
| | S09 | S10 | S11 | S12 |
| 1. Scientific ideas are subjected to change. Q: Why had the scientific ideas been changed? | “...they used different processes...so they concluded differently.” | “...with different methods they could produce new theories.” | “Scientific knowledge didn’t change because they had been proved conclusively.” | “...may be their concepts had changed...they wanted to find out more knowledge, new knowledge.” |
| 2. Science demands evidence. Q: Why did the scientists need to do the experiments? | “...to prove how it happened. The expectation was to find answers to the questions.” | “...to construct a new theory...to provide support providing how things came about...” | “...they wanted to observe and then describe what they didn’t understand...” | “...to prove their ideas, their hypotheses...” |
| 3. Science is a complex social activity. Q: How did the scientific knowledge come about? | “They carried out experiments to find out what they wanted to know...after which they would use to construct a theory...” | “...they used the knowledge ...techniques...and practice to get the principle...” | “First is observation, second is proposing a theory.” | “...to uncover the hidden truth unknown by others to provide support...” |
| The summary of ideas about the nature of science. Q: How had the photosynthesis knowledge been developed? | “With scientists’ curiosity and thought ...the knowledge was developed.” | “It has been developed through experiment... argument and conclusion of scientists. After it was accepted by [people], new theories would be born.” | “The knowledge was developed by observation, note and experiment.” | “Scientists cooperatively observed, collected, and experimented with others. Then, they proposed the conclusions of their ideas, knowledge.” |

5.4) Principle IV: Enabling Students to Relate Photosynthesis Knowledge to Conserve the Environment

5.4.1) Mrs. Amp's Practices on Principle IV

Perhaps, the school events might limit teaching time. Mrs. Amp did not appear to relate photosynthesis knowledge to conserve the environment in the classroom. Students' personal stories of their environment had not been discussed to initiate operating the science project. However, interviews with her and the students indicated that she assigned operating the science project to the students, outside teaching periods. The students needed to report on the science project as a part of taking the biology examination.

5.4.2) Students' Ability to Relate Photosynthesis Knowledge to Conserve the Environment

According to the students' work reports and interviews with the students, this study found that most of students were not convinced to operate the science project based on Mrs. Amp's assignment. S09 noted that he just knew that he got the assignment on the science project, during the interview. "...really? What's the project?" he questioned. Interview with S12 also supported that she just knew that she used misconceptions to relate photosynthesis to conserve the environment. Her project involved producing plant-fertilizer. She thought that plants used to produce fertilizer still photosynthesized. The photosynthesis of the fertilizer was expected to increase photosynthesis rate of a growing plant. Only two groups of students in Mrs. Amp's class operated the project that involved environmental conservation. One group used waste-water plants to nit the disk matte. Another group developed the pamphlets. Those informed people in community which plants should be grown to decrease air pollution.

Not only relating photosynthesis knowledge to conserving the environment, this study expected the teaching by regarding on learning society and culture in classroom.

5.5) Principle V: Having Regard to Culture and Society as Socio-Cultural Perspectives on Teaching and Learning

Because the students assume roles of learner, member of family and member of society in the classroom and the learning was perceived as functioning of a good citizen in the classroom (Cobb, 1994; Packer and Goicoechea, 2000), the students' living style, views about plants, educational value and school society influencing the learning were regarded for practice on teaching photosynthesis.

5.5.1) Mrs. Amp's Practices on Principle V

Mrs. Amp believed that "*smart students must study science*", it is impossible that the students would not like to study science. Her teaching appeared to focus on taking the Entrance examination. Observations and interviews indicated that she rarely developed friendly interactions with students, to probe students' views about plants, and to encourage the students to value biology for living in the society.

Follow up the teaching, the students did not appear to be convinced of sharing their ideas or argument with the teacher even they did not understand the teaching.

5.5.2) Students' Learning Based on Thai Society and Culture

Although the students studied biology with different objectives, they respected the teacher's authority on classroom study. Observations and interviews indicated that the students had attempted to keep quiet and listen to Mrs. Amp's lecturing. Whenever they did not understand the teaching they would ask their friends or additionally read other textbooks rather than directly questioning the

teacher. S12, the student who had studied biology for everyday living and for taking the National Entrance Examination, addressed that “*I’m going to study biology with a private tutorial institute, [outside schooling study]*”. She felt uncertainly in her understanding of photosynthesis. S11 who had studied biology for everyday living supported that “... *[Even though] the teacher sometimes repeated lecturing, I didn’t understand... [So,]I studied photosynthesis from other textbooks [by myself]...*”

5.6) Principle VI: Encouraging Students to Participate in Learning Activities

Students’ engaging in thinking what to do, inside and outside period, other than students’ passively listening to teacher’s lecture was expected by this study. The students were expected to form a meaningful learning style of studying photosynthesis in classroom. What the teacher had done basing on this principle was described.

5.6.1) Mrs. Amp’s Practices on Principle VI

Mrs. Amp might be not confident to change the teaching tradition, teacher-centered approach, to new tradition based on the new teaching unit. She inconsistently encouraged the students to participate in learning activities. She appeared to appreciate intently lecturing and dependently moving of her students. Only one teaching period of encouraging the participation in discussing and mapping concepts of plant food, was found in the classroom. S09-S12 supported that “*the teacher [usually] gave lecture and the students took note...*”

5.6.2) Students’ Participation

Observations and interviews with students indicated that students was not basically changed their learning style from usual. They still intently listened and looked at the teacher. S10 described that “*the teacher, in front of the class, held*

the book and summarized the concept [which] differed from our book. The students, then, needed to take note. The key ideas would be re-pronounced by the teacher...”

Up to this point, it seems to this study that Mrs. Amp alternatively implemented the teaching intervention. Her practices on the six principles of the intervention differed from other two participant teachers. This study summarizes the practices and the students' learning in the context of this case below.

6. Summary of the Babysat School

Belief of learning and content knowledge might impact teaching and learning about photosynthesis. In this case, the teacher was not confident in her content knowledge, and she believed that lecturing and guided experiment were the best way of teaching science. Her teaching appeared to emphasize reading homework and lecturing. The teaching was used to correct the misconception about introductory photosynthesis, to enhance the understandings about advanced photosynthesis and its relation with environment, and to illuminate the understanding of nature of science. The findings indicated that the students incompletely corrected the misconception, and they uncertainly understood about advanced photosynthesis. They held misconceptions about plant food, partial understanding with misconceptions about the dark phase, and partial understanding about the light phase and structures and functions of chloroplast. They also had no ideas about the necessary factors. They did not appear to be convinced of relating photosynthesis knowledge to conserve the environment. Also, the findings showed that they were ambiguous in understanding the nature of science. They perceived science as a social complex society, but they believed that scientific knowledge did not change, and were less aware of scientific processes and methods.

In addition, the teacher had rarely appeared to develop friendly interactions, regard on attitudes towards biology study, and to encourage learning participation. The study found that the students' learning style was not basically changed from usual, intently listening and taking notes. They were less aware of classroom study.

They appeared to study biology for particular taking the Entrance examination. Some students would like to study biology outside the school, with private institutes.

Up to this point, the three case studies with Mrs. Engka in the Border School, Mr.Vyn in the Market School and Mrs. Amp in the Babysat School have been crossed to discuss and generate whole views of the implantation and the impacts of the photosynthesis teaching intervention based on the six guiding principles.

Cross Case Studies:

Implementation and the Impacts of the Teaching Intervention

This study describes the context that three participant teachers studied in an intensive manner. Mrs. Engka, Mr. Vyn and Mrs. Amp, the three different biology teachers, differed in terms of the teaching background, in particular content knowledge, the belief about how students learned and how teachers should teach, and the teaching planning. These differences individually resulted in teaching and learning photosynthesis.

The teacher's belief of student learning had affected correcting Grade 11 students' misconception about introductory photosynthesis. The teachers, who believed in constructivist approach, appeared to focus on explicating and correcting the students' prior/introductory misconceptions using several learning activities. For example, Mrs. Engka who believed that teaching by only lecturing could not longer develop the students' learning about biology consistently corrected her students' misconceptions using discussion, game, reading assignment, concept mapping and collaborative learning. Then, a majority of her students were found to complete correcting the misconceptions about plant food and plant materials. Hazel and Prosser (1994) and Brown (2003) supported that concept mapping with discussion powerfully helped teachers to explore and analyze the students' conceptions. The discussion might enable correcting the misconceptions.

On the other hand, the teachers, who were unaware of the prior misconceptions and strongly believed in teacher-centered approach, appeared to teach by emphasis on lecturing. For example, Mr. Vyn who believed that students had to learn from teacher's transmission, and Mrs. Amp who believed that students learned from writing words/statements on their notebook, often used lecture and reading homework without discussion. The study found that their students retained the misconceptions and generated new misconceptions about introductory photosynthesis.

This study found that students who could not correct their prior misconceptions about introductory photosynthesis would hardly develop the understanding about advanced photosynthesis. The case study of the Market school was an example. S06 and S08, Mr. Vyn's students, could not fully understand about the light and dark phases because they held some misconceptions about plant food and plant materials (see Tables 5.8 and 5.9).

The teacher's content knowledge and educational value of biology had affected enhancing the understanding of advanced photosynthesis. The teachers who had not strong content of science did not appear confident to teach and evaluate the understanding. If the teachers had strongly attempted to develop their content and were interested in developing the teacher-student interactions, however, the teachers appeared to be able to adapt the teaching unit for their students' needs. Mrs. Engka was an example of the teachers. She consistently developed her content knowledge and friendly interactions between her and students. Then, she appeared to be able to enhance the students' understanding based on the unit, in the classroom. Her teaching was varied to cooperative learning, experimenting, questioning, discussing, role playing and concept mapping. There were a majority (80 %) of students in her class who understood photosynthesis, in particular the dark phase. Also, a majority of the students had better learning about photosynthesis than the students of other participant teachers.

On the other hand, the teachers, who had extensive knowledge in science and focused on learning for particular taking the examination, rarely appeared to adapt the teaching unit for enhancing the students' understanding. Mr. Vyn was an example of the teachers described. His lecture was often used prior to implement the learning activities based on the new teaching unit. Also, he focused on teaching abstract photosynthesis concepts, definitions and formulas to cover all contents for the end-of-topic examination. He often asked the students to complete the activities and develop their understanding outside teaching periods. The findings indicated that less than half students (43%) of Mr. Vyn class developed scientific conceptions of photosynthesis, in particular dark phase.

