THESIS

TEACHING AND LEARNING IN A LABORATORY IN BIOLOGY COURSE OF FIRST-YEAR PRE-SERVICE SCIENCE TEACHERS IN ACCORDANCE WITH THE NATIONAL EDUCATION ACT, 1999

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THESIS

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This study aimed to investigate how instructors taught and how first-year pre-service science teachers learned in a Laboratory in Biology course during the implementation of an instructional set consistent with the educational guideline in the National Education Act (NEA), 1999. This study had two phases: an Exploratory Phase and a Development and Implementation of the Instructional Set Phase. In the exploratory phase, first-year pre-service science teachers learning outcomes from the regular course were assessed by a Biology Concept and Science Process Skill Questionnaire, a Views on the Nature of Science Questionnaire, and an Attitudes towards Biology Inventory in the first semester of 2004 academic year. The results from this phase, the guidelines for a learner-centred approach from the NEA, and a literature review of laboratory teaching, learning and assessment were utilized to generate guiding principles for the development of the instructional set based on social constructivism. The teaching and learning activities in the set emphasized learners' expression of prior ideas, sharing and reflection of ideas and development of understandings, skills and attitudes through laboratory activities, and collaborative group work. Some formative assessment strategies were included to help the pre-service science teachers achieve the learning outcomes and provide information for instructors about the impact of the teaching. The instructional set was implemented in a public university in Bangkok with 29 first-year pre-service science teachers in the second semester of 2005 academic year. Two experienced biology instructors participated in the implementation. The first instructor implemented the instructional set in the first two weeks and the second instructor continued the implementation from the third week to the end of the semester. During the implementation multiple data gathering methods were used including classroom observation, instructor and student interviews, and document analysis. A meeting of the instructor and researcher was held each week to provide feedback to the instructors so they could adjust the activities over the course of the implementation. After learning through the instructional set, the pre-service science teachers were asked to complete the questionnaires and inventory employed in the first phase.

The results revealed that at the beginning of the implementation both instructors hesitated to follow the teaching and learning activities in the instructional set. They modified the teaching and learning activities according to their beliefs about teaching. They gave a brief lecture about the fundamental concepts in the laboratory activities then observed how the pre-service science teachers conducted the laboratory activities and provided assistance and guidance. Formative assessment and the researcher providing information about student learning helped them shift their teaching practice towards a more learner-centred approach. The second instructor gained more confidence in the instructional set after she found that the pre-service science teachers had done well in the midterm examination. After this she followed most of the activities in the instructional set and conducted whole class discussions and student presentations. The findings show that the instructional set helped the pre-service science teachers develop their biological understandings and science process skills through the use of hands-on and minds-on activities, reflection on their learning and social interaction. Nearly all of the pre-service science teachers had appropriate understandings in the nature of science and had positive attitudes towards biology at the end of the implementation.

The findings of this study indicate on an instructional set based on social constructivism that incorporates formative assessment can be effective in assisting instructors to adopt a more learner-centred teaching approach. However, instructors need to be assured that a new teaching approach will not lower achievement relative to their regular approach. In addition, the study indicates that pre-service science teachers benefit from opportunities to share, reflect on and construct ideas.

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Student's signature Thesis Advisor's signature

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

Page

TABLE OF CONTENTS (CONTINUED)

Page

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

LIST OF TABLES (CONTINUED)

LIST OF TABLES (CONTINUED)

Table **Page**

LIST OF FIGURES

CHAPTER I

INTRODUCTION

This chapter discusses the significance of the study which was a result of educational reform in Thailand and problems in science laboratory teaching and learning, both worldwide and in a Thai context. The following sections are research purposes and questions, anticipated outcomes, delimitation of the research study and definitions of terms relating in this research. The last section is a summary of the chapter.

Significance of the Study

The significance of the study came from the urgent requirement of educational reform and to transform the guideline in the National Education Act, 1999, into practice in classrooms, along with the problems of laboratory teaching and learning in Thailand which share the similar aspects to those all over the world. Details are discussed as the followings.

Educational Reform in Thailand

Because Thailand faced a crisis in 1997, the government decided to create an economy where this would not recur. These problems include the use of technology without the attempt to learn and apply scientific and technological knowledge. It was argued that Thai citizens lacked logical and critical thinking skills, and sufficient understanding of the natural world (Office of Education Council [OEC], 2001). This was a reflection on the tertiary education; the quality of Thai graduates was low in that they do not have the ability of independent analytical thought and tertiary education itself has not been changed to respond to the crisis (OEC, 2005; Office of the National Education Commission [ONEC], 1999c). Areekul (2005) described the tertiary curricula as narrow, inflexible, out-of-date, and resistant to change and to accommodate globalization. Teaching and learning activities were also seem to be out-of-date and unproductive because of the use of a teacher-direct approach by lecture. A critique of general characteristics of Thai teaching style by ONEC (1999a) noted:

> … the teacher is at the center of the learning process. Some teachers stick to the traditional teaching style with everything moving around the teacher's desk and the blackboard in the classroom. The "chalk and talk" style relying solely on lectures and rote memorization with limited subjects prescribed in the curricula and no alternative available seems to be ineffective.

A study by Polsaram and Thephasdin Na Ayudhaya (2000) confirmed that, in the tertiary level, Thai science instructors used lecturing with a chalk and talk style. They also found that the numbers of science textbooks were insufficient, there was not enough time for completing much of the science content in a semester and there were inadequate tests and inventories for assessment. These problems could lead to the low quality of graduates who lack ability in analytical, critical, creative thinking skills, the ability to search for knowledge and use technology (OEC, 1999; Areekul, 2005).

The Thai government was concerned about these problems which led to a reconsideration of teaching science and technology. The development of science and technology literacy of Thai citizens has been stated as a fundamental national policy, appeared in the 1997 Constitution of the Kingdom of Thailand (Thai National Assembly, 1997) and the Ninth National Economic and Social Development Plan (National Economic and Social Development Board [NESDB], 2002). This produced The National Education Act (ONEC, 1999) which provides the guidelines for teaching and learning for Thai citizens through a learner-centered approach.

Chapter 4, Learning Reform, in the National Education Act is the heart of the educational reform. This chapter provides the guidelines of educational principles (section 22), content (section 23), learning process (section 24) and assessment of learning (section 26). The main idea of the chapter is that learners are regarded as the most important in the learning process. They should have an opportunity to develop themselves at their own pace and to the best of their potential. The content and the learning process emphasize an integration of scientific and technological knowledge and skills according to the learners' interests and aptitudes. The learning process would also incorporate thinking processes, application of knowledge and problem solving. An appropriate learning environment, various instructional media, facilities, learning resources, various and authentic learning activities, and practical work should be provided for learners. Suggested assessment strategies include observations of personal development, learning behaviours, participation in activities and the results of a variety of tests.

Teaching and learning reform should lead to the enhancement of the quality of graduates, enhancing knowledge, critical thinking skills, problem-solving ability, creation of innovation and desire for lifelong learning (OEC, 2005). These graduates must be prepared for a knowledge-based or intellectual society where they are prompted to learn new knowledge, and be able to adapt to changes using the knowledge and skills they possess (Areekul, 2005).

One problem for implementation of the reforms is from teacher development programs that still use a traditional approach in which unproductive teaching continues to be used in classrooms (ONEC, 1999b). Coble and Koballa (1996) noted that teaching strategies which pre-service science teachers experienced in science courses were lectures by the instructors, with structured laboratory activities where they followed experimental procedures as in cookbooks, and little emphasis was given to science as a process of inquiry. Science courses provided for pre-service science teachers should give opportunities for them to experience how to learn science. In addition, Thomas and Pedersen (2003) argued that teachers are likely to use strategies that they had experienced of in their own educational background in their own teaching practice. With this idea, it can be inferred that, if they often experience science by lecture, they are likely to use lecture as the main strategy when they teach science. But if they learn science by investigation, they will be more likely to use investigation to teach their future learners. This indicates that it is important to give pre-service science teachers appropriate experiences of science teaching and learning activities so as to influence the way they teach in the future.

Problems of Laboratory Teaching and Learning

Science instruction always has laboratory work which is regarded as essential because the appropriate laboratory work can provide the experience of what science is (National Science Teachers Association: NSTA, 2005). Laboratory work aims help the learners develop their understandings of scientific concepts, the nature of science, improve their thinking abilities, science process skills and attitudes, as well as motivate them in learning science (Friedler and Tamir, 1990; Hegarty-Hazel, 1990; Millar, 1991; Tamir, 1991; Lazarowitz and Tamir, 1994; Lunetta, 1998). Although the benefit of using lab has been accepted by science educators and researchers in many countries, in research reports of laboratory instruction, it has not seemed effective and productive for the learners.

Some of the problems in teaching and learning laboratory work, which are discussed in details in Chapter II of this study, can be summarized as giving too much emphasis on the content with very structured cookbook-style laboratory manuals. This type of laboratory manual presents science topics with little background information and provides steps of procedure that aim to present specific concepts underlying the laboratory work without the experience of scientific inquiry (Colburn, 2004). Thus, the laboratory work focuses on only the correct answers and ignores laboratory data and results (Berry *et al*., 1999). White (1996) argued that pre-determined and structured procedures make the learners learn in science laboratory as a routine and it is not necessary that they prepare themselves before the class. So, cookbook-like manuals teach the learners to be technicians, not scientists because the part that the learners do in laboratories is actually the part of technicians' work (Tamir, 1991).

The purposes of laboratory work have not been clear both for the instructors and the learners. The instructors seem to give the most emphasis on skills, but in practice they demonstrate that they most frequently use laboratory work for promoting the understanding of scientific concepts (Woolnough, 1998). The learners aim to complete a laboratory task rather than learn from it and have minimal mental engagement to the task (Berry *et al.*, 1999). When the learners are doing a laboratory activity without understandings of the relationship between the purposes and what they are doing, they fail to perceive the conceptual or even procedural goals of the activities and they cannot relate what they have just done and what they have done earlier (Lunetta, 1998). In addition, both instructors and learners seem to believe what textbooks tell them more than the actual results of laboratory activities (Tasker and Freyberg, 1985). This indicates that teaching and learning in laboratory has generally failed to help the learners construct their own knowledge of the natural world and conceptual understanding by a meaningful learning process.

Considering the learning outcomes which are likely to be promoted by laboratory work, the learners are not able to construct the correct concepts in science and still have alternative conceptions after instruction. Science process skills and the nature of science, regarded as aims of laboratory work and significant parts of science, are often not explicitly integrated in teaching in laboratories. Having no obvious roles in classroom practice, a positive attitude toward learning is also regarded as important in that it can promote the enjoyment of learning and lead to more encouragement to learn more complex science concepts. This means that the learners perceive science as part of human activities not a too difficult subject for them to understand.

Prior to this research study, the researcher had an opportunity to observe teaching and learning in the Laboratory in Biology course in the first semester of 2003 academic year at a university in Bangkok. During this time, the instructor was interviewed and students were asked to complete a questionnaire about their perceptions of learning in the laboratory. The results of the interviews and questionnaire are presented and discussed as follows.

This course had one three-hour period per week. The students who enrolled in this course simultaneously take the Principles of Biology course which provided them with theoretical concepts. In the lab section, there were 40 students separated into groups of four, pre-service science teachers were included in this section. The objectives of the course (from the course syllabus) were: promoting student understanding of biological concepts; promoting observational skills and creativity to initiate own experiments; and allowing the students to learn from real specimens.

From an interview with her, the instructor's aims of teaching were to allow the learners to experience science from real things and be able to remember for the examination. The teaching laboratory was for reinforcement of the lecture. She believed that students should have seen the correct results before they explored and experimented in their own groups. Before allowing learners to do laboratory activities, she believed that she needed to inform learners of the procedures and demonstrate how to use laboratory apparatus.

From observation, it was found that, at the beginning of each class session, the instructor began her teaching with a lecture that related to the content of the lab, there were pre-lab instructions, then the students engaged in laboratory activities, and post-lab discussion was led by the instructor. The learners completed the activities following the laboratory manual. She walked around the class to observe the students and simultaneously suggested and answered questions. Laboratory activities were observing cells through microscopes and experimental activities to find out underlying biological concepts. Instructional materials of the course were lab manuals, which were in cookbook-like style. Other materials were pictures of various cells, transparencies, overhead projector, slide projector, whiteboard and the microscope linked with the projector to project pictures from the microscope to the screen in front of the classroom. She usually confirmed the results to the students and asked questions to check their understanding of biological concepts. She had less emphasis on practical and attitude outcomes. It seemed that the lab activities only aimed to reinforce biology concepts.

From the pre-service science teachers' questionnaires, it was found that their aims of learning were consistent with those of the instructor. They expected the laboratory to help them understand biological concepts better, be able to remember knowledge for tests and to learn from real things. The learners did activities following the directions in the lab manual that provided every step of each procedure, and tables to collect data for them. During experiments, they were often confused about the steps of procedures, although the instructor had used pre-lab discussions before they began the experiments. They often waited to copy correct results from the instructor and did not pay much attention to the appropriate way of doing experiments and using a microscope, which was the most frequently used instrument to study in the course. They were mostly pleased with the lab activities, even though they had difficulties in practical skills and taking tests.