In case of the teachers e.g. Mrs. Amp who was not confident in the chemical knowledge and also not enthusiastic about the teacher-student interactions, mainly used reading homework to enhance the students' advanced understanding. This study found that a majority of students held some misconceptions. Less than half students (24%) in her class developed the scientific conceptions about the dark phase. Her students had less development of the advanced understanding than Mr. Vyn's students.

Also, this study found that the number of students who understood the photosynthesis was in relation to the number of students who understood the nature of science. This study described the students' understanding about the nature of science as follows.

The teacher's personal perception of the nature of science (NOS) indicates way of illuminating the three aspects of science that scientific ideas are subjected to change; that science demands evidence; and that science is a complex social activity. Mrs. Engka, who perceived understanding NOS as important as understanding photosynthesis concepts, consistently appeared to discuss about historical narratives involved photosynthesis. Also, she facilitated students' experimentation, role play, problem solving, and science project. This study found that a majority of her students could develop both the understanding about photosynthesis and the understanding about NOS in three aspects.

On the other hand, Mr. Vyn and Mrs. Amp, the teachers who perceived NOS as scientific concepts, appeared to teach NOS as similar to teach photosynthesis concepts. Mr. Vyn lectured NOS prior to experiment, role play and science project based on the unit. Mrs. Amp informally used reading homework and science project to illuminate the students' understanding without discussion. The findings indicated that a majority of their students did not understand some aspects of NOS. Mr. Vyn's students unclearly understood that scientific ideas were subjected to change. Mrs. Amp's students did not understand that science demanded evidence and scientific ideas were subjected to change. This study also found that their students who did not

understand the NOS tended to did not understand the photosynthesis. For example, S09, Mrs. Amp's student, who was unaware of scientists' inquiry methods and cooperation (Table 5.15), could not develop the understanding about advanced photosynthesis (Table 5.14). He also held new misconceptions about introductory photosynthesis (Table 5.13).

The teacher perceptions of role of teaching possibly affected enabling students to relate/apply photosynthesis knowledge to conserve the environment. The teachers, who perceive the teaching role in terms of facilitating each student to learn and formatively assessed student learning development, appeared to use hands-on activities and minds-on activities based on the students' interest. The teachers also consistently kept an eye on the students' development. For example, Mrs. Engka initiated science project of environmental conservation using discussion on students' personal stories of environment. The students' prior conceptions were probed prior to operating the project. Also, the operation had been monitored until the students completed the report on the project. Her students were found to use the accepted concepts and to be convinced of relating photosynthesis knowledge for environment.

On the other hand, the teachers who perceive facilitating and formatively assessing students' learning as extra work of teaching rarely appeared to use minds-on activities with hands-on activities. For example, Mr. Vyn and Mrs. Amp originally offered the science project without discussion, for the students. The students appeared to be *unconvinced* and to use *unaccepted* photosynthesis concepts to operate the project. For example, S09 and S12 in Mrs. Amp's classroom noted that they were not convinced to operate the project assigned by the teacher. In case of S12, she did not know that she was using unaccepted photosynthesis concepts to operate the project (see section 5.4.2 in the case study of the Babysat school).

This study also found that the teachers, who were interested in developing teacher-student interactions, appeared to regard to students' learning culture and society in the classroom. The teacher also encouraged students to participate in learning activities. For example, Mrs. Engka's teaching was explicit to investigate the

students' own views about plants as a basis of correcting the misconceptions, and to develop friendly relationships between the teacher and student, and student and student. She also facilitated students' argument in discussion, and promoted classroom participations for students valuing in classroom study. As the results, the students were found to be confident of the participation. They also could develop the understanding based on the new teaching unit by themselves.

On the other hand, the teachers who emphasized teacher-centered approach and perceived the student role as a passive learner rarely appeared to regard on the learning culture and participation. Teaching often focused on lecturing abstract photosynthesis concepts to cover all contents for taking the examination. The students did not appear to prefer the teaching. For example, S05, the student in Mr. Vyn's classroom addressed that "*It seemed to me that no problem solving in our class...there was just studying death knowledge...*" Also, S12, the student in Mrs. Amp's classroom, was going to study biology with the private tutorial institutes with her perceptions that the classroom teaching could not convince her for taking the National Entrance Examination.

Up to this point, the Chapter V illustrated many findings of the implementation and impacts of the photosynthesis teaching intervention. The summary of this Chapter V has been presented below.

Summary

This research conducted three case studies of the teachers. There were one hundred and eighteen students being taught using the photosynthesis teaching intervention. Twelve of the students were in-depth studied. The studies concerned their progress from the introductory knowledge about photosynthesis to the advanced knowledge and their views about the teaching intervention. The findings illustrated that teacher's belief of student learning, content knowledge, roles of teaching and formative assessment impacted on the teachers' implementation. The teachers who believe in constructivist approach, have strong contents and regard to Thai socio-

culture of learning appeared to implement the teaching intervention based on all principles of the intervention. Their students had been found to progress their understanding about photosynthesis. The students also developed their active way of participating in learning activities. On the other hand, the teachers who strongly emphasized teacher-centered rarely appeared to achieve the principles of the intervention. Their students could not develop the understanding about photosynthesis and still learned in the classroom passively.

Next is conclusions and discussion about all interesting ideas of this research.

CHAPTER VI

SUMMARY, DISCUSSION AND RECOMMENDATION

This chapter leads to a summary of how this research has been conducted to promote teaching and learning about photosynthesis in Thailand. Also, it offers a discussion about teaching for better understanding about photosynthesis. The teaching aims at understanding of photosynthesis, understanding photosynthesis in relation to the environment and understanding of the nature of science. Teaching in the Thai context is also presented. Then, the chapter summarizes the impact of the intervention on teachers and students and ends up with the recommendations.

Summary

According to the National Education Act in 1999 (ONEC, 2000a) and the National Science Curriculum (IPST, 2002), science education has been reformed to improve Thai students' learning. They are now required to understand biology and its relation with the environment, as well as the nature of science. Also, the literature indicates that students retain misconceptions about photosynthesis (IPST, 1989; Sukpimontree, 1988; Jantranon; 1999; Kijkuakul and Yutakom, 2004), after attending classes in introductory and advanced photosynthesis at school. It appears that teaching in the Thai classrooms has not overcome these problems yet (Kijkuakul and Yutakom, 2004). As a Thai biology teacher, the researcher would like to develop a teaching intervention to improve photosynthesis learning in Thailand.

This interpretive research has developed the photosynthesis teaching intervention as a model to enhance the students' understanding of photosynthesis and its relation with the environment and the students' understanding of the nature of science. The impact of the intervention on the teachers and the students has been examined in the three case study schools. The subjects were three biology teachers and their 118 Grade 11 students. They were from different public high schools located in the Bangkok suburban area. They were purposely selected to participate in

this research taking into account their interest in biology educational development. Twelve of the students were also purposely selected to participate in the in-depth study. This selection was based on their age, gender, biology achievement, attitude towards biology and their parent career.

The two surveys, the semi-structured interviews, the classroom observations and the students' works were the research methods used to collect data and find out answers to the following research questions:

1. How can the students' understanding of photosynthesis be enhanced through its relation to the environment and the nature of science?
2. What is the impact of the teaching intervention on the teachers and the students?

The processes of data collection were the following:-

1. Before teaching, the students' understanding of introductory photosynthesis, the environment and the nature of science was probed using the Introductory Photosynthesis Survey (IPS). The twelve selected students were also interviewed after responding the IPS.
2. Then, the teachers were challenged with the IPS data. The data indicated that their students had learning difficulties about photosynthesis.
3. Every teaching period, the classroom was observed to reveal the teachers' teaching and the students' learning.
4. After teaching, the teachers reflected on their teaching using individual and informal interviews. Also, they were encouraged to share ideas about teaching with each other. Difficulties in teaching and learning were discussed. The twelve students were also observed during teaching.

5. The students' understanding of advanced photosynthesis, its relation to the environment and the nature of science were probed using the Advanced Photosynthesis Survey (APS). Again, the twelve students were interviewed, following up the APS data.

The students' conceptions on the surveys were categorized and calculated in percentages. Discourse analysis was used during the interviews. Observation data was interpreted, and the filed notes were analyzed using content analysis.

As a result the research developed a new photosynthesis teaching unit. The literature review provided the six guiding principles for the developed unit. The principles are:

1. Correcting Grade 11 students' misconceptions about introductory photosynthesis,
2. Enhancing Grade 11 understanding about advanced photosynthesis,
3. Integrating nature of science into photosynthesis using historical narratives to illuminate the nature of science based on the national science curriculum (IPST, 2002),
4. Enabling students to relate photosynthesis knowledge to conserve the environment,
5. Having regard to culture and society as Socio-cultural perspectives on teaching and learning, and
6. Encouraging students to participate in learning activities.

Figure 6.1 summarized the research framework used to develop the intervention.

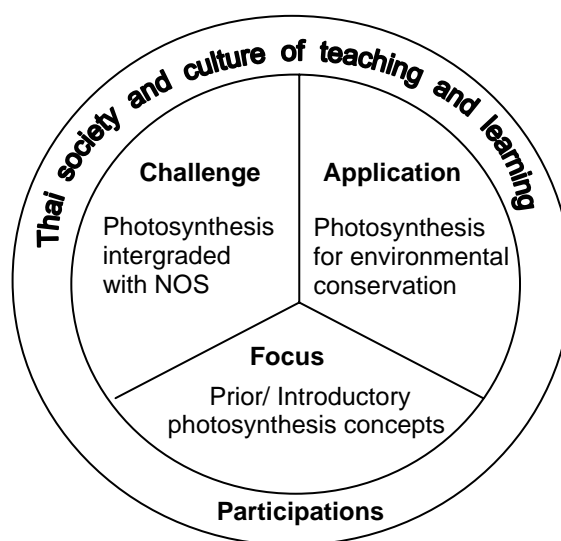


Figure 6.1 Research Framework Used to Develop the Teaching Intervention

Later, the seven lessons of the teaching unit were designed for the teaching intervention. The unit includes twelve 50-minute teaching periods. The impact of the teaching intervention is revealed through three case studies.

The case study at the Border School revealed that Mrs. Engka appears to correct the students' misconceptions and enhance the students' photosynthesis understanding. Her teaching relates photosynthesis to the environment and integrates the nature of science. She takes the learning cultural context into account and the students to participate in the classroom. A majority, eighty percent, of her students certainly corrected their introductory photosynthesis misconceptions, in particular plant food. They developed a scientific understanding of the advanced concepts especially the dark phase. Sixty percent fully understood the three aspects of the nature of science. They did the science project to relate photosynthesis knowledge to the conservation of the environment. In addition, they have a more positive attitude towards participation in learning activities.

However, Mr. Vyn, the teacher at the Market School inconsistently implemented the intervention based on the six principles. Facilitating group and classroom discussion with regard to Thai culture in the classroom, and encouraging

learning participation rarely appeared in his classroom. A majority of his students were uncertain how to correct their misconceptions about the introductory concepts, such as plant food. They retained their misconceptions or generated new misconceptions. They understood only two aspects of the nature of science. Less than fifty percent held scientific conceptions about the advanced concepts e.g. the dark phase. It appeared that students played a passive role in the scientific project and had to focus their effort on studying photosynthesis for taking the biology examination. They did not appear to enjoy the teaching provided in the classroom.

Mrs. Amp, the teacher at the Babysat School, did not appear to be convinced of the value of implementing the intervention based on the six principles. The findings show that less than half of the students corrected their misconceptions about introductory photosynthesis such as plant food. Less than thirty percent held scientific conceptions about the advanced concepts such as the dark phase. A majority of students understood only one aspect of the nature of science. It is not obvious that they applied photosynthesis knowledge to conserve the environment. They appeared to prefer studying biology at private tutorial institutes for taking the biology examination. Some students thought that classroom study could not enable them to understand biology.

The findings indicated that the three teachers implemented the intervention differently. One teacher consistently implemented the intervention, while two teachers inconsistently implemented the intervention based on the six guiding principles. It seems to this research that the students' understanding appears to be enhanced after the implementation of the intervention based on the principles. Therefore, revealing the different ways in which the intervention were implemented and which factors influence the implementations are also discussed in this chapter.

Discussion

The discussion focuses on the findings based on the research questions – How can the students’ understanding of photosynthesis be enhanced through its relation to the environment and the nature of science? And what is the impact of the teaching intervention on the teachers and the students?

Regarding the first question, the findings indicated that the teaching intervention contributed to enhancing students’ understanding of photosynthesis, the relationships between photosynthesis and the environment, and the nature of science.

1. Teaching for a Better Understanding of Photosynthesis

This research examined students’ conceptions in five introductory photosynthesis concepts: roles of chlorophyll, plant food, plant materials, plant and light energy, and simple photosynthesis equation. This research found that students who understand the introductory concepts appear to understand the advanced concepts. Those include four concepts: structures and functions of chloroplast, light dependent (light) phase, light independent (dark) phase, necessary factors affecting photosynthesis rate.

It seems to this research that teaching photosynthesis should begin with eliciting and correcting students’ prior misconceptions. Correcting the misconceptions should be done after having assessed the students’ introductory knowledge of photosynthesis and their Thai view about plants. Using concept mapping with explanation and discussion seems to facilitate the process of correcting the misconceptions. The studies of Hazel and Prosser (1994); Brown (2003) also supported that concept mapping with discussion powerfully helped teachers to explore and analyze the students’ conceptions.

Also, using story-telling to explain scientific ideas, such as what plant food is, where the food comes from, and how plants make food appear to powerfully facilitate

the students to understand the relationships between plant food, plant materials and the photosynthesis process. In the case study conducted at the Border School, the concepts were discussed using the booklet “why do plants make sugar?” The findings indicated that a majority of students could correct the misconceptions. For example, the misconception about plant food; “mineral, fertilizer, water and air are plant food...” was correctly substituted by the scientific concept; “glucose was plant food.” These findings are supported by the studies of Barker and Carr (1989b, 1989c); Matthews (1994).

Osborne and Wittrock (1985) also supported that exploring the students’ prior knowledge using think share pair, think pair square, challenging them link and generate new ideas about the concepts with their pair using game such as “True or False” and “Matching Me” game, and assessing their own ideas with anybody else in the classroom using story-telling and concept mapping helped them to correct their misconceptions. Observations and interviews (in the case studies of the Market School and the Babysat School) also supported that emphasizing on lecturing without exploring the prior knowledge probably decreased the teachers’ formative assessment. Students then had fewer chances to assess their own ideas. Some students retained their misconceptions or generated new misconceptions.

Surveys and interviews in the case studies indicated that the students’ prior understanding of introductory concepts support the students’ understanding of advanced concepts. S01, S07 and S12, the students who corrected the misconception about *plant food* appeared to scientifically understand *the light independent (dark) phase*. On the other hand, students’ learning difficulties of *chemical structure* and *oxidation-reaction* possibly had brought them to misunderstand the *light dependent (light) phase*. For example, S01 who perceived that oxygen atom of H_2O and CO_2 are electrons. S01 held some misconception that CO_2 is separated into the electron and the oxygen gas by light energy (see Table 5.4). Thus, there are introductory concepts that this research additionally suggests to enhance high school students’ understanding of advanced photosynthesis concepts. Teachers should probe and

correct any misconceptions before teaching photosynthesis. Those concepts are listed in Table 6.1.

Table 6.1 Introductory Concepts in Relation to the Understanding of Advanced Photosynthesis

| Introductory Photosynthesis Concepts | Advanced Photosynthesis Concepts |
|---|---|
| <ul style="list-style-type: none"> • Roles of Chlorophyll | <ul style="list-style-type: none"> • Structures and Functions of Chloroplast |
| <ul style="list-style-type: none"> • Plants and Light Energy • Plant Materials • Chemical structure of H₂O and O₂ • Valence electron • Oxidation-Reduction | <ul style="list-style-type: none"> • Light Dependent (Light) Phase |
| <ul style="list-style-type: none"> • Plant Food • Plant Materials • Chemical structure of monosaccharide | <ul style="list-style-type: none"> • Light Independent (Dark) Phase |
| <ul style="list-style-type: none"> • Plant Materials • Simple Photosynthesis Processes | <ul style="list-style-type: none"> • Necessary Factors Affecting Photosynthesis Rate |

The findings also indicated that the process of understanding photosynthesis should be enhanced along with its relation with the environment. This research now discusses the importance of teaching photosynthesis in the context of its relationship with the environment.

2. Teaching Photosynthesis and Its Relation to the Environment

This research supported the studies of Carlsson (2002); IPST (2002); Ekborg, (2003) that when teaching photosynthesis and its relationship with the environment, one should focus on using or applying the knowledge of photosynthesis to conserve the environment in the students' communities. The case study of the Border School illustrated that teaching by encouraging students' discussions about personal stories regarding the environment appeared to lead the students to assess themselves and to be aware of their own ideas about photosynthesis. Then, the students could initiate

the science project for environmental conservation by themselves. The projects include collection and experiment, survey and report, poster/display, model and demonstration of the research project. For example, S04 and her group consistently used the accepted scientific ideas of photosynthesis to conduct the science project involved decreasing water pollution in the local canal (see 5.4.2 in the case study of the Border School). The findings also supported the report of Manzanal *et al.* (1999). They showed that as a result of studying the environmental issue, the science concepts involved were clarified more easily and gave the students' more positive attitudes towards using science from the classroom in their everyday life.

In the case study conducted at the Market School, photosynthesis had been taught in relation with respiration. The researcher argues that teaching photosynthesis at high school level in Thailand should not be related to respiration. The concepts of respiration in Thai curriculum focus on animal respiration (Ministry of Education, 1991a, 1991b; IPST, 2002). Respiration is broadly presented in terms of inverse photosynthesis. Plant photosynthesis uses CO₂ and releases O₂, and animal respiration uses O₂ and releases CO₂. Kijkuakul and Yutakom (2004) indicated that Thai students misunderstood and thought that plants breathed like people and other animals. Misconceptions of respiration probably bring them to misunderstand photosynthesis: light and dark phases. The students at the Market School appeared to be confused about photosynthesis with misconceptions about respiration. They did not understand that the dark phase was a part of plant photosynthesis process. They thought that it was plant respiration during night time.

Eisen and Stavy (1993); Canal (1999) supported the above argument. Canal (1999: 364) noted the teaching photosynthesis as inverse respiration confuses the understanding of photosynthesis. The relationship between photosynthesis and respiration "...is not an idea that all pupils necessarily have to construct when trying to understand plant processes.", e.g. photosynthesis. Eisen and Stavy (1993) also indicated that if teachers are unaware of student difficulties in understanding respiration, the students would probably be confused between respiration and photosynthesis.

The findings also indicated that teaching photosynthesis should be integrated with the nature of science. Understanding the nature of science appears to give the students an incentive to study biology in the classroom.

3. Teaching the Nature of Science

The intervention has contributed to enhance students' understanding of the nature of science regarding specific ideas. Three aspects of science were considered: scientific ideas are subjected to change, science demands evidence and science is a complex social activity. The findings from the three case studies indicated that historical narratives with discussion illuminate the students' understanding. In the case study conducted in the Border School, role play and discussion were used to illuminate the understanding of science is a complex social activity, in particular. After participating in the role play, students appeared to understand that scientists could not individually work and scientists used the experimentation to evident the knowledge. S02 noted that "...the scientist would publish the discovery to advance the knowledge." S04 noted that "...the scientists continued the previous study and then found new substance involved photosynthesis..." (Table 5.5). Abd-El-Khalick and Lederman (2000) supported that explicitly addressing the specific ideas about science might powerfully enhance the understanding of the nature of science.