The students noted that they liked their instructor who had good interpersonal skills, had a sense of humour, paid much attention to them, and presented biological concepts before laboratory activities. For improvement, they would like the instructor to improve the transparencies to be clearer, teach biological concepts by lecturing in more detail and also teaching the content that was not included in the lab manuals. Only two students (out of 40) had some ideas about increasing the quantity of lab apparatus to allow the students to do activities individually, rather than groups, to check if the processes of lab activities were appropriate and their understanding was correct.

To assess the student learning in this course, the instructor used quizzes, which served for both helping the learners pay attention to reviewing the lessons and testing student understanding of previous lessons. The questions in the quizzes were mostly knowledge questions with few comprehension questions. Analyzing, criticizing, and evaluating questions were hardly found. There were midterm and final examinations, which assessed only cognitive outcomes, psychomotor and attitude outcomes were not assessed at all. The tests of examinations were in short answer form asking about biological concepts and steps of doing some laboratory activities that they had learned in the course.

From the laboratory classroom observation, it can be said that the laboratory in biology emphasized knowledge more than practice. The instructor was the most important person in teaching and learning activities who transferred knowledge to the learners by lecture. The activities were for confirming scientific concepts. The learners did not have an opportunity to use thinking processes as part of their learning and ignored details of procedures. More appropriate lab activities are likely to help students achieve three aspects of learning; cognitive, affective and psychomotor. After the course, they might achieve only cognitive outcome. However, it could not be determined if the learners had achieved the skills and attitudes outcomes because there was no assessment for these two achievements.

More appropriate instruction in science laboratory work is likely to solve the problem of the quality of graduates and provide a picture of appropriate science teaching and learning activities for pre-service science teachers who will take responsibility to teach science to future Thai citizens. This research study focuses on developing an instructional set for a laboratory instruction for first year pre-service science teachers based on a learner-centred approach according to the guideline for teaching and learning provided in Thailand National Education Act, 1999 and the information from a literature review of related document and research reports as well as constructivism, the mainstream theory of science education since the late 1980s (Duit and Treagust, 1998).

Research Purposes and Research Questions

Research Purposes

The purpose of the research study was to develop an instructional set for teaching and learning in a Laboratory in Biology (424112) course for first year pre-service science teachers in accordance with the National Education Act, 1999 and the literature review. The study was designed to achieve the following objectives:

- To design and develop an instructional set for the Laboratory in Biology course in accordance with the National Education Act for first-year pre-service science teachers;

- To monitor the process of implementing the instructional set for the Laboratory in Biology course;

- To explore pre-service science teachers understandings in biological concepts, science process skills, the nature of science and attitudes towards biology before and after the implementing the instructional set.

Research Questions

For achieving the objectives of the study, the instructional set for the Laboratory in Biology (424112) course was developed and implemented and illustrated how the instructional set affected first-year pre-service science teachers' learning and the instructors' teaching. The research questions were:

1) What were pre-service science teachers' understandings in biological concepts, science process skills, the nature of science and attitudes towards biology after the existing teaching and learning of the Laboratory in Biology course?

2) How did instructors teach and pre-service science teachers learn during the implementation of the instructional set developed in accordance with the National Education Act, 1999?

3) What were pre-service science teachers' understandings in biological concepts, science process skills, the nature of science and attitudes towards biology after the implementation of the instructional set?

Anticipated Outcomes

1) The developmental process of the instructional set can be used as a step-by-step guideline for instructors and teachers who would like to develop an instructional set for any courses or subjects.

2) After the research study is done, an instructional set for the Laboratory in Biology course was generated. The instructional set benefited instructors who teach biology laboratory courses for pre-service science teachers in having a guideline to develop their instructional activities, instructional material, and assessment strategies based on a learner-centred approach. They can adopt and adapt the instructional set to meets the needs of their classrooms.

3) Science educators can utilize the research results for future research studies and for development of teaching and learning activities for other biology laboratory courses and also chemistry and physics laboratory courses for pre-service science teachers and other non-science university students.

Delimitation of the Research Study

This research study was conducted during 2003-2006 academic year the Laboratory in Biology course in the faculty of science of a government university in Bangkok. There were 65 first-pre-service science teachers (36 pre-service science teachers in Phase I and 29 pre-service science teachers in Phase II) and two experienced biology instructors participated in the study. The content taught in the course were twelve topics in biology; microscopes, cell structure and function, cell membrane and cell transports, enzymes, bioenergetics, cell division, reproduction, growth and development, plant tissues, animal tissues, ecology and biodiversity. Science process skills focused in the research study were integrated science process skills; formulating hypothesis, identifying variables, designing an experiment, interpreting results and drawing a conclusion. The nature of science aspects were definition of science, the nature of science, scientific knowledge and methods, characteristics of scientists and the influence of science and society. The attitudes towards biology studied in three areas; attitudes towards biology, attitudes towards laboratory learning and attitudes towards the Laboratory in Biology course.

Definitions of Terms

The instructional set for the Laboratory in Biology course is a set of instructional units for teaching and learning activities of twelve basic biological concepts in the Laboratory in Biology (424112) course which provide learning objectives, teaching and learning activities, instructional materials and assessment strategies. The instructional set aims to enhance pre-service science teachers' understandings in biological concepts, science process skills, the nature of science and positive attitudes toward science.

Teaching in accordance with the National Education Act, 1999 is the teaching that provides content and activities in line with the learners' interests and aptitudes, training in thinking processes, authentic experience, and drill in practical work for complete mastery. It also provides an appropriate learning environment, various types of teaching-learning instructional media and cooperates with all parties concerned. Teaching in accordance with the National Education Act, 1999 can be observed by the researcher and recorded on a videotape.

Learning in accordance with the National Education Act, 1999 emphasizes thinking processes from practical work and authentic experience and it is a collaborative process of learners, teachers and all concerned contributing to creating an atmosphere conducive to learning. Learning in accordance with the National Education Act, 1999 also promotes learners' conceptions, laboratory skills and attitudes that can be observed by classroom observations, videotape recording and interviews.

Biological concepts are capacity to define, explain, analyze and apply 12 topics of the instructional set: microscopes, cell structure and function, cell membrane and cell transportation, enzymes, bioenergetics, mitotic and meiotic cell division, reproduction, growth and development, plant tissues, animal tissues, ecology and biodiversity. Biological conceptions can be assessed by observations, interviews, worksheets, student thinking books and Biology Concept and Science Process Skill Questionnaire.

Science process skills are the skills which scientists use to do their work. This study focuses on integrated science process skills: formulating hypothesis, identifying variables, designing an experiment, interpreting results and drawing a conclusion. These skills can be assessed by observations and interviews and checking responses in worksheets

Understandings in nature of science are the understandings of the definition of science, the characteristic of scientific knowledge and methods, characteristics of scientists and the interrelation of science and society. The understandings in the nature of science can be assessed by observations, interviews, student thinking books and Views on the Nature of Science Questionnaire.

Attitudes towards biology are feelings, appreciation and interests towards biology, laboratory learning and the Laboratory in Biology (424112) course before and after implementing the instructional set. Attitudes towards biology can be assessed by observations, interviews, student thinking books and Attitudes towards Biology Inventory.

Summary of Chapter I

This introduction chapter discusses the significance of the study in that Thailand has been facing an economic and financial crisis and tertiary education has not changed itself in response to the call for a higher quality of graduates. The Thai government proposed the National Education Act, 1999 as a guideline for teaching and learning for every subject and educational level. Science education and science teachers have an important role for this era. It is necessary for pre-service science teachers to have opportunities to experience appropriate science instruction, especially in the laboratories based on the National Education Act, 1999 and the information from science education literature.

This study aimed at development of an instructional set for the Laboratory in Biology course based on a learner-centred approach. It also aimed at monitoring the implementing process and investigating how the instructor taught and how pre-service science teachers learned during the implementation. This study was expected to introduce science instructors with a learner-centred teaching approach and provide productive science learning environment for pre-service science teachers. This hopefully resulted in the production of good science teachers, leading to good science teaching, and future Thai citizens who possess good scientific knowledge, science process skills and thinking skills which provide a possibility to overcome the crisis and yield sustainable development of the country. In the next chapter, a literature review of teaching and learning in science laboratory work covering historic ideas of laboratory work, laboratory work in Thai context, research studies on laboratory work and learning theories underlying teaching science are discussed.

CHAPTER II

LITERATURE REVIEW

Introduction

This chapter is a literature review of teaching and learning science laboratory work covering historic ideas of laboratory work, laboratory work in Thai context, research studies on laboratory work and learning theories underlying teaching science. In the first section, history of teaching and learning in laboratories from 1960 to present, the characteristics of approaches used in laboratories, the advantages and disadvantages of these approaches are discussed. The second section, laboratory work in Thai context, provides principles of Thai education as stipulated in the National Education Act, 1999, which attempts to promote desirable classroom environment through a learner-centred approach. This chapter also discusses the current practice in Thai tertiary laboratory classrooms, which needs an urgent reform to respond the call of a more productive environment.

Research studies on laboratory work covering purposes, learning outcomes, teaching strategies, and assessment are discussed in the third and the fourth sections. The fifth section of this review discusses constructivism, as a central learning theory in science education nowadays. The last section, the summary of this chapter, is a synthesis of ideas from this review, as a guideline for the development of an instructional set for the Laboratory in Biology course to promote pre-service science teachers' understandings in biological concepts, the nature of science, science process skills and positive attitude towards biology.

Laboratory Work

Laboratory work is "a form of practical work taking place in a purposely assigned environment where student engage in planned learning experiences, and interact with the materials to observe and understand phenomena" (Hegarty - Hazel, 1990, p. 4). National Science Teachers Association: NSTA (2005), regarded laboratories as essential to science where the learners can experience what science is, described the activities occurred in the laboratory hands-on and problem-solving activities integrating the nature of science. These activities are conducted by the learner as individual, small or large group aiming to enhance the learners' process skills, analytical skills, communication skills and conceptualization of science phenomena.

1. History of Laboratory Work

Although laboratory work has been accepted as an essential activity in science classrooms, the advantage and value of using it continue to be questioned. Attempts to address the problems of the effectiveness of practical work are continuing (Séré, 2002) and strategies for better practical science teaching are regularly proposed by science educators (for example, Osborne, 1997; Watson *et. al*, 1999; Haigh and Hubbard, 1997). In Europe and USA, laboratory work has been integrated as part of school science curriculum since the beginning of the twentieth century (Clackson and Wright, 1992). The characteristics of laboratory at the university level appeared as the separation between laboratories for each of the science disciplines and the separation between the theoretical instruction and the practical instruction (Arzi, 1998).

The movement of science laboratory teaching has progressed over time according to ideas among science educators. In the 1960s, it emerged as Discovery Learning, then Process Approach. In the 1990s, Investigation has become the approach that many researchers and science educators are trying to encourage the use of in classrooms. These ideas also took the important role at the tertiary level. This section will present the progression of approaches for practical science from 1960s to 2000s and how laboratory work is currently practiced.

1.1 Discovery approach

Discovery approach was originated in the 1960s as Nuffield and Biological Science Curriculum Study (BSCS) and was the central practice in classrooms. It gives the learners the opportunities to conduct science activates based on their prior ideas, as they are investigators (Driver, 1983). Discovery teaching is inductive that provides experiences for the learner to find out scientific knowledge through "recognition and understanding of the relationships among concrete experiences and the operation of putting these experiences into the compact form of language" (Shulman and Keislar, 1966). It is assumed that learners are well-motivated by direct inquiry-oriented experiments and learned primarily through unstructured, play-like activities. Hence the focus is on inquiry-oriented tasks, direct-experience and finding out for oneself (Hodson, 1996).

Hodson (1996), believing that discovery learning is unsound and pedagogically unworkable, argued that, it had distorted view of the nature of observation. A discovery approach assumes that data from observation are pure and uncontaminated by the observers' prejudices and the data can lead to reliable knowledge of the world. In practice, learners often have to use trial and errors with their unsure procedures and finally teachers present the best way to do the activities. Driver (1983) argued that learners cannot develop an understanding of scientific concept by experiencing phenomena in laboratories. Rather, they need guidance to show the appropriate way to discover the appropriate concepts. Additionally, results from only the experiments cannot provide the facts relating to the contents in curriculum due to the errors from many sources that make students unable to reach the expected results (Hodson 1996). These made teachers responded to problems in class by engaging students in direct or guided-discovery that they can direct and control the experiments, so student-driven inquiry is finished. Wellington (1998) also asserted that this approach holds the idea that "the data jumps to law and theory by an inductive process”. For these reasons discovery has not been much used in science classrooms.

1.2 Process approach

After discovery learning was unsuccessful in science teaching, efforts to promote students’ procedural knowledge by the process approach emerged by the early 1970s. The approach was drawn from the idea of Gagne in 1960s. As Finley (1983) summarized Gagne viewed science processes as a set of discrete systematic activities comprising of observation, measurement, inferring, interpreting data and drawing conclusion. Gagne gave the importance of science process as the primary outcome of science education and equated each process that has been done by scientists to the process that has been learnt in classrooms. Gagne also believed that these processes could be transferred across content and could be applied for any everyday life context. Significant examples of the programs focusing of process are Science - A Process Approach (SAPA) and Warwick Process Science.

Lawlor (1999) described SAPA as a highly organized and tightly sequenced experimental program developed in 1962 for elementary school science, sponsored by the American Association for the Advancement of Science (AAAS). It emphasizes achievement of competence in eight basic process skills. The principles of SAPA program are that science is best learned by doing science through hands-on activities and mimicking the processes used by scientists. The children would not learn many facts and the lessons must take into account the empirical findings of developmental psychology.