The findings of this research also revealed that the students had a better understanding of science as a complex social activity than understanding that science demands evidence and that scientific ideas are subjected to change. The better understanding appears to depend on learning activities teachers provided in classrooms. Surveys and observations indicated that participating in classroom discussion and experimentation was useful to understand that nature of science. On the other hand, when there were fewer chances of discussion, misconceptions related to scientific ideas subject to change were retained (see case studies of the Market School and the Babysat School). Skipping all experimentation activities in the Babysat School possibly caused their students to be unaware that science demands evidence. For example, S10 perceived that scientific knowledge could be changed

because old knowledge was reinterpreted by using different method and new techniques. However, he did not appear to focus on using scientific method to find out an evidence of new knowledge. Moss, Abrams and Robb (2001); Bell *et al.* (2003) supported that a lack of scientific experiments might lead the students to neglect the fact that science demands evidence.

After elaborating on these several aspects of teaching photosynthesis, this research attempts to show the importance of regarding the specific Thai context.

4. Teaching in the Thai Contexts

In Thailand, as a result of the local socio-cultural context, there are a large number of students in the classroom. Some students show respect to teachers and value science as they need it for taking the Entrance Examination (Buranakarn, 2003; Srivichit, 2004). The research findings indicated that Thai society and culture influence learning in the classroom. The students are not familiar with participating actively to the learning activities e.g. discussion. So, discussion in a Thai classroom should begin with small group discussions such as think pair share. Also, the teaching process should develop friendly interactions between the teacher and the students, and should promote formative assessment. In the case of the Border School, the students appeared to be familiar with this and have a more positive attitude towards participating in learning activities.

The case study conducted at the Border School additionally suggests that teachers should conduct friendly conversations with the students both within and outside teaching periods. The students should be free to form their own groups, be a bit of noisy during group discussion and be able to walk from one group to another. Launching a discussion should begin with think pair share before moving on to group discussion and class discussion. This strategy appears to encourage the students to have discussion with the teacher as well.

Formative assessment should be used to promote valuing classroom study. If students complete the learning activities and assignments, the teacher should share his/her opinion with them and reward during the teaching period. In the case of Mrs. Engka, the students would receive extra scores when they participated in learning activities or continued to improve their concept mapping. They appeared to have more positive attitudes towards participating in classroom study.

This research summarises the learning activities for teaching and learning about photosynthesis in Table 6.2.

Table 6.2 Learning Activities Suggested for Understanding Advanced
Photosynthesis Concept

| Advanced Photosynthesis Concepts | Learning Activities |
|---|---|
| 1. Structures and Functions of Chloroplast | <ul style="list-style-type: none"> • Experimentation with discussion about photosynthetic pigment. • Conducting 3-dimensional model of chloroplast with discussion • Discussion that elicit <i>both</i> structures and functions of chloroplast including pigments and stroma. |
| 2. Light Dependent (Light) Phase | <ul style="list-style-type: none"> • Developing the chemical concepts involved introductory photosynthesis concepts e.g. structure of H₂O and O₂ using discussion. • Experimenting and discussing about 1) photolysis or water splitting brought the prior electron, the proton and oxygen atom and 2) change of energy level during the electron transfer brought ATP and NADPH⁺. • Concept mapping describes the products of the photolysis and the electron transfer as the products of the light phase. • Summarizing roles of light energy and water. |
| 3. Light Independent (Dark) Phase | <ul style="list-style-type: none"> • Correcting the misconception about plant food using think pair share, game “True or False” and discussion “what is plant food?” • Discussing structure of CO₂ and monosaccharide/sugar • Historical narrative using role play integrating nature of science into the concepts about dark phase. • Summarizing roles of CO₂ • Concept mapping relates the dark phase to the light phase. |
| 4. Necessary Factors Affecting Photosynthesis Rate | <ul style="list-style-type: none"> • Correcting the misconception about plant materials and simple photosynthesis processes using think pair share, game “True or False” and discussion. • Emphasizing discussion about the relationships between types of plant e.g. C3- and C4-plants and number of chloroplast found in those plants’ tissues, using photograph of the tissues. |

According to the second question – what is the impact of the teaching intervention on teachers and students? - The findings indicated that the different teaching contexts of the three teachers probably influenced their implementation of the intervention.

5. The Impact of the Intervention on the Teachers

The findings indicated that the teachers' beliefs about learning, their content knowledge, their perceptions of the nature of science, and their role in the classroom had influenced the implementation of the intervention. Bell (1998) supported that teachers had different ideas, beliefs, interests and feelings while teaching. Those differences could lead to different outcomes within the objectives of teaching.

The attempts at correcting students' misconceptions and enhancing students' understanding of photosynthesis using several teaching strategies appears to depend on the teacher's belief in how students learn. For example, Mrs. Engka, who believed that teaching only by lecturing could not adequately help the students' learning about biology, consistently attempted to correct her students' misconceptions using several learning activities such as think share pair, concept mapping and discussions (see Table 6.2). On the other hand, Mr. Vyn, who thought that students learned directly from a teacher's lecture, appeared to correct the misconceptions by an emphasis on lecturing. Mrs. Amp, who rarely appreciated students who argued with the teacher and the school and who was not confident in her chemistry content knowledge of photosynthesis, appeared to be unconvinced to change her traditional teaching methods from a teacher-centred approach to a student-centred approach based on the intervention. Her teaching strongly emphasized good student discipline. The students must be quiet and not move around during her lecture class. The findings showed that their students could not correct the prior misconceptions. For example, a student in Mrs. Amp's classroom still held the misconception that "mineral, fertilizer, and water were plant food" and held new misconception that "CO₂ was also plant food". The findings also indicated that eighty percent of the students in Mrs. Engka's classroom and forty-three percent of those in Mr. Vyn's classroom developed adequate scientific

understandings about the light independent (dark) phase compared with only twenty-four percent in Mrs. Amp's classroom.

The teachers' personal perceptions of the nature of science appeared to affect their way of illuminating the nature of science. Teachers, who perceived that understanding the nature of science is as important as understanding of the photosynthesis concepts, consistently appeared to encourage the students to understand the nature of science. Historical narratives, experimentations and discussions about the scientists' discoveries were used in teaching photosynthesis concepts. Teachers, who perceived the nature of science as scientific ideas, however, appeared to teach the nature of science in a similar way as teaching the concepts. For example, Mr. Vyn emphasized lecturing for the students to understand photosynthesis and the nature of science (see Mr.Vyn's lecture about nature of science in Figure 5.4). His students appeared to repeat Mr.Vyn's lecture with unclear understanding. S07 thought that science appeared to change in term of application of old knowledge; old knowledge was not actually changed. The scientists individually experimented and developed the knowledge (see Table 5.10). Smith and Anderson (1984) also supported the ideas that teachers who misunderstood the nature of science could not completely teach science and have the students who fully understand science.

Teachers, who perceived that teaching photosynthesis with its relationship with the environment as an important aspect of teaching about photosynthesis appeared to facilitate students' application of photosynthesis knowledge to the environment.

6. The Impact of the Intervention on the Students

After teaching using the six guiding principles, the findings indicated that the students' understanding of photosynthesis progressed from the introductory level about photosynthesis to the advanced knowledge. The students could develop their understanding of advanced photosynthesis after they corrected the introductory misconceptions. The students then appeared to relate photosynthesis to the

environment using accepted photosynthesis concepts for environmental conservation. However, their abilities to correct misconceptions and to use the accepted concepts appeared to depend on the teaching as discussed in previous sections. Students who could not correct their misconception rarely improved their understanding and could not relate their knowledge to the environment.

Understanding the nature of science was illuminated after teaching (discussed in previous sections). More students completely understood that science is a complex social activity than that science demands evidence and that scientific ideas are subjected to change.

It has now been shown that, when teaching and learning about photosynthesis in Thailand, it is necessary to take into account the students' prior knowledge and the interactions between students and teachers. The students should be encouraged to learn by themselves. These considerations support the social constructivist belief of learning discussed in the literature (Chapter II). Also, the teacher needs to take into consideration the Thai social context. This research offers the following recommendations.

Recommendation

This research suggests that the development of the students' understanding about photosynthesis should be done in parallel with the teachers' development. Perhaps some Thai teachers have not been convinced to abandon old teaching tradition and to adapt a new one based on the National Education Act (ONEC, 2000a) and the National Science Curriculum (IPST, 2002). The three case studies indicated that even though the teachers were provided with teaching materials they did not appear to be convinced. The teachers' learning belief, science content knowledge, understanding of nature of science, perception on the roles of teaching possibly influenced their teaching practices.

Therefore, this research suggested that teachers should receive enough opportunities to reflect and share teaching experiences with other teachers within the department and with the school. The resulting reflection would probably help the teachers to be aware of and to accept the need for professional development. Then, they might be convinced to change their teaching practices. In addition, people concerned with teacher development might need to promote the teachers' understanding of both scientific content and of the nature of science. The school should emphasize the value of teaching as the teachers' main function. Teachers should be allowed enough time to prepare their lessons. Interviews with teachers also indicate that teaching periods should not be interrupted by school events.

This thesis has illustrated how three biology teachers from different high schools have taught to promote Grade 11 students' understanding about photosynthesis through its relation to the environment and the nature of science. Also, the thesis has provided results from different teaching. The teaching based on social constructivist belief of learning and Thai social context appears to result in better acquisition of knowledge. Correcting students' prior misconception appeared to support enhancing students' understanding of advanced photosynthesis. Encouraging students' participations in learning activities especially discussion appeared to promote interactions between teacher and student as well as student and other student. Therefore, the main resulting issue is to see how the teachers should be encouraged to teach using these ideas.

REFERENCE

- Abd-El-Khalick, F. and N. Lederman. 2000. The influence of history of science courses on students' views of nature of science. **Journal of Research in Science Teaching** 37 (10): 1057-1095.
- Aikenhead, G. and G. Ryan. 1992. The development of a new instrument 'Views on Science-Technology-Society' (VOSTS). **Science Education** 76: 477-491.
- Alfred, M. 2002. The promise of sociocultural theory in democratizing adult education. **New Directions for Adult and Continuing Education** 96: 3-13.
- Allchin, D., E. Anthony, J. Bristol, A. Dean, D. Hall, and C. Lieb. 1999. History of science – With Labs. **Science and Education** 8: 619-632.
- American Association for the Advancement of Science (AAAS). 1989. Science for all Americans. In **Project 2061** (Online). Available: <http://www.project2061.org>, October 1, 2001.
- Amir, R. and P. Tamir. 1989. When does a factor become a 'Limiting Factor'? –a study of students' misconceptions. **Journal of Biological Education** 23 (2): 129-134.
- _____. 1994. In-depth analysis of misconceptions as a basis for developing research-based remedial instruction: The case of photosynthesis. **The American Biology Teacher** 56 (2), p: 94. Retrieved August 7, 2003, from ProQuest database.