Warwick Process Science aims to train the learner to use science process skills as separate from content and assumes that the learner would be a problem-solver and an active learner who can internalize own ideas to solve problems through the processes (Screen, 1988). Berry and Loughran (2001) described Warwick Process Science as:

> …[placing] so much on emphasis on process that it appeared as though the process itself was almost ‘content-free’ and therefore the importance of science knowledge was - for some – downgraded.

There have been a number of criticisms of this approach. Hodson (1996) described this approach as having less focus on the acquisition of conceptual knowledge than on the understanding and development of skills and techniques. The aim was that students should be active and regarded as natural scientists. These ideas lead to content-free activities, with students selecting to study science topics according to their preference and interests. It was assumed that after students experienced the process they could learn concepts underlying the process automatically. However, the concepts had little significance. When students could master the process of science then they understood and used any content and the process could be transferred to other contexts.

Critics of the process approach have been dominated in the 1990s. Millar (1991) argued that using science processes in only a means to exploring and gathering the scientific knowledge and science processes cannot be taught. Gott and Mashiter (1991) noted that “that separation of procedural and conceptual understanding would be a mistake”. Hodson (1992, 1996) supported this idea in that the process approach had “lead to alternative conception of the nature of science inquiry” by assuming that procedures can be carried out without theoretical knowledge, the existing contents do not determine the designs of experiments, evidence from observation can directly generate facts and theories and every skill is transferable to any context. Wellington (1998) commented that the process approach “not only distorted the views of science but also led to a range of published teaching materials in 1980s which promoted a completely one-sided and potentially harmful approach to science education”. Thus, this approach is not often used in today’s classrooms.

1.3 Investigative approach

When the investigative approach was first introduced, the control-of-variables was emphasised. But it was soon found an inability to reflect the history and current practice in science. The investigation approach was then revised to have less emphasis on variables and their control and evidence (Wellington, 1998). Woolnough and Allsop (1985) described an investigation as an activity that is designed to give learners the opportunity to develop competence in working like a real problem-solving scientist. The investigation starts with a problem or a question which is real to the learner, then the learners analyse the factors relevant to the question and formulate an appropriate hypothesis, plan the procedure to test the hypothesis, conduct the activity follow their planned steps through observation or experimentation, collect data to answer the question, then evaluate and modify the planned activity.

Bently, Ebert and Ebert II (2000) described an investigation as a systematic search or inquiry that the investigators are searching information or solutions to problems by actively involved in the variety methods of investigation comprising of documenting, prediction testing, product testing, trial and error, reflecting and experimenting, generating models and inventing. Hodson (1996) presented ideas about investigation through constructivist views. He argued that an investigative activity is based on students' prior ideas. The activities could help students explore their own ideas in their own ways and help them develop, modify, re-think and reconstruct their ideas. He also noted that investigative activities can reflect the nature of science holistically because the stages of the learning activities are complementary to scientific way of seeking knowledge. He described the nature of science activities as:

> Doing science is a holistic and fluid activity, not a matter of following a set of rules that requires particular behaviours at particular stages. Science is an organic, dynamic, interactive activity, a constant interplay of thought and action. As it proceeds, the whole is continuously evaluated, re-planned and re-directed.

Haigh (1998) also highlighted the characteristics of a scientific investigative approach that reflected the views of science:

> Investigative science is seen as significant as it presents science with the opportunity to engage with science concepts and processes at the same time. An investigative pedagogy is seen as taking into account views of learning as views of science. Students are perceived as being encouraged to engage their minds as well as their hands.

In each of these descriptions of investigations, content and process are considered to be developed simultaneously in the same activity. The students' prior ideas shaping designs of investigative activities are also regarded as significant. However, students will not achieve the goal of learning if the process is not *for* themselves and *by* themselves (Hodson, 1993).

To sum up, ideas about teaching and learning in laboratory classrooms have changed over time and these ideas shape the practice in the real classrooms. Most classrooms still use the old ideas of teaching which can not help students to achieve desirable outcomes in science learning. The investigative approach has the potential to help students develop knowledge, skills and an understanding of the process as well as positive attitudes. It also seems to be the most corresponding approach to learner-centred teaching and learning. The next topic will discuss the current practice of laboratory teaching and learning in tertiary level.

2. Current Practice in Laboratory Classrooms in Tertiary Level

Most laboratory classes have one three-hour session per week (Abraham *et al.*, 1997). The number of students varies from 20 to 40 in one laboratory section with students usually working in pairs or in small groups. A survey by Abraham *et al.*

(1997) found that instructors of large and small institutions have different duties. In small institutions, instructors of lecture courses are also responsible for instruction and preparation of materials and equipment for laboratory courses. In large institutions, demonstrators and laboratory staff are employed to facilitate students learning activities. The demonstrators or tutors have a role of giving a mini-lecture for students before laboratory activities and helping students to complete the tasks and the instructors act as a source of information (Tapper, 1999). The laboratory staffs are the ones who gather material and equipment needed for learning in each laboratory session.

The laboratory activities at university level are generally use an expository or traditional approach (Hegarty-Hazel, 1990; Domin, 1999; Petersen, 2000), and the purpose of teaching and learning is an emphasis on conceptual understandings of scientific concepts (Abraham *et al.*, 1997; Sundburg, *et al.*, 2000). Domin (1999) described that, in the traditional approach, instructors expect their students to verify the facts that have been taught in lectures. By means of a deductive approach, the students are presented with the concepts related to what they are going to explore before they engage in hands-on laboratory activities.

Domin (1999) also addressed that the outcomes of the activities are predetermined by the instructor so that data from laboratory activities are “used to verify or confirm the validity of a concept (concept → data)”. He also highlighted the important characteristics of cookbook-like manuals that are essential tools for instructors and students when doing activities. The manuals inform step-by step procedure for students to follow so as to collect expected and predictable data. Students are all lead to conclusions or subjected to “see-and memorize” experiences (Petersen, 2000).

The pattern presented in laboratory manuals in biology of two universities (The University of Waikato, New Zealand: Manual 1 and Kasetsart University, Thailand: Manual 2) begins with an introduction section, followed by procedure to complete with questions following the activities. The introduction section presents the contents covered by the lab activities. Manual 2 presents a larger number of concepts in details than Manual 1. Manual 1 includes pre-lab questions about the content related to the activities, but this section is not presented in Manual 2. Aims of teaching and learning also included in this section. Various aims are found in the manuals.

The majority of the aims stated in both laboratory manuals give greater emphasis on the promotion of conceptual understanding in biology concepts than skills. Manual 2 has a greater number of this type of aims (87.5%) than Manual 1 (64%). About one third of the aims stated in Manual 1 and one eighth of the aims in Manual 2 were to promote specific laboratory skills and techniques that scientists use for their work. Interestingly, none of the aims in both current laboratory manuals stated about the promotion to understand and demonstrate the ability to use scientific method, so as the nature of science. The aims illustrated the learning in laboratory as an exposure of the observable truths and practices of specific laboratory techniques. Table 2.1 summarized the number and percentage of the aims of the two laboratory manual.

Table 2.1 The number and percentage of two types of aims in two laboratory manuals

Aims Stated in Lab Manuals	**Number of Aims**	
	The University of Waikato (Manual 1)	**Kasetsart University (Manual 2)**
Promotion of conceptual understanding	23 (64%)	42 (87.5%)
Promotion of laboratory skills, techniques, experiences, plot graph, etc.	13 (36%)	6 (12.5%)
total	36 (100%)	48 (100%)

The procedural section in the manuals are similar, they introduce the materials and equipment needed for each activity and step-by-step procedure. The students are provided spaces to write specific results of the activity such as a space to draw pictures of cells observed by light microscope, table to collect data of given experiments and blanks requiring specific short answers. They are expected to be filled by students during the laboratory activity. The following section in each manual consists of questions for students to answer after completing all the activities in each session. The questions are about the results of activities and the concepts underlying the activities.

Instructors and laboratory manuals directed student behaviours in the laboratory classroom. University instructors plan the laboratory activities and ask students to complete them, but they seldom include the reasons for choosing the activities in the laboratory instructions in lab manual or laboratory worksheets (Sére, 2002). Hegarty-Hazel (1990) described behaviours of instructors in laboratory at university level as guiding the students into activities and talking much more than their students. They often tell students what to do too much, so student inquiry could be considered as non-existent because students do not need to use their thinking for the laboratory activities. Meanwhile, students usually listen to what the instructors say and follow the steps provided in laboratory manuals. They do not have clear understanding of what they are doing in the lab, but they never ask the instructors the reasons for doing the activities. They do not understand the procedure and the underlying reasons, this results in their not having reached a desirable level of understanding after completing the course.

Russell and French (2002) also found that students who learned in a traditional laboratory tended to follow the directions in the laboratory manual, whether or not they understand the concepts behind the experiments they were performing. One student said about her frustration in doing laboratory activities in an interview during participating in the study that “sometimes we would say we understood it, and we wouldn’t because we wanted it done…But we didn’t always understand it”.

Tapper (1999) observed a laboratory class of second year microbiology and found that students’ major talk in the class was about what had to be done to complete a specific task; including talk about materials and equipment. The second most frequent topic of talk was about the meanings and implications of the results obtained by the activities. The manuals limit the openness of the activities, students often follow the procedures with little or no opportunity to do activities beyond the activities given, identify problems to be investigated, and design their own experiments (Abraham *et al.* 1997). The nature of cookbook-like manuals and instructors influence what students do in the laboratory and the only parts left for students are completing the tasks and linking the outcomes with the concepts presented.

University teachers have less emphasis on inquiry thinking in practical activities. Ziman (1980) argued that the university teachers who know how science really works seldom transfer their ideas of science and discuss this thoroughly with their students. However, institutes can provide better opportunities for students to develop technical skills and encounters in a professional scientific setting by spending an extended period of time working in laboratories in the universities or industry alongside professional scientists (Leach, 1998).

Assessment strategies for university laboratory courses are found in form of examinations, lab quizzes and lab reports. Laboratory examinations focus underlying conceptual knowledge and the results of the laboratory activities. The reason for assessing the concepts is not surprising of the lab courses in which the major purpose is to promote conceptual understandings. However, this is not the only purpose of learning in the laboratory course; science process skills, laboratory skills and positive attitudes are also encompassed. It is odd that laboratory courses seldom have practical assessment or finding out students' attitudes at the end of the course. Other assessments that usually found in laboratory are quizzes and laboratory reports (Hegarty-Hazel, 1990). Lab quizzes are used at the beginning of each class session. Instructors use them to find out the concepts that the students are expected to know from the previous laboratory sessions as well as the questions of the activities the students going to do in the present session. Laboratory reports are usually found for checking if students get the correct results.

In summary, laboratory has been integrated with science education for long time. Ideas of teaching laboratory have emerged from imitating what scientists do their jobs (by the discovery approach), treating science as a content-free process (by process approach) to blending aspects of science including content, process and the nature of science based on the learners' prior ideas (by investigative approach). The ideas from science educators do not seem to affect much on the teaching in current classrooms. In practice, university instructors are attached to the ideas that they need to help students understand scientific concepts by confirming what has been taught in the lecture classes and seem not to give much emphasis on processes and skills. The large amount of content needed to be covered makes laboratory activities become less meaningful to students. In addition, the nature of science has rarely been integrated in laboratory lessons. The next section will discuss the desirable characteristics of and the current practice in laboratory teaching and learning in Thailand.

3. Laboratory Work in Thai Contexts

Education at the tertiary level in Thailand is in the age of reform and the enactment of the National Education Act 1999 also made higher education reform essential. The reform will undoubtedly serve as the driving force for various aspects of national development. It also provides academic resources necessary for developing and strengthening the community, the society and ultimately the nation as well as enhancement of competitiveness in the international arena (Office of Education Council, 1999). Thus, teaching and learning in laboratory in Thailand should be on the basis of the National Education Act 1999. It is necessary for tertiary science instructors to enhance their teaching according to match the National Education Act 1999. This section presents the principle of education, the desirable characteristics of teaching and then the problems occur in tertiary science classrooms.

3.1 Principles of education of Thailand: the desirable characteristics of science teaching and learning

The provisions in all chapters in the National Education Act, 1999, those lead to aim at maximum benefits for learners and adoption of the learner-centered approach, Chapter 4 is the heart of learning reform which is stated as "learners are the highest importance”. The chapter provides principles, content and process of learning and guidelines to create novel teaching-learning activities based on the learner-centered approach. Provisions relating to teaching-learning principles are to be found in section 22-24 and 26, as in the Learning Reform: A Learner-Centered Approach (ONEC, 2000):

Section 22 (Principles of Education) All learners are capable of learning and self-development, and are regarded as being most important. The teaching-learning process shall aim at enabling the learners to develop themselves at their own pace and to the best of their potentiality.

Section 23 (Content of Learning) Emphases shall be given to knowledge, morality, the learning process and integration of knowledge about oneself and the relationship between oneself and society, scientific, mathematic and technological knowledge and skills, knowledge of Thai society culture, Thai wisdom and the application of wisdom.

Section 24 (Learning Process) Education institutions should provide substance and arrange activities in line with the learners’ interests and aptitudes regarding individual differences, and provide training in thinking process, application of knowledge and solving problems. The activities should be multidisciplinary integrated and drawn from authentic experiences in order to promote practical skills, thinking skills and life long learning. The instructors should create the appropriate learning environment, a variety of instructional media and facilities for learners.

Section 26 (Assessment) Instructors should use a variety of assessment to assess learners but focus on their performance; through observation of their development personal conduct, learning behaviour, and participation in activities. The results of assessment will also be taken into consideration in providing opportunities for further education.

According to ONEC (2001), every aspect of teaching and learning in accordance with the National Education Act, 1999 is based on learner-centred approach which holds the principle of learning that people differ in capacity and competence and have their own particular pattern of development and they can learn by different means and environments and the best learning is occurred by directly contact, practice, and drill skills The meaning of the learning process through the learner-centred approach is the process of identification of objectives, contents, activities, learning resources, instructional materials and evaluation aimed at development of the "person" and enrichment of their "lives" which help learners learn at their highest potential and match with their needs, interests and aptitudes.

So, during the learning process, teachers have to create a variety of activities for enabling individual learners to develop themselves to the best of their potential and capacity as well as motivate them and provide support in all activities until learners can, on their own, find answers and solution to problems. The learners should be provided opportunities to learn from actual situations which are useful and related to real life. They should be allowed to investigate, experiment and exchange views with others until lesson content are crystallized and also are familiar with critical thinking, able to use their own imagination and express them clearly and critically.

Tertiary institutions should update and improve the instruction and curricula in order to produce effective learners who are competent in knowledge, are creative, and always use critical and logical thinking (OEC, 1999). Instructors in tertiary institutions should help learners understand themselves and understand the knowledge of science and technology. The learners should also be encouraged to practice their science skills using activities that match their interests and aptitudes and are relevant to real life experiences. During activities learners will interact with various instructional materials and learning resources, with observations of their development being incorporated as part of the assessment process. For laboratory teaching, learners can learn how to find scientific knowledge by using science inquiry in real situations that are similar to those of scientists, using teamwork to practice collaboratively working in a group and benefiting from others knowledge and skills. In the laboratories, they are not the places to tell students what is going to happen if they do some experiments but doing and learning by using thinking skills, decision making and problem-solving skills.

3.2 Classroom practice and problems of teaching science at tertiary level in Thailand

According to Polsaram and Thephasadin Na Ayudhaya (2000), the problem in tertiary instruction was insufficient teaching and learning strategies implemented in the classrooms. Instructors used lectures as common teaching strategies for most content by transferring only knowledge not thinking abilities and practices. Their aims in teaching were for students to memorize knowledge for examinations. They did not emphasize analytical and critical thinking, self-learning and a thirst for knowledge. Instructors frequently emphasized theory more than practical ability, and lacked skills and techniques to create instructional materials. This is similar to the finding of OEC (2003) which frequently found that instructors in tertiary institutions emphasized transferring content knowledge to students that provided them with less opportunity to search for knowledge, practice in using higher-order thinking skills for problem-solving and develop their lifelong learning ability.

Polsaram and Thephasadin Na Ayudhaya (2000) also found that learners had deficiencies in personal relationships, patience, creative thinking, and communication skills such as writing reports in Thai language and speaking English. They also had insufficient opportunities to drill practical skills and experience in conducting research. There was no integration of curriculum for learners to develop themselves to become a desirable person. Curricula for bachelor’s degree emphasized the special field of knowledge and adopted too much from foreign curricula. Also, there was no quality control of curricula in tertiary education. In instructional material aspects, university libraries were not up-to-date and could not be a storehouse of knowledge for researching. The quality of textbooks was low because they were out of date, not academically accurate and not integrated with Thai contexts. Updated instructional and practical materials were also insufficient and the instructors had insufficient opportunities to participate in professional development programs.

The current practice and problems of tertiary teaching and learning in the laboratory in Thailand have not been extensively researched and presented. There is little evidence in literature so the problems cannot be argued here confidently. However, the practice in laboratory classrooms in tertiary level can be inferred using the findings of problems in science and technology subjects of Polsaram and Thephasdin Na Ayudhaya (2000). It can be inferred that in the laboratory, instructors use a teacher-direct approach to guide student activities. They might basically help students learn the conceptual understanding underlying the procedures rather than encourage them to use thinking skills and science process skills. They might use inappropriate teaching strategies and manuals to cover all of the topics that they have to finish in one semester. Also, they might use inappropriate assessment strategies to assess students in laboratory courses such as multiple-choice and short answer types that require students to show their conceptual knowledge rather than the skills associated with laboratory activities.

In summary, the educational guideline for teaching and learning in the National Education Act, 1999, emphasize a learner-centred approach that learners will be supported to develop their ability according to their potentials and interests. The development of inquiry process, mastery of skills and the ability to solve problems are also regarded as important in the learning process. The learner should be allowed to investigate, do experiments and exchange views with others so they understand the science content. But it was found that Thai science instructors mainly aimed to promote only understandings in science through laboratory activities. Teacher-directed is used and help the learner come up with the expected content underlying the laboratory activities with less emphasis on process skills. The next section discusses the mainstream theory in science education, constructivism, which is consistent with the educational guideline in the National Education Act, 1999.

Constructivism

As stipulated in the National Education Act, 1999, of Thailand, a learner-centered approach is the central idea of educational practice (ONEC, 2000). A learner-centered approach is consistent with constructivism (Henson, 2003; Matthews, 2003). This approach can be described as active, “child directed not teacher directed” (Matthews, 2003) and “contends that to learn anything, each learner must construct their own understanding by tying new information to prior experiences” (Henson, 2003). The guidelines for learning process in the Act focused on both personal and social development. For the personal facet, individual learner is encouraged to develop their ability to use high order thinking and management skills in various situations and apply knowledge to solve everyday-life problems. For the social facet, learners learn through interactions with peers, instructors, various instructional materials, other facilities and the community. Also, learners need to learn the scientific inquiry method which benefits themselves as to gain further knowledge from authentic experiences. They are provided the chances to interact with peers, instructors and others in various situations with a variety of learning resources and instructional materials for enhancing their knowledge. These could be said that the guideline shares its significant aspects with social constructivist teaching and learning principles.

Constructivism is a theory of knowledge used to explain how we know what we know (Lorsbach and Tobin, 1992). This knowledge is gained through a knower’s senses; seeing, hearing, touching, smelling and tasting that an individual uses to interact with the environment and build a picture of the world. Constructivism is not a unified theory, it has different position with varying emphases, but its common principle is the building of knowledge by active construction by individuals or social interaction (Tynjälä, 1999). Thus, constructivism can be classified as two main subgroups; *cognitive constructivism* of Jean Piaget that stresses individuals' knowledge construction processes and *social constructivism* of Lev Vygotsky which emphasizes social interaction and collaborative process.

Cognitive Constructivism

Cognitive constructivism can be explained as knowledge that can be developed inside the individual mind when the learner is older and has more experience. Learning is viewed as an internal self-regulating mechanism that occurs through life-long period in which the individual tries to organize structure and restructure experiences (Bodner, 1986). Piaget was "unquestionably the pioneer of the constructivist approach" (von Glasersfeld, 1995). Piaget explained that:

> …intelligence consists of two interrelated processes, organization and adaptation. People organize their thoughts so that they make sense, separating the more important thoughts from the less important ones as well as connecting one idea to another. At the same time, people adapt their thinking to include new ideas, as new experiences provide additional information. This adaptation occurs two ways, through assimilation and accommodation. In the former process new information is simply added to the cognitive organization already there. In the latter, the intellectual organization has to change somewhat to adjust the new idea (Berger, 1978, cited in Crowther, 1997).

Ernst von Glasersfeld, elaborating his radical constructivist theory from the work of Piaget, introduced his theory by focusing on individual self-regulation and the building of conceptual structures through reflection and abstraction (von Glasersfeld, 1995). The epistemology of radical constructivism is from everyday observations, so knowledge is created by the observer in the boundary of the observer's perspectives so that reality is unreachable; everything that we know of it is generated by human beings (Terhart, 2003). "Thus, no individually constructed viewpoint is judged as less correct than another, although individually constructed perspectives can be judged partly in terms of their alignment with consensually accepted cultural norms” (Derry, 1996). Consistently, Nola (1997) noted that the constructivist perspective agrees that scientific knowledge is human-dependent and that knowledge is constructed by our experiences.

Thus, learning regarding the constructivist view is not transmission and memorization of knowledge from teachers but it a process of inventing knowledge. Fosnot describes constructivist teaching and learning as:

> Many of the concepts we teach in the schools required construction involving reordering and invention. I use the word “invent” here on purpose so as to differentiate it from discovery learning. Discovery is a more passive process of uncovering to get at the truth (an objective truth which the teacher holds). The process of construction is more like the process of inventing, or at least re-inventing, in that it is akin to the creative process. It requires the reorganization of old “data” and the building of new models for that learner (Fosnot, 1992, cited in Kiraly, 2000).

Social Constructivism

The constructivist movement has emphasized the active role which students play in acquiring knowledge and the social construction of knowledge (Terwel, 1999). Piaget constructivism has been considered as problematic (O’Loughlin, 1992) in that it ignores the subjectivity of the learner and distorts the social interaction and historical contexts influencing the construction of knowledge. Vygotsky emphasized the socio-cognitive area in which learning takes place as a crucial factor in the learning process, thus the designation ‘social constructivism’ which has been applied particularly to the neo-Vygotsky form of constructivism (Kiraly, 2000). In Vygotsky’s view, development and learning is the combination of higher mental functioning the individual derives from social interaction (Leach and Scott, 2002). John-Steiner and Manhn (1996), Osborne (1996) and Palincsar (1998) noted that the social constructivism of Vygotsky considered learners' construction of knowledge could not be separated from the context of learning. Jaramillo (1996) and Palincsar (1998) also noted that construction of knowledge is not internalized over time but occurs in interaction, negotiation and collaboration.

Social constructivism has three major themes that elucidate the nature of its interdependence between individual and social processes in learning and development (Wertsch, 1991, cited in Palincsar, 1998). The first theme is that individual development requiring higher mental functioning originates in social sources. This theme can be explained as learners participate in a broad range of joint activities and internalize the effects of working together, they acquire new strategies and knowledge of the world and culture. The second theme is that human action, on both the social and individual planes, is mediated by semiotics that are languages, counting, symbols, arts, writing and drawings.

Similarly, Hirtle (1996) argued that learners mediated knowledge within a social context, and language is the first tool provided for learners to engage in collaborative thinking, mediating between learners and the world, shaping and extending thought. The third theme is that individual development and social interaction are best examined as the process of cognitive development which is called genetic analysis or the process of change. Based on genetic analysis, cognitive development is dynamic and takes place in socially and culturally shaped contexts (John-Steiner and Mahn, 1996).

Yager (1991) argued that in constructivist view, "Learning outcomes do not depend on what the teacher presents. Rather, they are an interactive result of what information is encountered and how the student processes it based on perceived notions and existing personal knowledge … All learning is dependent upon language and communication". In addition, Bell (1993) noted that the constructivist view of learning recognizes that the learners construct rather than absorb new ideas, because learning is not to put ideas into learners' heads or that learners acquire new ideas, but learning is about the learners developing or changing their prior ideas by actively engaging in meaning-generative activities based on their experiences.

The idea that learners usually have knowledge and beliefs about the natural world before they are taught in the classrooms is widely accepted by many researchers (Driver and Oldham, 1986; Bell, 1993). However, it was found that what a learner knows and believes is often inconsistent with accepted scientific knowledge. In addition, the prior knowledge often persists even after science teaching (Driver, Guesne and Tiberghien, 1985; Wandersee, Mintzes and Novak, 1994). The learners' prior ideas are often resistant to change to match the scientific ideas because of the lack of awareness of their own misunderstandings, stability of the form of thinking, and errors from common sense and language in everyday life (Champanario, 2002).

Lorsbach and Tobin (1992) suggested that a constructivist oriented curriculum should emphasize the negotiation of meaning. Negotiation, involving discussion and careful listening to others' ideas, making sense of other's ideas and comparing personal ideas to peers' ideas, is for resolving the discrepancies that occur in learning activities. "Students need to be given opportunities to make sense of what is learned by negotiating meaning; comparing what is known to new experiences, and resolving discrepancies between what is known and what seems to be implied by new experiences". They also argued that when a person understands how a peer is making sense of a point of view, it is then possible to discuss similarities and differences between the theories of peers within group, justifying one position over another and selecting those theories that are viable. This can lead to consensuses that are understood by those within a peer group and to comparing the group theories with scientific knowledge accepted by the community of scientists.

Vygotsky's conception of the Zone of Proximal Development (ZPD) underlies the idea of construction of knowledge within the interaction with others; Vygotsky stated the meaning of ZPD 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, cited in Palincsar, 1998).

Application of ZPD concept leads to the scaffolding process which is a process of guiding the learner from what is presently known to what is to be known and this process allows learners to perform tasks normally beyond their ability without assistance and guidance from the teacher and peer collaboration (Murphy, 1997). Thus, the more experienced members such as more skilled classmates or the teachers are important to help individual learners in knowledge and skill construction (Driver *et al.*, 1994).

The constructivist views of researchers and science educators can be summarized into six aspects (Cosgrove and Osborne 1985; Yager, 1991; Bell, 1993; Tobin and Tippins, 1993; Murphy, 1997; Perkins, 1999; Tynjälä, 1999; Tytler, 2002; Plourde and Alawiye, 2003).

1) Valuing learners' ideas related to the concept being taught; listening to learners, discovering their prior knowledge and trying to understand their ideas; then using the learners' ideas to guide preparing for the lesson.