- Amir, R. and P. Tamir. 1995. Proposition generating task (PGT): a measure of meaningful learning and of conceptual change. **Journal of Biological Education** 29 (2): 111-118. Retrieved August 7, 2003, from EBSCOhost database.
- Anderson, J. 2002. Changing concepts about the distribution of photosystems I and II between grana-appressed and stroma-exposed thylakoid membranes. **Photosynthesis Research** 73: 157-164.
- Anderson, C., T. Sheldon, and J. Dubay. 1990. The effects of instruction on college nonmajors' conceptions of respiration and photosynthesis. **Journal of Research in Science Teaching** 27 (8): 761-776.
- Ann, F. 2000. **Biology** (2nd Ed.). Oxford: Heinemann Educational Publishers.
- Appleton, K. 1997. Analysis and description of students' learning during science classes using a constructivist-based model. **Journal of Research in Science Teaching** 34 (3): 303-318.
- Asia Times Online**. 2001. Thailand's government policy (March 21, 2001). (Online) Available: <http://www.atimes.com/se-asia/cc21Ae04.html>, 8 Jan 04.
- Bahar, M., H. Johnstone, and Hansell, H. 1999. Revisiting learning difficulties in biology. **Journal of Biological Education** 33 (2): 84-86.
- Bangkok Post**. 2001a. Western forest wins pledge of protection: lushest green area in Southeast Asia (May 3, 2001). (Online). Available: www.bangkokpost.com, 19 Dec 2003.
- Bangkok Post**. 2001b. City's green area to get a big boost (January 13, 2001). (Online). Available: www.bangkokpost.com, 19 Dec. 2003.

- Barker, M. 1985. Teaching and learning about photosynthesis. **Working Papers No. 220-229**. Hamilton: University of Waikato.
- _____. 1986. **The description and modification of children's views of plant nutrition**. Ph.D. Thesis, University of Waikato, New Zealand.
- _____. 1995. A plant is an animal standing on its head. **Journal of Biological Education** 29 (3): 201-208.
- _____. 1997. History in New Zealand science education: progress and prospects. In Bell, B and R. Baker. (Eds.). **Developing the Science Curriculum in Aotearoa New Zealand**. Auckland: Addison Wesley Longman, chapter 16, pp. 187-212.
- Barker, M. and M. Carr. 1989a. Teaching and learning about photosynthesis, Part 1: an assessment in terms of students' prior knowledge. **International Journal of Science Education** 11 (1): 49-56.
- _____. 1989b. Teaching and learning about photosynthesis, Part 2: a generative learning strategy. **International Journal of Science Education** 11 (2): 141-152.
- _____. 1989c. Photosynthesis—can our pupils see the wood for the trees? **Journal of Biological Education** 23 (1): 41-44.
- Bell, B. 1981. Animal, plant and living: note for teachers. **Working paper No. 30**. Hamilton: University of Waikato.
- _____. 1985. Students' ideas about plant nutrition: What are they? **Journal of Biological Education** 19 (3): 213-218.

- Bell, B. 1998. Teacher development in science education. In Fraser, B and K. Tobin. (Eds.). **International Handbook of Science Education**. UK: Kluwer Academic Publishers, p. 681-693.
- Bell, B. and J. Gilbert. 1996. **Teacher Development: A Model from Science Education**. UK: Falmer Press.
- Bell, R., N. Lederman, and F. Abd-El-Khalick. 1998. Comments and criticism: implicit versus explicit nature of science instruction - an explicit response to palmquist and finley. **Journal of Research in Science Teaching** 35 (9): 1057-1061.
- _____, L. Blair, B. Crawford, B. Crawford, and N. Lederman. 2003. Just do it? Impact of a science apprenticeship program on high school students' understandings of the nature of science and scientific inquiry. **Journal of Research in Science Teaching** 40 (5): 487-509.
- Benson, A. 2002. Following the path of carbon in photosynthesis: a personal story. **Photosynthesis Research** 73: 29-49.
- Berk, L. and A. Winsler. 1995. **Scaffolding Children's Learning: Vygotsky and Early Childhood Education**. New York: The National Association for the Education of Young Children.
- Bettencourt, A. 1993. The construction of knowledge: a radical constructivist view. In Tobin, K. (Ed.). **The Practice of Constructivism in Science Education**. Washington, D.C: American Association for the Advancement of Science Press, chapter 3.
- Bianchini, J. and A. Colburn. 2000. Teaching the nature of science through inquiry to prospective elementary teachers: a tale of two researchers. **Journal of Research in Science Teaching** 37 (2): 177-209.

- Boonklurb, N. 2000. Thailand. In Poisson, M. (Ed.), **Final Report of the International Workshop on the Reform in the Teaching of Science and Technology at Primary and Secondary Level in Asia: Comparative References to Europe, Beijing, March 27-31, 2000.** UNESCO. Available: <http://www.ibe.unesco.org/National/China/chifinal.htm>, August 8, 2003.
- Bogdan, R. and S. Biklen. 1982. **Qualitative Research for Education: An Introduction to Theory and Methods.** Boston: Allyn and Bacon.
- Bredo, E. 1994. Reconstructing educational psychology: situated cognition and Deweylian pragmatism. **Educational Psychologist** 29 (1): 23-35.
- Brown, D. 2003. A group approach to concept mapping. **The American Biology Teacher** 65 (3): 192-197.
- Buchanan, B. 1994. **Daniel I. Arnon** (Online). Available: <http://books.nap.edu/html/biomems/darnon.html>, 30 April 2004
- Buffalo villages. (pseud.). 2003. **History of Thai Houses.** (Online). Available: http://www.buffalovillages.com/en/showbaan/songthai_his.htm, 24 Jan 2004
- Buranakarn, V. 2003. Graduate experience influenced from elementary study: Thailand case study. In **Grade-Blueprint 2003** (Online). Available: <http://www.grad.chula.ac.th/GRADBLUEPRINT/Fulltex/Vorasun.htm>, 10 Jan 2004.
- Bybee, R. and R. Sund. 1982. **Piaget for Educators.** (2nd ed.). Ohio: A Bell and Howell company.
- Campbell, N. 1996. **Biology.** (4th ed.). California: Benjamin Cummings.

- Campbell, N. and J. Reece. 2002. **Biology**. (6th ed.). n.p. Pearson Education.
- Canal, P. 1999. Photosynthesis and ‘Inverse Respiration’ in plants: An inevitable misconception? **International Journal of Science Education** 21 (4): 363-371.
- Carlsson, B. 2002. Ecological understanding 1: ways of experiencing photosynthesis. **International Journal of Science Education** 24 (7): 681-699.
- Clayton, R. 2002. Research on photosynthetic reaction centers from 1932 to 1987. **Photosynthesis Research** 73: 63-71.
- Cobb, P. 1994. Where is the mind? Constructivist and sociocultural perspectives on mathematical development. **Educational Researcher** 23(7): 13-20.
- Cobb, P. and E. Yackel. 1996. Constructivist, emergent, and sociocultural perspectives in the context of developmental research. **Educational Psychologist** 3 (3/4): 175-190.
- Cobern, W. 1993. Contextual constructivism: the impact of culture on the learning and teaching of science. In Tobin, K. (Ed). **The Practice of Constructivism in Science Education**. Washington, D.C.: American Association for the Advancement of Science Press, chapter 4.
- _____. 1998. The culture study of science and science education. In Cobern, W. (Ed.). **Socio-Cultural Perspectives on Science Education: An International Dialogue**. Science and Technology Education Library, Vol. 4. Netherlands: Kluwer Academic Publishers, pp. 1-5.

- Cohen, L. and L. Manion. 1994. **Research Methods in Education**. (4th ed.). New York: Routledge.
- _____, L. Manion, and K. Morrison. 2000. **Research Method in Education**. (5th ed.). London: Taylor and Francis Group.
- Dean, L. 1996. The Hill reaction of photosynthesis in isolated chloroplasts: a quantitative approach. **The American Biology Teacher** 58 (5): 303-304.
- Denscombe, M. 1998. **The Good research guide: for small-scale social research projects**. England: Open University Press.
- Denzin, N. and Y. Lincoln. 1998. Introduction: Entering the field of qualitative research. In, Denzin, N and Y. Lincoln. (Eds.). **The Landscape of Qualitative Research: Theories and Issues**. California: SAGE, chapter 1, pp. 1-34.
- Dreyfus, A. 1995. Biological knowledge as a prerequisite for the development of values and attitudes. **Journal of Biological Education** 29(3): 215-219.
- Driver, R., E. Guesne, and A. Tiberghien. (Eds.). 1985. **Children's Ideas in Science**. Philadelphia: Open University Press.
- _____, H. Asoko, J. Leach, E. Mortimer, and P. Scott. 1994. Constructing scientific knowledge in the classroom. **Educational Researcher** 23: 5-12.
- _____, J. Leach, R. Millar., and P. Scott. 1996. **Young People's Images of Science**. Buckingham: Open University Press.

- Duit, R. and D. Treagust. 2003. Learning in science – from behaviourism towards social constructivism and beyond. In Fraser, B. and K. Tobin, K. (Eds.). **International Handbook of Science Education: Part One**. KLUWER ACADEMIC PUBLISHERS, pp. 3-25.
- Eilam, B. 2002. Strata of comprehending ecology: looking through the prism of feeding relations. **Science Education**: 86: 645-671.
- Eisen, Y. and R. Stavy. 1993. How to make the learning of photosynthesis more relevant. **International Journal of Science Education** 15 (2): 117-125.
- Ekborg, M. 2003. How students teachers use scientific conceptions to discuss a complex environmental issue. **Journal of Biological Education** 37 (3): 126-132.
- Erickson, F. 1986. Qualitative methods in research on teaching. In, Wittrock, M. (Ed.). **Handbook of Research on Teaching**. (3rd ed.). New York: Macmillan.
- Eskilsson, O. and I. Holgersson. 1999. Everyday phenomena and teachers' training. **European Journal of Teacher Education** 20 (2/3): 231-245.
- Fernandez Manzanal, F., Rodriguez Barreiro, L.M. and Casal Jimenez, M. 1999. Relationship between ecology fieldwork and students attitudes toward environmental protection. **Journal of Research in Science Teaching** 36 (4): 431-453.
- Fontana, A. and H. Frey. 1998. Interviewing: the art of science. In N. Denzin and Y. Lincoln. (Eds.). **Collecting and interpreting qualitative materials**. CA: Sage, pp. 47-78.