2) Setting goals and objectives of learning from the learners' ideas or from negotiation with the teachers, hence the learning is derived from learners' interest, and is relevant to real life.

3) Engaging the learners in multiple, active, challenging learning activities that foster problem-solving and higher-order thinking skills. Encouraging them to negotiate the meaning of the concept. The learning environment is collaborative, safe and free to enable sharing of ideas.

4) Encouraging the learners to be responsible for their own learning and using scaffolding to help them perform beyond the limits of their ability.

5) Providing sufficient time for learners to reflect, reform, and modify their ideas and apply the new ideas in other situations.

6) Using assessment that is authentic and embedded in the learning process.

Scientific knowledge and facts are from negotiations between scientists taking place in scientific practices, so it can be said that the knowledge and facts are socially constructed (Driver *et al.*, 1994; Detel, 2001). Lorsbach and Tobin (1992) argued, based on a constructivist perspective, that it is necessary for teaching and learning in science to give the opportunities for the learner to experience the process of making sense of the nature as scientists do. Hence, teaching and learning in laboratory is the means to help the learner experience such process by socially interact and actively construct their own knowledge of the natural phenomena.

Learning models based on these ideas have been suggested by many science educators and researchers (e.g. Wheatley, 1991; Yager, 1991). Wheatley (1991) proposed problem-centred learning comprised of three components; tasks, groups and sharing. This model starts with presenting learning as problematic tasks that focus on the key concepts of the discipline, then the learners work on the tasks in small groups using a cooperative learning strategy, and then groups present their solution to the class for discussion. The Constructivist Learning Model (CLM) suggested by Yager (1991) consists of a series of four aspects for constructivist classrooms:

- invitation: the teacher engages the learners in a learning activity based on asking questions about and explanation of phenomena;

- exploration: the learners solve the problem by collecting evidence from various sources such as experiments, observations, constructing a model, brainstorming and debates;

- proposing explanations and solutions, the learners communicate and explain the acquired ideas from the exploration phase;

- taking action: the learners make decisions, apply and transfer knowledge and skills, and share information.

The role of constructivist teachers is discussed by many researchers. The role of teachers noted by Brooks and Brooks (1999) is seeking and valuing learners' ideas, challenging learners' ideas, emphasizing big ideas not small pieces of information, introducing conceptions that are relevant to learners' daily life, and assessing learners' learning in the context of daily classroom investigations. Simpson (2001) suggested teachers should diagnose learners' prior knowledge, engage learners in purposive activities and monitor their engagement, use social situations to encourage knowledge construction, use a variety of techniques to assess learning, and report learning results for individual. Bell (1993) noted as the role of constructivist teachers that teachers should work alongside the learners; both teachers and learners learn together, simultaneously teachers facilitate learners' learning to help the learners reach to learning goals. Airasian and Walsh (1997) suggested that teachers should encourage learners to construct their own meaning in a safe, free learning environment that was not restricted to right or wrong answers and also argued that the role of learners is to change, that is, the learners:

> have to think for themselves, not wait for the teacher to tell them what to think; to proceed with less focus and direction from the teacher; to express their own ideas clearly in their own words, not to answer restricted-response questions; to revisit and revise construction, not to move immediately on to the next concept or idea.

Emphasizing constructivist theory, Shiland (1999) suggested five implications for laboratory teaching and learning and laboratory activities.

1) Laboratory activities should be designed to increase the cognitive activity of learners. Teachers can use activities that include identifying variables, designing the procedure for a table to collect data, using a standard lab design worksheet that includes the important concepts in experimental design and providing opportunities for learners to suggest the sources of error in the lab and modifications to eliminate these sources of error, and raising questions about the lab.

2) Laboratory activities should be used to create learner interest and discover prior knowledge. New knowledge must be related to prior knowledge. Teachers can ask learners to make predictions and explain them before doing laboratory activities. Ideally, that will create dissatisfaction with their prior knowledge.

3) Laboratory activities should provide problems that challenge learners' prior knowledge. Teachers should be the problem posers and facilitators.

4) Laboratory activities should include group and whole class activities because knowledge construction is primarily a social process in which meaning is constructed in the context of dialogue with others, social interaction and negotiation of the ideas among learners.

5) Learning needs application to demonstrate how the learners use the new conceptions acquired. Teachers should give learners the opportunity to demonstrate applications after the lab and use new ideas in a wide range of contexts.

In summary, constructivism explains how learning occurs, through active collaborative activities and construction of knowledge by mental functioning in the individual's mind. Constructivist theory can be used as a basis of teaching and learning activities. Teaching and learning based on a constructivist perspective should emphasize the learner's prior ideas and help the learner to construct the knowledge that is accepted by the community of scientists by exchanging ideas and negotiating the meaning of the concepts, and making a distinction between the prior ideas and the new ideas by applying in them in different contexts. Teachers should be both facilitators and scaffolders who create an active, challenging and collaborative learning environment to help the learner achieve the learning goals. In laboratory classrooms, eliciting learners' prior knowledge and making them clear about their ideas are important so as to make a clear distinction between their prior knowledge and the laboratory results when discrepant events occur. Teachers need to help the learners to acquire the accepted scientific ideas and provide opportunities to elaborate these acquired ideas.

Research on Laboratory Work

This section discusses what research studies say about laboratory work regards purposes, outcomes, teaching and learning strategies as well as assessment strategies of laboratory work. Details are discussed as the followings.

1. Research on Purposes of Laboratory Work

Laboratory is the essential part of science teaching (Solomon, 1980). However, research showed that learners had little understanding of the actual goals of laboratory teaching and learning and often failed to identify what could be learned from laboratory activities, and therefore why they should be taught. (Tasker and Freyberg, 1985; Berry *et al.*, 1999). Consequently, their learning outcomes are less than the teacher's expectations (Hegarty-Hazel, 1990). Among many science educators and researchers (Friedler and Tamir, 1990; Hegarty-Hazel, 1990; Millar, 1991; Tamir, 1991; Lazarowitz and Tamir, 1994; Lunetta, 1998), five main goals are found significant in laboratory teaching; helping students understand science subject matter; helping teachers to capture students' misconceptions; promoting understanding the nature of science and appreciation the spirit of science; development of cognitive abilities, skills and attitudes; and motivating students in learning science.

Considering what teachers had identified the purposes of laboratory teaching in research over thirty years (from 1962 – 1996), Woolnough (1998) found the consistent results among science teachers in England. The teachers seemed to perceive the skills and attitudes as the most significant. However, in their practice, structured experiments that promote the understanding of scientific theories were the most frequently they used in classroom. This indicated that the conceptual understanding was the main concern of their laboratory teaching. A study by Millar (1989) showed that a laboratory work aimed to promote the understanding of a scientific theory did not always successful. From individual interviews of biology teachers revealed that when the results of an experiment were not likely to reach the information provided in the textbook, both teachers and learners tended to follow the textbook and distorted the experimental data. This illustrated the content priority and cognitive skills and attitudes had less emphasis.

Berry *et al.* (1999) interviewed learners about how they perceive the purposes laboratory work, they found that learners firstly expressed no ideas but later indicated that laboratory work helped them understand the scientific theories and verified the theories they previously learned. Not knowing the clear purposes of laboratory work, the learners were likely to focus on completing the tasks and learned very little from laboratory work. They tended to ignore experimental results and sought for only correct answers. Similarly, Tasker and Freyberg (1985) noted that when learners did not understand the purposes of laboratory work, they used their intuitive ideas to guess what the teacher expected them to do and ignore the why of the activity. Inevitably, focusing on unexpected results often took place but they saw the activities as getting the right results and finally accepted what the teacher told them and textbook.

In brief, clear purposes of laboratory work is regarded as significant aspect to achieve the outcomes of laboratory teaching and learning. Unclear purposes of laboratory work perceived by teachers and learners could yield unproductive and time-waste results consequently they finally distort the results of the activities and follow the content in textbooks.

2. Research on Learning Outcomes from Laboratory Work

Teaching and learning in science laboratory classrooms includes both intellectual and practical components; learners learn by problem-solving, inquiry thinking, planning their experiments activities in as well as handling with scientific apparatus, measuring, collecting data, and presenting their findings. By the laboratory work, the learner could develop their intellectual and practical skills which are scientific concepts underlying the laboratory activities, science process skills, understandings in the nature of science and attitudes toward science.

2.1 Biological concepts

Learners' concepts have been widely studied by science educators and researchers. According to these studies, learners usually possess their own ideas, prior knowledge, before they come to the classrooms. Learners' prior knowledge is often erroneous or incomplete when compared with scientific ideas. In this section, misunderstandings is used to express the learner's erroneous or incomplete conceptions The features of misunderstandings are personal because they are developed based individual experiences of the world, influenced by direct observation, perception and also culture and language as well as previous teachers' explanations and teaching materials. All this information is processed to construct the meanings of phenomena (Driver, Guesne and Tiberghien, 1985; Wandersee, Mintzes and Novak, 1993). Learners' misunderstandings also found to be similar across age, ability, gender and cultural boundaries, resistant after teaching, parallel to previous generations of scientists and philosophers explanations of natural phenomena (Wandersee *et al.*, 1993). Also, many studies found that teachers have similar misunderstandings (e.g. Douvdevany, Dreyfus ungwirth, 1997; Mak, Yip and Chung, 1999; Yip, 1998).

In biology, it was found that learners had misunderstandings in many topics. This section is to summarize the misunderstandings found from research studies across countries and ages covering the topics taught in the Laboratory in

Biology course; cell biology, metabolism, cell division and reproduction, and ecology and classification.

1) Cell biology

The term "cell" was found to be confused with "molecule" at the secondary school level in Scotland (Arnold, 1983 cited in Driver, Leach, Millar, and Scott, 1996). Arnold found that the learners perceived that cells were very small units that make up larger things. The Scottish learners also thought that all substances were comprised of cells but organisms were not made of cells but energy and heat were. The idea that organic materials are made of cells was also found in the studies by Marek (1986). Flores, Tovar and Gallegos (2003) surveying misunderstandings of cell and its process among high school learners in Mexico, also found that the majority of the learners thought that the size of the cell was the same as that of molecules and atoms. Dreyfus and Jungwirth (1988, 1989) found that sixteen-year-old Israeli learners thought that protein molecules are bigger than the size of a cell.

Cell structure and function was found to be problematic in school science. A study of 36 Turkish teachers' difficulties in teaching biology revealed that about 40% of the teachers indicated that the lack of understanding of cell structure creates difficulties in the learning of other topics in biology (Öztap, Özay and Öztap, 2003). Flores *et al.* (2003) found that some learners indicated that cell organelles were like organs. Several misunderstandings of the functions of different organelles was found: the nucleus was the organelle in which reproduction was carried out and regulates the amount of water in the cell and shares out the nutrients; chloroplast and Golgi apparatus were where the respiration process took place. They also found that learners had difficulties in understanding about cell shapes; they thought that plant cells were all the same and animal cells were generally round.

The enzyme mechanism is another topic taught related to cell biology, where learners faced difficulties and had misunderstandings. Ragsdale and Pedretti (2004) noted that, based on wet lab exercises, the majority of learners did not understand enzyme actions, or how an enzyme achieved the end of a reaction and is still present at completion. They argued that the difficulties were because the learners could not see the cellular and molecular reactions and they learn about enzymes by memorization of enzyme structure and function.

Many studies showed that learners at different ages from secondary school to college levels often have misunderstandings about diffusion and osmosis (Simpson and Marek, 1988; Westbrook and Marek, 1991; Odom, 1995; Odom and Barrow, 1995; Odom and Kelly, 2001; Sanger, Brecheisen and Hynek, 2001). Odom and Barrow developed a two-tier multiple-choice test, Diffusion and Osmotic Diagnostic Test (DODT), to probe learners' understandings of diffusion and osmosis. This test was also used by other researchers and revealed similar misunderstandings among learners. The common misunderstandings detected by DODT are:

- particles generally move from high to low concentration because particles tend to move until the two areas are isotonic and then stop;

- the rate of diffusion will decrease when the concentration is high enough; the particles will spread less and the rate will be slowed;

- when blue dye is dropped in clear water, the molecules of blue dye continue moving because the dye and water are liquid, or the dye spread into small particles and mixed with water;

- if a solid is put in clear water, the molecules would stop moving after they spread all over in the container and they would settle to the bottom of the container

- when given a context of a cell, learners view diffusion and osmosis as a biological phenomena rather than the random movement of matter ;

- learners are likely to be confused about tonicity (Odom, 1995; Odom and Barrow, 1995; Odom and Kelly, 2001; Sanger *et al.*, 2001).

Westbrook and Marek (1991) investigated the misunderstandings about diffusion and osmosis of learners in Grades 7 and 10 and at college level. They indicated that none of the learners could explain the complete scientific conception in these topics. They found that the learners had misunderstandings about the distribution of the molecules of substances (dye) in water and the change in color, form or molecular nature of the dye during the diffusion process and the learners used the term diffusion and osmosis interchangeably.

2) Photosynthesis and respiration

The misunderstandings in photosynthesis have been investigated by researchers in many countries and with learners at different levels from young learners to college learners. At the elementary level, Bell (1985) found New Zealand learners' photosynthesis misunderstanding in the Learning in Science Project that the learners did not have a correct understanding about chlorophyll; they thought that chlorophyll was functioning as attracting the light, protection, food substance, food storage and giving life to the plants. Also, the learners understood that plants obtained food from the environment such as water, minerals and air rather than producing their own. Leach, Driver, Scott, and Wood-Robinson (1996a) also found from interview results that the majority of English primary learners thought that plants get food from the soil.