- Fry, G. 2000. **The Evolution of Educational Reform in Thailand**. Paper presented at the Second International Forum, ONEC, Bangkok, September 2-5, 2002.
- Fullick, A. 2000. **Heinemann Advanced Science: Biology**. (2nd ed.). Oxford: Heinemann.
- Garnett, P. and D. Treagust. 1992. Conceptual difficulties experienced by senior high school students of electrochemistry: electric circuits and oxidation-reduction equations. **Journal of Research in Science Teaching** 29 (2): 121-142.
- Geelan, D. 1997. Epistemological anarchy and the many forms of constructivism. **Science and Education** 6: 15-28.
- Germann, P. 1989. Directed-inquiry approach to learning science process skills: treatment effects and aptitude-treatment interactions. **Journal of Research in Science Teaching** 26 (3): 237-250.
- Gust, H. 2002. History of the word photosynthesis and evolution of its definition. **Photosynthesis Research** 73: 7-10.
- Gil-Perez, D. *et al.* 2002. Defending constructivism in science education. **Science and Education** 11: 557-571.
- Good, R., J. Wandersee, and J. Julien. 1993. Cautionary notes on the appeal of the new 'Ism' (Constructivism) in science education. In Tobin, K. (Ed.). **The Practice of Constructivism in Science Education**. AAAS PRESS, pp.71-87.
- Govindjee, J. and H. Gest. 2002. Celebrating the millennium – historical highlights of photosynthesis research. **Photosynthesis Research** 73: 1-6.

- Govindjee, J., T. Beatty, and H. Gest. 2003. Celebrating the millennium – historical highlights of photosynthesis research, Part 2. **Photosynthesis Research** 76: 1-11.
- Griffard, P. and J. Wandersee. 2001. The two-tier instrument on photosynthesis: What does it diagnose? **International Journal of Science Education** 23 (10): 1039-1052.
- Guba, E. and Y. Lincoln. 1998. Competing paradigms in qualitative research. In, Denzin, N. and Y. Lincoln. (Eds.). **The Landscape of Qualitative Research: Theories and Issues**. California: SAGE, chapter 6, pp. 195-220. .
- Gunstone, R. 1990. 'Children's Science': a decade of developments in constructivist views of science teaching and learning. **The Australian Science Teachers Journal** 36 (4): 9-19.
- Gust, D. 1996. **Why study photosynthesis?** (Online). Available: <http://photoscience.la.asu.edu/photosyn/study.html>, 21 Dec 03
- Haldimann, P. 1999. How do changes in temperature during growth affect leaf pigment composition and photosynthesis in *Zea mays* genotypes differing in sensitivity to low temperature? **Journal of Experimental Botany** 50 (333): 543-550.
- Haslam, F. and D. Treagust. 1987. Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument. **Journal of Biological Education** 21 (3): 203-211.

Hazel, E. and M. Prosser. 1994. First-year university students' understanding of photosynthesis, their study strategies and learning context. **The American Biology Teacher** 56 (5): 274-279.

Hipkins, R., *et al.* 2002. **Curriculum, Learning and Effective Pedagogy: A Literature Review in Science Education**. Wellington: Centre for Science and Technology Education Research, University of Waikato and New Zealand Council for Education Research, Wellington, with Auckland College of Education.

His Majesty King Bhumibol Adulyadej (of Thailand). 1993. **The speech of His Majesty King Bhumibol Adulyadej on the occasion of the Royal Birthday Anniversary**, December 4, 1993. (Online). Available: <http://www.kanchanapisek.or.th/speeches/1993/1204.th.html>, 8 Jan 04.

Hodson, D. 2003. Time for action: science education for an alternative future. **International Journal of Science Education** 25 (6): 645-670.

_____, and J. Hodson. 1998. From Constructivism to social constructivism: a Vygotskian perspective on teaching and learning science. **School Science Review** 79 (289): 33-41.

Howe, A. 1996. Development of science concepts within a Vygotskian framework. **Science Education** 80 (1): 35-51.

Institute for the Promotion of Teaching Science and Technology (IPST). 1989. **Report Studies of Alternative Conceptions and Misconceptions in the Lesson of Photosynthesis**. Bangkok: IPST. (in Thai).

_____. 1998. **Biology 049: Teaching Manual**. Bangkok: Ku-Ru-Sa-Pa-Lad-Praw Press. (in Thai).

Institute for the Promotion of Teaching Science and Technology (IPST). 2000a.

Biology 101. Bangkok: Ku-Ru-Sa-Pa-Lad-Praw Press. (in Thai).

_____. 2000b. **Biology 203.** Bangkok: Ku-Ru-Sa-Pa-Lad-Praw Press. (in Thai).

_____. 2000c. **Biology 441.** Bangkok: Ku-Ru-Sa-Pa-Lad-Praw Press. (in Thai).

_____. 2000e. **Biology 042.** Bangkok: Ku-Ru-Sa-Pa-Lad-Praw Press. (in Thai).

_____. 2002. **The National Science Curriculum.** Bangkok: IPST. (in Thai).

_____. 2003. **The National Science Curriculum, B.E. 2544 (AD 2001): School Manual.** Bangkok: IPST. (in Thai).

Jantranon, J. 1999. **A Study of Mathayomsuksa 1-6 Students' Conceptions of Food in Bangkhanwittaya School, Changwat Nakhon Si Thammarat.** M.S. Thesis, Kasetsart University. (in Thai).

Jarusombuti, S. *et al.* 2005. Products of agriculture for wood substitution. In **Kasetsart Research** (Online). Available: <http://www.ku.ac.th.kaset60.Theme04/theme-04-19/index-04-19.html>, December 30, 2005

John-Steiner, V. and H. Mahn. 1996. Sociocultural approaches to learning and development: a Vygotskian framework. **Educational Psychologist** 3 (3/4): 191-206.

- Julian (pseud.). (2000). The value of trees. **WETlands** (Dec 2000): 7 (3).
(Online). Available: <http://www.sbwr.org.sg.wetlands.text/00-7-3-9.htm>,
20 Dec 03
- Kijkuakul, S. 2002. Classroom Observations: Grade11 Photosynthesis Teaching. Aug 10, 2002. Bangkok.
- Kijkuakul, S. and N. Yutakom. 2004. A study of level 4 students' photosynthesis conceptions. **Kasetsart Journal (Social Science)**: 25 (2): 139-149.
- Kinchin, I. 2000a. Concept-Mapping activities to help students understand photosynthesis – and teachers understand students. **School Science Review** 82 (299): 11-14.
- _____. 2000b. Concept mapping in biology. **Journal of Biological Education** 34 (2): 61-68.
- Kuhn, G. and B. Hand. 1995. Using writing and talking to assess student understandings in junior secondary science geology topics. In Hand, B. and V. Prain. (Eds.). **Teaching and Learning in Science: The Constructivist Classroom**. Sydney: Harcourt Brace.
- LaBoskey, V. 2002. Stories as a way of learning both practical and reflective orientations. In, Lyons, N. and V. LaBoskey. (Eds.). **Narrative Inquiry in Practice: Advancing the Knowledge of Teaching**. New York: Teaching College Press.
- Lavoie, D. 1997. **Using a Modified Concept Mapping Strategy to Identify Students' Alternative Scientific Understandings of Biology**. Paper presented at the 1997 Annual Meeting of the National Association for Research in Science Teaching, Chicago, Illinois, March 21-24, 1997.

- Lin, H. and C. Chen. 2002. Promoting preservice chemistry teachers' understanding about the nature of science through history. **Journal of Research in Science Teaching** 39 (9): 773-792.
- Lincoln, Y. and Guba, E. 1985. **Naturalistic Inquiry**. California: Sage Publications.
- Linn, M. and N. Burbules, N. 1993. Construction of knowledge and group learning. In Tobin, K. (Ed.). **The Practice of Constructivism in Science Education**. Washington, D.C.: American Association for the Advancement of Science Press, chapter 6.
- Lumpe, A. and J. Staver. 1995. Peer collaboration and concept development: learning about photosynthesis. **Journal of Research in Science Teaching** 32 (1): 77-98.
- Manuel, D. 1986. History and philosophy of science with special reference to biology: What can it offer teachers? **Journal of Biological Education** 23 (3): 195-200.
- Marshall, H. 1996. Implications of differentiating and understanding constructivist approaches. **Educational Psychologist** 31 (3/4): 235-240.
- Marx, R., J. Freeman, J. Krajcik, and P. Blumenfeld. 1998. Professional development of science teachers. In Fraser, B and K. Tobin, K. (Eds.). **International Handbook of Science Education**. UK: Kluwer Academic Publishers, pp. 667-680.
- Matthews, M. 1993. Constructivism and science education: Some epistemological issues. **Journal of Science Education and Technology** 2: 359-370.

- Matthews, M. 1994. **Science Teaching: The Role of History and Philosophy of Science**. New York: Routledge.
- _____. 1995. **Challenging New Zealand Science Education**. Palmerston North, NZ: Dunmore Press.
- _____. (Ed.). 1997. **Science and Education** 6 (4): 323-329.
- _____. 1998. The nature of science and science teaching. In, Fraser, B. and Tobin, K. (Eds.). **International Handbook of Science Education**. UK: Kluwer Academic Publishers, pp. 981-999.
- May, T. 2001. **Social Research: Issues, Methods and Process**. (3rd ed.). UK: Open University Press.
- Maykut, P. and R. Morehouse. (Eds.). 1994. **Beginning Qualitative Research: A Philosophic and Practical Guide**. London: The Falmer Press, chapter 7, pp. 68-117.
- McComas, W. and J. Olson. 1998. The nature of science in international science education standards documents. In, McComas, W. (Ed.). **The Nature of Science in Science Education: Rationales and Strategies**. Netherlands: Kluwer Academic Publishers, chapter 2, pp. 41-52.
- _____, M. Clough, and H. Almazroa. 1998. The role and character of the nature of science in science education. In, McComas, W. (Ed.). **The Nature of Science in Science Education: Rationales and Strategies**. Netherlands: Kluwer Academic Publishers, chapter 2, pp. 1-39.
- McLaughlin, C., L. Hampton, and S. Moxham. 1999. Shining on photosynthesis: teaching about photosynthesis and plant growth in the primary classroom. **Science and Children** 36 (5): 26-31.

- Merriam, S. 1988. **Case Study Research in Education: A Qualitative Approach**. San Francisco: Jossey-Bass.
- Messadie, G. 1991. Photosynthesis. **Great Scientific Discoveries**. New York: Chambers.
- Ministry of Education. 1991a. **Junior High School Curriculum B.E. 2521 (Revised B.E.2533)**. Bangkok: Karn-sat-sa-na printing. (in Thai).
- _____. 1991b. **Senior High School Curriculum B.E.2524 (Revised B.E. 2533)**. Bangkok: Karn-sat-sa-na printing. (in Thai).
- Mintzes, J., J. Wandersee, and J. Novak. 2001. Assessing understanding in biology. **Journal of Biological Education** 35 (3): 118-124.
- Moss, D., E. Abrams, and J. Robb. 2001. Examining student's conceptions of the nature of science. **International Journal of Science Education** 23 (8): 771-790.
- National Research Council. 1996. **National Science Education Standards**. USA: The National Academy of Sciences.
- Novak, J. and D. Gowin. 1984. **Learning How to Learn**. New York: Cambridge University Press, pp.15 – 40.
- Office of the National Education Commission (ONEC). 2000a. **National Education Act B.E. 2542 (1999)**. Bangkok: Prig Wan Graphic Co., Ltd.
- _____. 2000b. **Learning Reform: A Learner-Centred Approach**. Bangkok: Watana Panit Printing and Publishing Company Limited.

- Office of the National Education Commission (ONEC). 2002. **Education in Thailand 2002/2003**. Bangkok: Watana Panit Printing and Publishing Company Limited.
- Ogawa, M. 1998. A cultural history of science education in Japan: an epic description. In Cobern, W. (Ed.). **Socio-Cultural Perspectives on Science Education: An International Dialogue. Science and Technology Education Library, Vol. 4**. Netherlands: Kluwer Academic Publishers, chapter 7.
- Orihara, K., D. Wright, and M. Knowlton. 1988. **Thailand: Children of the World**. USA: Gareth Stevens Publishing.
- Osborne, J. 1996. Beyond Constructivism. **Science Education** 80 (1): 53-82.
- _____, and M. Wittrock. 1985. The generative learning model and its implications for science education. **Studies in Science Education** 12: 59-87.
- _____, S. Collins, M. Ratcliffe, R. Millar, and R. Dusch. 2003. What 'Ideas-about-Science' should be taught in school science? A Delphi study of the expert community. **Journal of Research in Science Teaching** 40 (7): 692-720.
- Ozay, E. and H. Oztas. 2003. Case study: secondary students' interpretations of photosynthesis and plant nutrition. **Journal of Biological Education** 37 (2): 68-70.
- Packer, M. and J. Goicoechea. 2000. Sociocultural and constructivist theories of learning: ontology, not just epistemology. **Educational Psychologist** 35 (4): 227-241.

- Patton, M. 1990. **Qualitative Evaluation and Research Methods**. (2nd ed.). London: Sage Publications.
- Pfennig, N. 1987. van Niel Remembered. **Features** 53 (2): 75-77.
- Phillip, E. 1996. Using history to teach biology. **The American Biology Teacher** 58 (4): 200-206.
- Piaget, J. 1950. **The Psychology of Intelligence**. London: Routledge and Paul.
- Porra, R. 2002. The Chequered history of the development and use of simultaneous equations for the accurate determination of chlorophylls *a* and *b*. **Photosynthesis Research** 73: 149-156.
- Posner, G., K. Strike, P. Hewson, and W. Gertzog. 1982. Accommodation of a scientific concept: toward a theory of conceptual change. **Science Education** 66: 211-227.
- Punchai, B. 1992. **Evaluation of Learning in Science**. (Online). Bangkok: Ramkumheang University, Press. Available: <http://e-book.ram.edu/e-book/m/mr326/mr326.htm>, October 6, 2003.
- Purves, *et al.* 2001. **Life: The Science of Biology**. (4th ed). Boston: W. Grant Press
- Reiss, M., R. Millar, and J. Osborne. 1999. Beyond 2000: Science/Biology education for the future. **Journal of Biological Education** 33 (2): 68-70.
- Roberts, R. 2001. Procedural understanding in biology: the 'Thinking Behind the Doing'. **Journal of Biological Education** 35 (3): 113-117.

- Robinson, J. 1998a. Science teaching and the nature of science (orig. 1965)*. **Science and Education** 7: 617-634.
- _____. 1998b. Reflections on 'Science Teaching and the Nature of Science'. **Science and Education** 7: 635-642.
- Rogoff, B. 1990. **Apprenticeship in Thinking: Cognitive Development in Social Context**. New York: Oxford University Press.
- Russel, N. 1988a. Teaching biology in a wider context: the history of the discipline as a method 1. **Journal of Biological Education** 22(1): 45-50.
- _____. 1988a. Teaching biology in a wider context: the history of the discipline as a method 2: worked examples. **Journal of Biological Education** 22 (2): 129-135.
- Sawyer, R. 2004. Creative teaching: collaborative discussion as disciplined improvisation. **Educational Researcher** 33 (2): 12-20.
- Sarantakos, S. 1993. **Social Research**. Hong Kong: Macmillan Education Australia PTY Ltd.
- Sitti, B. 1994. **Effects of Using Concept Mapping Teaching Technique on the Change of Students' Misconceptions in Biology**. M.S. Thesis, Chulalongkorn University. (in Thai).
- Slingsby, D. 2003. Biological education: Where next? **Journal of Biological Education** 37 (4): 160-161.
- Smith, E. and C. Anderson. 1984. Plants as producers: a case study of elementary science teaching. **Journal of Research in Science Teaching** 21 (7): 685-698.

- Smith, M. and L. Scharmann. 1999. Defining versus describing the nature of science: a pragmatic analysis for classroom teachers and science educator. **Science Education** 83: 493-509.
- Son, H., T. Quang, and N. Hanh. 2002. **Sustaining Food Security and Managing Natural Resources in Southeast Asia – Challenges for the 21st Century**. Paper presented at Chiang Mai, Thailand. 8-11 January 2002.
- Songer, C. and J. Mintzes. 1994. Understanding cellular respiration: an analysis of conceptual change in college biology. **Journal of Research in Science Teaching** 31 (6): 621-637.
- Srivichit, T. 2004. **Thailand in the 90s**. Available:
<http://www.thailandlife.com/thaifamily.html>, 8 Jan 2004.
- Sukpimontree, T. 1988. **Misconceptions in Biology of Mathayomsuksa V Students in Changwat Surat Thani**. M.S. Thesis, Kasetsart University. (in Thai).
- Suzuki, D. 1997. **The Sacred Balance: Rediscovering Our Place in Nature**. n.p. Allen and Unwin.
- Taiz, L. and E. Zeiger. 2002. **Plant Physiology**. (3rd ed.). n.p. Sinauer Associates, Inc., Publishers.
- Taprab, S., *et al.* 2003. Acid Sulfate Soil Tolerant Promising Line of Photosensitive Lowland Rice from Pathum Thani Rice Research Center. In **Rice Research Institute** (Online). Available:
<http://www.doa.go.th/rri/s04.htm>, January 20, 2006.

ThaiWorldView (Online). Thai School. Available:

<http://www.thaiworldview.com/society/day5.htm>, 31 May 2004.

Tobin, K. 1990. Social constructivist perspectives on the reform of science education. **The Australian Science Teachers Journal** 36 (4): 29-35.

Trakoontivakorn, G. *et al.* 2005. Potential of natural antioxidant from Thai indigenous vegetables on health and rancidity aspects. In **Kasetsart Research** (Online). Available:

<http://www.ku.ac.th.kaset60.Theme04/theme-04-30/index-04-30.html>,
December 30, 2005

Treagust, D. 1988. Development and use of diagnostic tests to evaluate students' misconceptions in science. **International Journal of Science Education** 10 (2): 159-169.

_____. 1991. Assessment of students' understanding of science concepts using diagnostic instruments. **The Australian Science Teachers Journal** 37 (4): 40-43.

Tribe, M. and P. Whittaker. 1982. An Evaluation of historical events. **Studies in Biology No. 31: Chloroplasts and Mitochondria**. (2nd ed.). London: Edward Arnold Limited.

Triolo, R. and R. Lewis. 1998. **A Thai Journey**. Australia: Curriculum Corporation.

Vermaas, W. 1998. An introduction to photosynthesis and its applications. **The World and I** (March 1998): 158-165. (Online). Available:
<http://photoscience.la.asu.edu/photosyn/education/photointro.html>,
December 19, 2003.

- Von Glasersfeld, E. 1995. **Radical Constructivism: A Way of Knowing and Learning**. London: The Falmer Press.
- Vygotsky, L. 1978. **Mind in Society: The Development of Higher Psychological Processes**. n.p. Harvard University Press.
- Walker, D. 2002. 'And Whose Bright Presence' –An Appreciation of Robert Hill and his reaction. **Photosynthesis Research** (73): 51.
- Wandersee, J. 1983. Students' misconceptions about photosynthesis: a cross-age study. In H. Helm and J. Novak (Chairman), **Proceedings of the International Seminar on Misconceptions in Science and Mathematics**. Cornell University, pp. 441-466.
- _____. 1985. Can the history of science help science educators anticipate students' misconceptions? **Journal of Research in Science Teaching** 23 (7): 581-597.
- Waheed, T. 1992. Understanding interrelated topics: photosynthesis at age 14. **Journal of Biological Education** 26 (3): 215-213.
- Wertsch, V. and B. Kanner. 1992. A Sociocultural approach to intellectual development. In Sternberg, R. and C. Berg. (Eds.). **Intellectual Development**. Cambridge: Cambridge University Press, chapter 12.
- Yager, R. 1993. Science education in the pacific region. **Studies in Science Education** 22: 43-65.