At the secondary level, a large amount of research investigated learners' conceptions in photosynthesis and reported misunderstandings. Barker and Carr (1989) found that most of New Zealand learners aged thirteen could state that photosynthesis is a food-making process, but they had difficulties identifying what the food is. However, only nineteen percent of the thirteen-year-old learners in the study could indicate that photosynthesis is a process of producing carbohydrate. Özay and Öztas (2003) found that less than twenty percent of Turkish ninth graders could identify that the source of weight increase in plants is from the food manufactured by the plants themselves. Eisen and Stavy (1993) found that among Israeli learners, some learners did not realize that plants produce oxygen. Studies by Halsam and Treagust (1987) and Sander (1993) found that many learners thought that this process was an energy provided for plants. Many studies found that secondary learners thought that photosynthesis was the same as respiration (Stavy, Eisen and Yaakobi, 1987; Eisen and Stavy, 1993; Amir and Tamir, 1994; Kao and Su, 2004) or photosynthesis was a reverse or opposite of respiration (Stavy *et al.*, 1987; Amir and Tamir, 1994) or photosynthesis and respiration were complementary process (Amir and Tamir, 1994).

At the college level, the majority of learners could identify that photosynthesis is the process for making carbohydrate in plants (Barker and Carr, 1989). However, Hazel and Prosser (1994) found that after learning in a general biology course, analysis from concept mapping and final examination, the learners still had only a moderate level of understanding about photosynthesis, and lacked ideas about the role of water, ATP and NADPH in photosynthesis. The results from a questionnaire with first year student teachers in Sweden revealed that the learners' did not possess a complete understanding of both concepts and did not view these concepts as chemical reactions taking place in cells. Songer and Mintzes (1994), developing an open-ended to explore two hundred introductory and advanced biology learners, found that the learner thought that plants need only sunlight and water. They described the light reaction in photosynthesis as consuming carbon dioxide and producing oxygen, and the dark reaction consuming oxygen and producing carbon dioxide.

Carlsson (2002), using individual interview with ten student teachers in Sweden, found that the learners' conceptions about photosynthesis fell into four categories. First, plants take in and use some components and produce others, the process of photosynthesis was viewed as an unknown mechanism occurred in plants. Second, photosynthesis is a transformation process that changes substances to a new constellation. The, transformation and living processes belong to the third group.

Photosynthesis is the process that changes carbon dioxide and water into sugar, then plants use energy from the sugar. Fourth, photosynthesis creates resources by creating higher order compounds. The capability to transform carbon dioxide, water and sunlight into the higher order compounds of sugar and oxygen makes plants unique in the living sphere. Plants store the sugar and later transform it into energy.

Across levels of schooling, respiration was often found to be confused with photosynthesis, it was also found to be confused with breathing and gas exchange; taking oxygen and release carbon dioxide (Halsam and Treagust; 1987; Anderson, Sheldon and DuBay, 1990; Eisen and Stavy, 1993; Sander, 1993; Mann and Treagust; 1998; Flores *et al.*, 2003; Kao and Su, 2004). The respiration process is often viewed as the process that occurs at night or when there is no light (Sander, 1993; Kao and Su, 2004). Less than thirty percent of ninth grade Turkish learners could identify that plants carry out respiration all day (Özay and Öztas, 2003). Stavy, Eisen and Yaakobi (1987) as well as Amir and Tamir (1994) found that about half of Israeli secondary learners thought that plants do not respire. Songer and Mintzes (1994) also found that introductory and advanced biology learners could not explain respiration at the cellular level.

Halsam and Treagust (1987), using a two-tier multiple choice test probing secondary learners’ misunderstandings, found that the learners did not have an understanding of the nature and function of respiration in plants, and had little comprehension of the relationship between photosynthesis and respiration in plants. Sander (1993), researching misunderstandings about respiration in animals, found that both teachers and learners had misunderstandings in many aspects of respiration. The majority thought that the purpose of respiration is to provide oxygen and to remove carbon dioxide, and more than half thought respiration occurs in the lungs and cellular respiration in the tissues. The mechanism of breathing, gas exchange and respiration were discussed by Kao and Su (2004), and Mann and Treagust (1998). They found that misunderstandings of secondary learners were similar, and lungs were viewed as filters of air that came into the body, and there was an incomplete understanding of breathing movement, and the role of oxygen and carbon dioxide in respiration.

3) Cell Division and reproduction

Learners' misunderstandings about cell division and reproduction were studied by many researchers. A large number of learners in different countries found these topics difficult. Marbach-Ad and Stavy (2000) used questionnaires and interviews to examine Israeli secondary learners' and pre-service teachers' understanding of cell division in prokaryotic and eukaryotic cells. They found that cell division in eukaryotic cells was more complex than the cell division in prokaryotic cells. These interviews also revealed that interviewees had difficulties in giving the reasons for their answers and were confused about mitosis, meiosis and crossing over. Kindfield (1994) assessed learners' conceptions by a meiosis-reasoning problem and found that several learners did not have complete understanding of meiosis and this lead to the failure to solve a Mendelian genetic problem.

Lewis, Leach and Wood-Robinson (2000) investigated English learners aged fourteen to sixteen for their conceptions of mitosis, meiosis and fertilization and reproduction. Results from a questionnaire revealed terminological confusion such as cell - chromosome, and split - divide - multiply, and also many misunderstandings held by those learners. Many learners did not distinguish between mitosis and meiosis or they could give correct answers but often with wrong reasons. Only forty percent of the learners could identify that the chromosome number and genetic materials in the cell would remain the same after mitotic division, and fourteen percent of them could identify that the number of chromosomes would reduce and genetic materials would be different after meiotic division. Half the learners were unaware that chromosomes were copied before division. Only one third could identify that mitosis occurs only in somatic tissues and meiosis occurs only in ovaries and testes. More than half thought that meiosis does not occur in plants and about one fifth thought that cell division does not occur in plants.

In studying fertilization and reproduction, Lewis *et al* (2000), found terminological confusion when the learners gave reasons for their answers. The confusing terms were cross pollination - self-pollination - sexual reproduction.

Reproduction in plants was found to be problematic; some learners thought that seeds were from asexual reproduction and about half thought that only asexual reproduction occur in plants due to plants inability to make sexual contact because they could not move, the latter misunderstanding is similar to that found in some Mexican learners in the study of Flores *et al*. (2003).

4) Ecology and classification

Ecology can be the integration of many concepts related to the environment. This topic covers from physical components to the mechanisms occurring in organisms that sustain the environment. The concepts of food, energy, photosynthesis, respiration, decomposition, food chain, food web are also related to this topic. Many studies showed the limited and unconnected information learners have about ecology. Young learners at primary levels are likely to have an egocentric view of the environment; some of them think that plants remove carbon dioxide for the well-being of the animals, especially human beings(Leach *et al.*, 1996a), and plants and animals depend on humans who supply them with their food (Leach, Driver, Scott, and Wood-Robinson, 1996b). Leach *et al.* (1996a) also found that water was the most frequent material when learners listed about what plant needs, a minority of them listed air, oxygen and carbon dioxide. Özay and Öztas (2003) found that some Turkish learners thought that plants are called producers because they produce oxygen, fruits and vegetables and only one fourth of them had the idea that animals could not live without plants. Leach *et al.* (1996b) found that the majority of English learners used the terms “food”, “nutrient”, and “energy” interchangeably and none of them had an understanding of decay.

A study by Adeniyi (1985), exploring Nigerian secondary learners’ understanding of ecology, found that some learners had terminological confusion between some scientific concepts; community-population, and habitat-ecosystem. This study found that the understanding of the pyramid of food and energy was problematic among the learners. Many misunderstandings were also found; small animals such as butterflies were viewed as producers; stronger organisms could feed on all weaker organisms; energy was adding up along the trophic levels—the highest level gets all of the energy; the number of producers must always more than the consumers; and plants have more energy because they are nearer to the sun.

Food chains and food webs were found to be difficult for learners to understand. Griffiths and Grant (1985) found that most secondary learners failed to consider that the effect of a change in one population could be passed along the other populations in the food web and to different pathways. Some learners thought that only direct predator-prey relationship could affect the change in the food web. Leach *et al.* (1996b) also found that learners aged 15 and in undergraduate zoology major were likely to interpret the problems about food web in a limited way focusing on a small number of food chains in the web.

Munson (1994) surveyed ecological misunderstandings from many research studies and summarized that learners had some understanding of the food chain but they did not understand the idea of a food web and the complexity of interactions that occur with in a food web. The species at the top of a food chain was viewed as having advantages and gaining most energy, and being able to feed on all species lower on the food chain. An organism would be affected by changes only in populations of organisms to which they were directly connected by a food chain relationship. Some species were important to an ecosystem and others were not; some of organisms' population could be alter without any effects to the ecosystem. Also, learners did not understand the scientific concept of niche, and some believed that the needs of any species were general and typical of similar species that carried out the same role within the ecosystem.

Learners' conceptions about classification of organisms have been studied by many researchers. The reasons for classifying organisms as animals were focused on the obvious features of animals. Trowbridge and Mintzes (1988), exploring the concepts of animal characteristics across ages from elementary to college levels, found that the animals were viability, appendages, movement, heterotrophic, respiration and reproduction. The reasons that kindergarten to Grade

Eight American learners gave to classify animals were movement, breathing, feeding, being pets and having fur (Barmann, 2000).

Barmann (2000) also found that learners from kindergarten - Grade Two could identify certain types of vertebrates and invertebrates better than Grades Three - Eight learners. Elementary learners did not view humans as animals (Barmann, 2000; Trowbridge and Mintzes, 1988). Trowbridge and Mintzes (1988) also found the misunderstandings were about the characteristics of each type of organism; for example, snakes were invertebrates, crayfish and spiders had backbones, and butterflies were not animals. They had difficulties classifying animals in the classes of amphibia, reptilia and fish. Nazario, Burrowes and Rodriguez (2002) explored first year university learners' conceptions and found that some learners thought that having vertebral column is a characteristic that is shared by all chordate animals. Table 2.2 presents main misunderstandings in biology from overall of this literature review.

Table 2.2 Summary of main misunderstandings in biology

Topics	Main Misunderstandings
Cell biology	- Terminology confusion of molecule, cell and organelle - The enzyme mechanism is not well understood by learners because they cannot understand the reactions at cellular and molecular levels - Particles generally move from high to low concentration because particles tend to move until the two areas are isotonic and then stop
Photosynthesis and Respiration	- Plants get food from the soil - Respiration is breathing or gas exchange that occurs at night time
Cell division and Reproduction	- Terminology confusion of cell and chromosome - Mechanisms of mitosis and meiosis are not well understood - Cell division does not occur in plants - Seeds are from asexual reproduction
Ecology and Biodiversity	- Food chain and food web are not well understood and interpreted in a limited way - Invertebrates and vertebrates cannot be identified correctly

Teachers are responsible for helping the learner go beyond misunderstandings to scientific views (Driver *et al.,* 1994). Appropriate learning in the laboratory can promote accepted scientific knowledge by engaging in meaningful activities and making sense of experimental and observational results (Friedler and

Tamir, 1990; Millar, 1991; Tamir, 1991; Lazarowitz and Tamir, 1994; Lunetta, 1998). Considering learners' prior knowledge and misunderstandings makes teachers plan the laboratory lesson which is more relevant to learners' ideas and helps them overcome their difficulties in learning scientific concepts. Additionally, investigating misunderstandings of pre-service science teachers and help them develop correct concepts is also important. They need to possess the correct concepts to create teaching and learning activities in their future classrooms. Science process skill is another significant learning outcome from learning in the laboratory, and is discussed in the next section.

2.2 Science process skills

Science process skills are the skills related to the scientific process or methods or inquiry that scientists use for their work. Millar and Driver (1987) defined scientific process as "the process scientists use in investigating the natural world; the cognitive processes involved in learning science and the pedagogical processes taking place in classrooms". Jinks (1997) defined science process skills as "a set of intellectual skills that are associated with acquiring reliable information about nature". These skills are named differently by science educators; scientific skills by Wellington (1989), inquiry skills by Etheredge and Rudnitsky (2003), process skills by Harlen (1992) and science process skills by Harlen (1999). These skills foster the development of understanding in science which benefits the learner in the construction of their knowledge by testing their initial ideas via a scientific investigation, interpretation and judgment of evidence. This then disproves or confirms their prior ideas and leads them to modify their own knowledge where appropriate (Harlen, 1992).

The American Association for the Advancement of Science: AAAS (1989; 1993) described skills as way of thinking and acting in science in the "Habits of Mind" in *Science for All Americans* and *Project 2061's Benchmarks in Science Literacy*. AAAS's skills are comprised of computation and estimation, manipulation and observation, communication skills and critical-response skills. Computation and estimation skills relate to the ability in the use of numbers, calculation and judgment approximate answers for obtaining a precise measurement or careful calculation. Manipulation and observation are the skills to deal with choosing and handling instruments and scientific apparatus and looking for the change of a system. Communication skills are the ability to express and share ideas with an understanding of scientific concepts. The last skills, critical-response skills, are used to make a critical analysis to decide what evidence to pay attention to and what to dismiss for observations, argumentation and conclusions.