APPENDIXES

APPENDIX A:
INTRODUCTORY PHOTOSYNTHESIS SURVEY (IPS)

Introductory Photosynthesis Survey (IPS)

ID.....

School

Tick item which are your personal data.

If the item generated do not fit with yours, please add the information in other ...

Sex: Male Female

Age: 14 15 16 17 18 years old

Nationality: Thai

Ethnicity: Thai

Religion: Buddhism Christianity Islam

Parents: live together divorced

Your mother's career:

teacher soldier police doctor nurse chef

scientist engineer artist technician grocer labourer

librarian receptionist office worker no career other

Your father's career:

teacher soldier police doctor nurse chef

scientist engineer artist technician grocer labourer

librarian receptionist office worker no career other

Who is your closed friend?

What would you do after schooling time/in weekend?

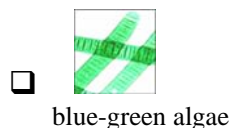
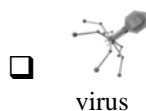
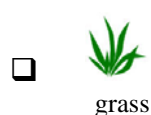
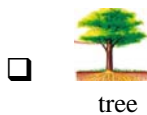
tutorial assignments work hobby other

Do you like studying biology? Yes No Please explain your reason.

.....

.....

1. Tick any of these items which can perform photosynthesis.



I chose this/these because

.....

.....

2. Tick any items which you think are nutrients for plants.

- | | | | |
|-------------------------------------|-----------------------------------|--|---|
| <input type="checkbox"/> water | <input type="checkbox"/> starch | <input type="checkbox"/> light energy | <input type="checkbox"/> carbohydrate |
| <input type="checkbox"/> oxygen | <input type="checkbox"/> minerals | <input type="checkbox"/> sugar | <input type="checkbox"/> carbon dioxide |
| <input type="checkbox"/> fertilizer | <input type="checkbox"/> protein | <input type="checkbox"/> other (s) | |

I chose this/these because

.....

.....

3. Tick any items which supply energy for photosynthesis:

- | | | | |
|---------------------------------------|---|--------------------------------------|---|
| <input type="checkbox"/> oxygen | <input type="checkbox"/> glucose | <input type="checkbox"/> fruits | <input type="checkbox"/> sunlight |
| <input type="checkbox"/> carbohydrate | <input type="checkbox"/> water | <input type="checkbox"/> fertilizer | <input type="checkbox"/> heat from the sunlight |
| <input type="checkbox"/> soil | <input type="checkbox"/> carbon dioxide | <input type="checkbox"/> chlorophyll | <input type="checkbox"/> other (s) |

I chose this/these because

.....

.....

4. Tick any items which are parts of a plant where photosynthesis takes place.

- stems leaves roots bark
 stomata cap root branches other (s)

I chose this/these because

.....

.....

5. Tick any items which contain stored energy which plants use

- minerals oxygen sugars carbon dioxide
 carbohydrates water atmosphere sunlight
 soil protein other (s)

I chose this/these because

.....

.....

6. Which statements are TRUE or FALSE? Please tick the item and explain your reasons.

- 6.1) Fertilizers are nutrients which plants need to grow. TRUE FALSE

The reason is

.....

- 6.2) Photosynthesis is energy production. TRUE FALSE

The reason is

.....

- 6.3) Plants get some energy from the soil. TRUE FALSE

The reason is

.....

- 6.4) Plants store sugars in the form of starch. TRUE FALSE

The reason is

.....

6.5) Plants need carbohydrate for their growth. TRUE FALSE

The reason is
.....

6.6) All plants make sugar. TRUE FALSE

The reason is
.....

6.7) Light is a food of a plant. TRUE FALSE

The reason is
.....

6.8) Carbon dioxide provides energy for plants. TRUE FALSE

The reason is
.....

7. What is the plants' process of photosynthesis?

Please describe the process and write the chemical equation for photosynthesis.

.....
.....
.....
.....

8. After scientists have developed a theory (e.g., atomic theory, cell theory, evolution theory) does the theory ever change?

Yes, it does change. No, it does not change.

If you believe that scientific theories do not change, explain why you think this.

.....
.....
.....

If you believe that theories do change, explain why you think this.

.....
.....
.....

9. Here is a statement about plants written by an earlier scientist, Joseph Priestley in 1771:

“Plants tend to keep the atmosphere sweet and wholesome (clean), when it has become poisonous because of animals either living and breathing or dying and putrefying (rotting) it”.

Do you think this statement reflects scientists’ thinking today?

Yes, scientists today basically still agree with this idea

because

.....

.....

No, scientists today basically still reject this idea

because

.....

.....

10. This day Bangkok has bad air pollution. The sources of bad air are cars, engines and any machines which release the bad air into the atmosphere.

10.1) What effects could this bad air have? Yes, it has. No, it has not.

Please explain your ideas

.....

.....

.....

.....



10.2) What could you do about this situation?

Please explain and organize your process steps towards a solution

.....

.....

.....

.....

.....

APPENDIX B:
ADVANCED PHOTOSYNTHESIS SURVEY (APS)

Advanced Photosynthesis Survey (APS)

ID.....
School

1. Tick any of these items which can perform photosynthesis.

- | | | |
|------------------------------------|--|--|
| <input type="checkbox"/> Red algae | <input type="checkbox"/> Moss | <input type="checkbox"/> Blue-green algae |
| <input type="checkbox"/> Tree | <input type="checkbox"/> Cyanobacteria | <input type="checkbox"/> Grass |
| <input type="checkbox"/> Virus | <input type="checkbox"/> Fungi | <input type="checkbox"/> Orange-red leaf plant |

I chose this/these because

.....

.....

2. Tick any item (s) which you think apply/applies to **carbon dioxide** in photosynthesis.

- | | | |
|--|--|--------------------------------------|
| <input type="checkbox"/> Carbon source | <input type="checkbox"/> Food source | <input type="checkbox"/> Others..... |
| <input type="checkbox"/> Oxygen source | <input type="checkbox"/> Carbohydrate production | |

I chose this/these because

.....

.....

3. Tick any item (s) which you think are role (s) of **water** in the photosynthesis reaction.

- | | | |
|--|---|--|
| <input type="checkbox"/> Sunlight absorption | <input type="checkbox"/> Food source | <input type="checkbox"/> Oxygen production |
| <input type="checkbox"/> An electron donor | <input type="checkbox"/> An electron receptor | <input type="checkbox"/> other (s) |

I chose this/these because

.....

.....

4. Tick any item (s) which you think are the roles of **sunlight** in photosynthesis.

- | | | |
|--|---|--|
| <input type="checkbox"/> Oxygen source | <input type="checkbox"/> Activates pigments | <input type="checkbox"/> An electron donor |
| <input type="checkbox"/> Activates electron transfer | <input type="checkbox"/> Food source | <input type="checkbox"/> Splits water |
| <input type="checkbox"/> other (s) | | |

I chose this/these because

.....

.....

5. Tick any item (s) which you think are the roles of **chloroplasts** in photosynthesis.

- Electron donation Light absorption other
 Carbon dioxide fixation Combines with water

I chose this/these because

.....

.....

6. Tick any item (s) which you think are function of the light independent (dark) reaction.

- Light absorption Electron transfer Carbon dioxide fixation
 Oxygen production Food production Plant respiration
 Other

I chose this/these because

.....

.....

7. When does a plant carry out photosynthesis?

- only day time day and night time others.....
 only night time day and/or night time

I chose this/these because

.....

.....

8. Which statements are TRUE or FALSE? Please tick the item and explain your reasons.

8.1) Photosynthesis is energy production. TRUE FALSE

The reason is

.....

8.2) Plants release carbon dioxide at night by photosynthesis. TRUE FALSE

The reason is

.....

9. Tick any items (s) which can affect the rate of photosynthesis and explain your reasons.

9.1) humidity yes, it can no, it cannot

The reason is

.....

9.2) light intensity yes, it can no, it cannot

The reason is

.....

9.3) carbon dioxide concentration yes, it can no, it cannot

The reason is

.....

9.4) numbers of leaves yes, it can no, it cannot

The reason is

.....

10. Ferns and brown algae have combinations of pigment as follows:

Ferns – A, B, and C

Brown algae – A, C and D

Is the fern's absorbing ability similar to the algae's?

Please explain your ideas.....

.....

.....

11. Do all plants have the same mechanism for fixing CO₂?

Please explain your ideas.....

.....

.....

12. Here is a statement about plants written by an earlier scientist, Leonardo da Vinci, about 1490.

“The leaf serves as a mother to every branch and fruit by bringing them the water of the rains and the moisture of the dew that falls there at night from above, and it often takes from them the excessive heat from the sun’s rays.”

Do you think this statement reflects scientists’ thinking today?

Please tick either the ‘Yes’ box or the ‘No’ box and explain your ideas

Yes, scientists today basically still agree with this idea because

.....

No, scientists today basically still reject this idea because

.....

.....

13. How can photosynthesis knowledge have established and developed?

.....

.....

.....

14. The temperature increase around Bangkok and suburban areas is becoming an environmental issue. Air conditioners are used to decrease the temperature inside any building (e.g. office, house and school) but people are sometimes unaware of the consequences. For example, CFC’s circulating in some air conditioners can be accidentally released creating a hole in the ozone layer. Subsequently, UV rays can get through the hole and cause skin cancer. According to photosynthesis concepts, what would you do to lower the increasing air temperature? Please explain your ideas.

.....

.....

.....

.....

.....

.....

BIOGRAPHICAL DATA

Name: Miss Sirinapa KIJKUAKUL

Date of Birth: July 13, 1976

Place of Birth: Bangkok

Graduation: B.S. (Biochemistry), Kasetsart University.
Dip. (Teaching Science Profession), Kasetsart University.

Work: Science Teacher

Place of Work: Utok Witayakom School, Panusnikom, Chonburi.

Rewards: -

Scholarships: The scholarship to pursue B.S. degree (1995-1998) and Diploma degree (1998-1999) under the Project for the Production of Science and Mathematics Talented Teachers (PSMT) which conducted jointly by the Royal Thai Government Agencies and the Institute for the Promotion of Teaching Science and Technology (IPST).