Science educators also identified the components of science process skills similarly but not identically. Most of the skills are part of scientists' activities for development of scientific knowledge. Watt (1991) identified science process skills which are related with a problem-solving approach. These skills are formulating hypothesis, experimenting, designing, evaluating, recording, interpreting and communicating. Harlen (1992) listed the science process skills involved in learners' scientific knowledge development as: observing, formulating hypothesis, predicting, investigating, interpreting findings and drawing conclusions, and communicating. Jinks (1997) classified science process skills as basic process skills and integrated process skills following AAAS. The basic process skills are observation, measurement, classification, quantification, inferring, predicting, relationships and communication. The integrated process skills are formulating hypothesis, defining operationally, identifying and controlling variables, experimenting and interpreting data and drawing conclusion.

In this review, science process skills will focus on the integrated science process as they are important to be promoted for tertiary learners. Also, to achieve using integrated science process skills, learners need to gain a capable of basic science process skills as fundamental ability. These focused skills are discussed in the following section.

Formulating hypothesis is ability to defined a statement that tries to explain some happening or feature (Harlen, 1992), or a potential solution to a specific research problem (Jinks, 1997) based on evidence or initial knowledge. Jinks (1997) argued that formulating hypothesis is "an intrinsic and creative mental process rather than a more straightforward and obvious behaviour" (p. 5) which is consequently developed from experience and based heavily on specific, personal ideas about the natural world.

Defining operationally is providing a specific term for an experimental factor in a measurable or observable form that is explicit and limited to the parameter (Jinks, 1997) and the ability to explain about the experiment and methods to do with the variables (Roadrangka and Dechakoop, 1989).

Identifying variables is identifying independent variables, dependent variables, and variables to be held constant of an experiment (Roadrangka and Dechakoop, 1989).

Experimenting is to perform a process to find out the answers from the formulated hypotheses, comprised of planning an experiment, doing an experiment, and recording data (Roadrangka and Dechakoop, 1989).

Interpreting data and drawing conclusions, these two skills could be always addressed together. Interpreting data refers to "the intrinsic ability to recognize patterns and associations within bodies of data" (Jinks, 1997). Interpreting is comprised of organizing, analyzing and synthesizing of results using tables, graphs and diagrams to locate patterns or relationships between variables and drawing conclusions is making a statement that shows a relationship that is not only found in the investigation but can be applied generally to other similar cases (Harlen, 1992).

Research studies report that the learner had competency in skills of using scientific apparatus, observation and measurement. Doran *et al.* (1993) developed an alternative format for the assessment of the learner's performance in the laboratory. The learners were asked to plan, collect and interpret data and draw conclusions based on their results. The researchers found that twelfth-graders in the United States could perform well in manipulative skills (handling with apparatus, observing, measuring and recording relevant data with appropriate units) but they could not perform well in reasoning skills (making appropriate interpretation of data and drawing proper conclusion).

Doran, Fraser and Giddings (1995) assessed ninth-graders' laboratory skills in Australia. Using the similar assessment format to Doran et al. (1993), they found also similar results in that the learners' reasoning skills were found to be the source of most errors occurring in their investigation. Beaumont-Walters and Soyibo (2001) analyzed integrated process skills of secondary learners in Jamaica. They found that the skills where the learners showed low scores were in interpreting data, recording data, making conclusions, formulating hypotheses and identifying variables. These studies suggested that difficulties were in using the processes dealing with the skills relating to cognitive process, not the manipulative skills. These results agreed with a study by Tobin (1986), an investigation of the relationship between task involvement and achievement. Tobin's results showed that science process skill competency increased when the learner was highly engaged with the tasks and the ability to use skills depended on formal reasoning ability.

Science process skills can be developed by practice and made explicit by the teacher. Roth and Roychoudhury (1993) indicated that in the early lessons, most learners showed a lack of understanding of science process skills. However, these skills could be highly developed during the fourteen months that the learners performed a series of open-ended tasks that required the learners to state problems, formulate hypotheses, plan, carry out the experiment, interpret data and make a conclusion, then create further problems based on what they had found. Tamir (1989) argued that learners cannot understand the concepts underlying the science process skills, such as hypotheses and controlling variables, automatically when they engage in laboratory activities. The teacher is the key person who, by explicit teaching of the skills, helps learners to understand and use the skills for their investigation.

Hodson suggested that science process skills should be assessed not as separate, independent skills, but rather as they are used in the context of investigative activities (1992). Many researchers developed assessment in forms of investigative tasks; asked learners to state their own problems, plan and carry out an investigation (Suits, 2004); plan an experiment (Tamir, 1974); or complete the tasks and answer questions for each step of the given procedure (Tamir, 1974; Doran *et al.*, 1993; Doran *et al.*, 1995; Beaumont-Walters and Soyibo, 2001). Harlen (1999) suggested the assessment of science process skills including formative and summative purposes. For formative purposes, the teacher can use: observation with listening to how the learners explain their work and reasoning; questioning for the learners to explore their ideas and reasoning; setting tasks that require the learners to use certain skills; and asking the learners to communicate their thinking. For summative purposes, the teacher can use the information available from formative assessment, creating criteria and deciding the level of each learner achievement.

In Thai contexts, teachers did not emphasize the integration of science process skills in science learning activities because the teachers themselves had difficulties in science process skills (Roadrangka and Dechakoop, 1989). This could be seen in classrooms which teachers allowed learners to follow only predetermined steps and the correct results were told to the learners. From this, the learners did not have any chances to develop their ability of science process skills in learning activities.

In brief, although the component science process skills have not been identified identically by all science educators, their definitions are not very different for each other. The competence to use science process skills is an important outcome of science learning in that the learners could have experience of scientists’ work, test their ideas and come to know the scientific knowledge behind the science activities. Thus, it needs a practical test to assess these skills. However, all of these skills are related to cognitive ability and they cannot be taught and assessed separately, independent of content and context. Development of teaching and assessment of science process skills need to be context-bound with the appropriate level of the learner's content knowledge and conducted as a whole investigation, not a series of a single skill assessment. For teacher education, this implies that it is necessary for pre-service science teachers to clearly understand all these characteristics of science process skills and be able to perform the skills themselves to enable effective teaching of science process skills in science laboratories.

2.3 Understandings in the Nature of Science

An adequate understanding of the nature of science is regarded as a desirable outcome of science learning (Abd-El-Khalick and Lederman, 2000; Lederman, 1992; McComas *et al.*, 1998). The definition of the nature of science is given differently by a number of philosophers, historians, scientists, and science educators (NSTA, 1998). Lederman (1992) and Lederman, Wade and Bell (1998) referred to the nature of science as "the values and assumptions inherent to science, scientific knowledge, and/or the development of scientific knowledge". Hand *et al.*, (1999) argue that having an understanding of the nature of science is the combination of possessing scientific literacy, as knowing the scientific ideas in the history of science developed over time, the role of science in daily life and the reciprocal influence of science and society. Driver, Leach, Miller and Scott (1996) along with McComas *et al.*, (1998) propose that understanding of the nature of science is also about the enhancement of the learner's science content, values in science and ability to make decisions about science issues.

Although the nature of science have various definition, documents and research studies showed some consensus on the aspects of the nature of science: definition of science (Pomeroy, 1993; Moore and Foy, 1997), characteristics of scientific knowledge (Aikenhead, Fleming and Ryan, 1987; Moore and Foy, 1997; Haidar, 1999), characteristics of scientists (Moore and Foy, 1997; Haidar, 1999) and interrelation of science and society (Zeidler *et al.*, 2002; Abd-El-Khalick, 2005).

The understanding of the nature of science is in one science content standard, as in Strand 8: The Nature of Science and Technology (IPST, 2003). To achieve the standard, learners need to be able to use the science process and scientific attitudes for inquiry and solving problems. They should understand that most natural phenomenon happen by repeated patterns which can be explained and investigated by available scientific instruments and methods. In addition, they should recognize the interrelation of science, technology, society and environment. In this research study, possessing of appropriate views on the nature of science is another learning outcome to be focused as it required to be developed in all Thai science learners.

Many studies about pre-service science teachers' views on the nature of science were done and most of these studies revealed various inappropriate views. The use by many researchers of the Test on Understanding Science, (TOUS) developed by Klopfer and Cooley in 1961, has detected a variety of misunderstandings in the nature of science among learners and teachers. Synthesizing a number of research studies by Lederman (1992) found that both learners and teachers often possess inadequate understandings of the nature of science conceptions. Responding to misunderstanding of the nature of science, several curricula had been developed as a strategy to promote a more appropriate understanding. Results reviewed by Lederman indicated that using the curricula showed that the understanding of the nature of science was varied among learners who were taught by different teachers. The importance of the nature of science concepts possessed by teachers has interested and been investigated by researchers. The views on the nature of science among pre-service science teachers have been investigated and the results linked to the way the teachers would teach science (Bloom, 1989; Aguirre, Haggerty and Linder, 1990; King, 1991; Gustafson and Rowell, 1995).

Bloom (1989) investigated 80 elementary student teachers' understanding of the nature of science by a questionnaire containing six questions and a rating scale related to knowledge of science, theories, science teaching and evolution. The results revealed that the teachers had an anthropocentric view that perceived science as being for the benefit of mankind and the confusion that scientific theories related to beliefs rather than the empirical observation. The beliefs of these student teachers also were demonstrated when they taught the evolution concepts. Aguirre, Haggerty and Linder

(1990), using an open-ended question format consisting of 11 questions, assessed 74 secondary pre-service science teachers on their conceptions of the nature of science, teaching and learning. They found that most of the teachers had inadequate conceptions of the nature of science in that they viewed science as either a body of knowledge consisting of a collection of observations and explanations, or of propositions that have been proven to be correct. Their ideas of the nature of science had an effect on their belief in teaching with some of the teachers believing that science learning was the intake of knowledge.

King (1991), asking 13 student teachers to complete a questionnaire at the beginning of an introductory curriculum course and results of the evaluations of the course, found that most of the teachers perceived the history and philosophy of science as being important to teaching. However, a lack of the knowledge of history and philosophy of science in formal study made them unable to integrate these aspects of science in their teaching. Gustafson and Rowell (1995) administered questionnaires, investigating 27 elementary science teachers' views of teaching and learning science and the nature of science. The results of the nature of science questions showed that the most popular view of the nature of science was that science was a body of knowledge involving active seeking and discovery. The science teachers' views also revealed their views on teaching as being that the learners themselves had responsibility to know the already existing conception of science. Results from these studies strongly suggested that inadequate conceptions of the nature of science had significant link to teachers' teaching. Enhancement of an adequate understanding of the nature of science, hence, is regarded as important.

Two approaches, implicit and explicit, were established to promote an understanding of the nature of science. The implicit approaches focus on the nature of science as an affective outcome (Barufaldi *et al.*, 1977). It assumes that the integration of science inquiry activities and science process skills in instruction could automatically enhance the learner's conceptions of the nature of science. However, Lederman (1998), synthesizing a number of studies, argued that the nature of science was not a "by-product of doing science-based activities" and the learners would not be able to simply understand the nature of science by the performance related to science activities (Lederman and Abd-El-Khalick, 1998). Two years after the assumption that the implicit approach to teaching the nature of science did not seem productive, Abd-El-Khalick and Lederman (2000) concluded from their literature reviews of teaching the nature of science that only half of the implicit instructions promoted better learners' understanding of the nature of science. Research studies reported the efficiency of the explicit approach, they all yielded positive results, suggesting that the explicit approach was more effective than the implicit approach. This idea was also agreed with by many science educators (e.g. Hodson, 1985; Lederman, 1998; 1999; Lederman, McComas and Matthews, 1998; Meichtry, 1992).

Teaching the nature of science conception by the explicit approach, the goals, teaching strategies and assessment must be set and appear in the lesson plans explicitly (Lederman, 1998; 1999). Teachers are responsible for giving opportunities to the learner to give adequate reasons for what they believe about science, reflect on and justify their ideas about science rather than simply accept what teachers say (Matthews, 1997). Teachers must help the learner link their learning about science content and their laboratory experiences with the nature of science conception so the learners could explicitly see the intertwining of the content, science activities and the nature of science.

Teaching the nature of science through the explicit approach was suggested and implemented by science educators (Clough, 1998; Colburn, 2004; Wellington, 1999). Colburn (2004) suggested that when teaching in laboratory the main focus was on the tentativeness of science. To help the learners recognize this, he used questions to help the learners focus on their experiences and reflect on their thinking about doing laboratory activities. He noted that the teacher was the important person who made the learners realized when they were mimicking what scientists do by pointing out the actions and telling the learners explicitly. Similarly, Clough (1998) suggested that the nature of science could be discussed explicitly in the post-lab discussion as well as the learners' reflection of their experiences in laboratory journals.

Wellington (1999) suggested several strategies to teach the nature of science. Two strategies relating directly to the laboratory work were described as:

- The development of a scientific model and the history of the model and the scientist who discovered it can be integrated in teaching of an experiment underlaid by a difficult abstract concept in which the link between the results and the concepts could not be made easily. The learner would enjoy the story and understand that “scientific ideas have been created and develop in different cultures and in different times”.

- The teacher gives a list of steps for an experiment, but not in a chronological order, to the learner, asks the learner to sequence the steps and evaluate the experiment if each step is “making a hypothesis”, “observing”, “doing an experiment”, “prediction” or “reaching a conclusion”. After this, the teacher gives an opportunity to the learner to discuss whether the experiment is a fair test.

In summary, the nature of science is one of the desirable outcomes of science education. It enhances science learning and facilitates learners to learn science better. The teachers also need to have a good understanding in the nature of science so they can teach effectively as research studies show there is a link between the understanding of the nature of science and the teaching of science. The teachers have an important role in helping learners understand the nature of science by using the explicit approach.

2.4 Attitudes towards Science

The student attitude towards science is one of the affective outcomes influenced by laboratory work, but upper secondary science teachers give less emphasis to it and ranked it as less important than cognitive objectives, psychomotor skills and scientific attitudes (Gardner and Gauld, 1990). Different teaching strategies and science activities can determine student attitudes towards science. In a traditional laboratory class, in which students act passively, listen to information from the teacher, do laboratory activities as a routine where the students usually know the outcomes in advanced, the students are likely to have lower positive attitudes towards and interest in science (Okebukala, 1985; Gardner and Gauld, 1990). In the other hand, students usually enjoy meaningful, nontrivial but not too difficult experiences laboratory work (Lazarowitz and Tamir, 1994). The laboratory work includes problem-solving activities and open-ended investigations were often found in the secondary level science laboratory teaching (e.g. Shepardson and Pizzini, 1993; Chase, 2002; Zion *et al*., 2004). In such activities students have opportunity to investigate their own problems, formulate hypotheses, design and implement their methods in the activities as well as analyze data and evaluate their findings.

Shepardson and Pizzini (1993) investigated student perceptions, in which they argued that perceptions had potential to influence student attitudes towards science, they compared student perceptions of three teaching approaches; a lecture-worksheet strategy, a traditional laboratory exercise and a problem-solving activity. They found that the problem-solving activity could promote more positive attitudes towards science. The students perceived the activity as fun and they had ownership of their study because they actively engaged in every step. Zion *et al.* (2004) also found affective aspects of Israeli students when they learned in the “Biomind Curriculum”. The students were expected to demonstrate self-direction, personal initiative and teamwork during the learning. They experienced an open and authentic inquiry process in which the beginning and the end of the process were not predetermined. They also found that the students expressed curiosity, frustration, excitement, surprise and disappointment when they obtained unexpected results from their experiments.

In the tertiary level, Russell and French (2001) compared two teaching styles; traditional and inquiry-based laboratory in the introductory biology course. They found that inquiry-based approach could engage students in the laboratory activities more than in traditional approach. In addition, participation was positively related to attitude and increase in content knowledge.

This research shows that open-ended inquiry can promote positive attitudes toward science in which students have involvement and ownership of their learning. Pre-service science teachers should experience in these activities in order to promote the appreciation of science, and give more attention to doing science laboratory work in classrooms. When they can perceive the experiences directly, they can teach students more explicitly (McComas *et al.*, 1998). McComas *et al.* (1998) argued that it would be a disadvantage if the teachers' experience science laboratory work as too complicated and develop negative attitudes towards doing practical work. Gardner and Gauld (1990) made an interesting point noting that not all students enjoy the laboratory work equally and each student could find some aspects of the activity unsatisfying. So, teachers should carefully consider students' different styles and views of learning when planning laboratory activities, especially with regard to creating an appropriate learning atmosphere and emphasizing open-ended laboratory work.

Overall, the learning outcomes discussed in this literature review are desirable to be promoted by teaching and learning in laboratories. A correct understanding of scientific concepts is regarded as important in learning science. The nature of science and science process skills help the learners perceive the distinct characteristics of science and experience how science works. Positive attitudes toward learning plays a role as teachers are responsible for help the learners develop the competency in science according to their interests and potentials. Thus, to prepare competent teachers, it is necessary for pre-service science teachers to experience laboratory teaching and learning activities which promote a correct understanding of scientific knowledge and the nature of science concepts, provide an opportunity for them to engage with the use of science process skills and help them develop their competency with the desire to learn. These could give a more appropriate picture of science teaching and learning for future science teachers.

3. Research on Teaching Strategies for Laboratory Work

Laboratory work can be taught in many ways according to the aims of teaching, content, and student background knowledge. Roberts (2004) suggested 5 types of laboratory work including skill practicals, observation tasks, technological tasks, investigations and exploratory tasks, and illustrative tasks, discussed as follows.

- Skill practicals are aimed to train students in scientific skills which are often perform in doing practical work by asking them to follow complex protocol.
- Observation tasks involve the application of substantive ideas to real contexts. Technological tasks involve application of substantive ideas to a logical way. Investigations and exploring tasks are the strategies to engage students in consideration of an open-ended problem which has no easily reachable solution.
- An exploring task is not restricted to only two variables in that many variables can be involved at the same time. It allows students to be creative inventing new ways to get around practical problems and apply ideas to new contexts, synthesize ideas to solve the problem and analyze the data to evaluate the evidence.
- An illustrative task refers to any experiments that teachers bring out concepts and process ideas to fit in a particular context.

There are many types of laboratory activities, however, investigations are often used in research to promote students conceptual and procedural understandings and it is assumed that its nature of open-ended activity can transfer the ownership from teachers to students and it can contribute to the development of life-long learning (Grant and Vatnick, 1998).

Research in laboratory courses at tertiary level in the 1990s and 2000s is often found the emphasis on investigative activities (for example, Chaplin, Manske and

Cruise, 1998; Grant and Vatnick, 1998) An investigative activity is based on open inquiry method that leaves the problems; students pose their own questions to investigate (Silvius and Stutzman, 1998; Lundford, 2002), it also leaves the answers and the methods open for students to solve (Roth and Roychoudhury, 1993). Students are asked to formulate hypotheses, plan to conduct experimental, execute their planned experiments, collect and analyze data, and make conclusions from their results. The questions to investigate could come from instructors' specific guides for learning in a topic (Glasson and McKenzie, 1997; Grant and Vatnick, 1998; Harker, 1999; Pertersen, 2000). In order to help students pose their own questions, instructors create situations related to a topic to stimulate student curiosity such as instructor demonstration of an experiment (Foote and FitzPatrick, 2004), and student observation of animal behaviours (Lundford, 2002).

Before investigative activities, students are provided with the background knowledge of the subjects. Students acquired the background knowledge from lectures and laboratory worksheets (Chaplin *et al.*, 1998; Darling, 2001). This background knowledge serves as students' prior knowledge. Students are assumed that they would have sufficient knowledge for designing their experiment at the appropriate level of difficulty. Students are also introduced to use the scientific method as a basis of their investigation (Murphy, 2002), specific techniques for each subject area and data analysis methods (Chaplin *et al.*, 1998) for handling their own experiments.

Length of investigative activities is varied in different science laboratory course. In advanced courses the period of doing an investigative activity is longer than that in the introductory courses. Most of investigative activities in the advanced courses lasted entire semester. Some activities in an introductory course took more than 6 weeks to complete (Lundford, 2002) and some activities; in a module form, took three to four weeks (Glasson and McKenzie, 1997; Tien, Rickey and Stacy 1999). Lundford (2002) introduced students with aspects of the scientific method and the nature of science to help the students understand the characteristic of scientific research and then conduct a six-week inquiry activity about animal behaviours in an introductory biology laboratory course. The activity began with students' brainstorming to select the type of animals they were to investigate in the class. They came up with a cricket species and brought the cricket to feed in the class in a fish aquarium. Students worked in small group and each group studied about behaviours. They were asked pose their researchable questions, formulate hypotheses and conducted their own experiments or observation on the crickets.

The three- or four-week activities were presented in form of laboratory modules. Students completed each topic by doing laboratory activities within three or four weeks. Each module start with a presentation of background information by lecture and group questioning, teaching students the techniques or methods used to test hypotheses. Then students pose questions to investigate and formulate hypotheses. They will conduct their experiments according to their plan, collect data, and analyze data (Glasson and McKenzie, 1997).

Tien *et al.* (1999) developed MORE (Model-Observe-Reflect-Explain) thinking frame. It was assumed as a presentation of the thought process of scientists and it was used to help students think about the inquiry process and their own process of learning science concepts in the laboratory. MORE thinking frame was based on POE (Predict-Observe-Explain) model that students made predictions before doing experiments or observing a demonstration and then attempted to reconcile observed results with their initial predictions. Tien *et al.* developed 3 modules to teach first year chemistry students that fit one semester period, each module lasted three to four weeks. Each MORE module started with an overarching issue that motivates specific experimental questions within the broaden topic. In the initial weeks students were given specific experimental questions. They were asked to present their model of how the systems under study function predict. Then they conducted their own experiments to test their models and made an observation, they were encouraged to reflect on the experiment (during and after the experiment) and explain their results. In each successive week, students updated their model of the systems base on the previous week(s) observation, reflection and explanation before they progress to another experiment related to the overarching questions.

During the activity, instructors acted as facilitators, who answered few questions but provided suggestion (Lundford, 2002). It is necessary for instructors and teaching assistants (if available) to provide a guide for students to understand the purposes of the laboratory rather than let them do any experiments that are not related to the purposes (Glasson and McKenzie, 1997). The instructor should help students engage in thinking process, ask the students to think back to what they have done in the lab. At the end of investigations activities, students are required to write laboratory reports in scientific format to describe their experiments, identify the materials used, detailed of procedure and the results they got (Darling, 2001; Russell and French, 2001).

At the end of the investigation activities, students are required to write laboratory reports to reflect their thinking of doing the activities. Meaningful laboratory reports and Science Writing Heuristics are considered to develop students' conceptual understanding and logical thinking (Rudd II, Hand and Greenbowe, 2002). Students also asked to prepare posters to present their data and present their results to the whole class for 10-15 minutes for each group (Chaplin *et al.*, 1998; Grant and Vatnick, 1998; Silvius and Stutzman, 1998; Darling, 2001; Henderson and Buising, 2001; Foote and FitzPatrick, 2004). The stage of poster constructing challenges students to work together to make viewers convince of their data analysis and interpretation (Knabb, 1997)

4. Research on Assessment Strategies for Laboratory Work

Two types of assessment strategies are found in research that use investigative learning; assessment during student do the activity and assessment after student complete the activity. Assessment during the activity comprises of formative assessment and assessment of students' performance during the activity. Providing feedback during the learning, known as formative assessment. Formative assessment is "the process used by both teachers and students to recognize and respond to student learning in order to enhance that learning, during the learning" (Bell and Cowie, 2001). The information gathered by formative assessment will provide decisions about the next steps in learning and teachers' actions to help students learn.

Harlen (1999) characterizes formative assessment as the assessment that is embedded in a pedagogy of which it is an essential part, shares learning goals with students, involves students in self-assessment, provides feedback which leads to students recognizing the gap and closing it, is underpinned by confidence that every student can improve, and involves reviewing and reflecting on assessment data. Harlen also argued that formative assessment could be used to assess process skills by observing students including listening to how they describe their work and their reasoning, questioning using open questions, setting tasks of them to perform certain skills and asking students to communicate their thinking through drawings, concept mapping and writing.

Formative assessment can be use to help students plan their experiments. Chaplin, Manske and Cruise (1998) provided feedback for students after they had collected preliminary results from their own procedure and they wrote a mini-report including their hypotheses, methods, results and a short summary of their finding in their laboratory work, they argued that it was extremely helpful in revising and refining the study so that each group had a well-designed investigative activity with substantive results. During experiments, formative assessment is also useful to find out if students can perform common and specific skills necessary for their own experiments.

Instructors can also assess their student during laboratory activities by using observation over a period of learning (Giddings, Hofstein and Lunetta, 1991). They argued that observation should be conducted continuously over the whole course and this should be informed to students at the beginning of the course. Instructors observed and rated each student during normal laboratory activities using rating scales and checklists. It is not necessary to assess all students on the same day or on the same experiment and one experiment cannot provide the opportunity to give student's data on performing every skill. Silvius and Stutzman, (1998) emphasize the aspects of student performance during laboratory activities including the quality of experimental design, execution of their experiments, statistical data analysis, interpretation of results and presentation.

Assessment after students complete the activity consists of assessment of laboratory reports, poster and oral presentation and peer assessment. This type of assessment was use widely in research (for example, Foote and FitzPatrick, 2004; Henderson and Buising, 2001; Knabb, 1997). These assessments could help students reflect on what they had done during the laboratory activities. Laboratory reports could help instructors to find out students' conceptual understanding and thinking ability (Rudd II, Greenbowe and Hand, 2000). Poster and oral presentation can be used to assess student understanding of doing their laboratory activities and it was considered to be an effective way to assess group collaboration (Sundberg *et al*., 2000).

Peer assessment is used for students to reflect the participation of their peers in the same group as well as in different groups. It provides information for both students and teachers. Same-group, students could grade their peer participation, concentration on the tasks and cooperation while doing the laboratory activity. Different-group peer assessment can be used while students present their results of laboratory activities in posters and oral presentation. Foote and FitzPatrick (2004) provided a checklist assessment tool for students to evaluate their peer's presentation. Knabb (1997) provided an instrument for students to comment on their peer posters' style, content, visual appeal and oral presentation skills. The presenters were required to answers their peers' questions and the posters were count 20 percent of the course grade. Henderson and Buising (2001) suggested poster evaluation criteria including general appearance and style which students were asked to determine how readable, orderly, accessible and attractive the posters were. The content shown in the posters was also evaluated using guiding questions of the instructors considering the appropriate of abstract, background, methods, results and discussion.

From this section of the literature review, discussed factors that have potentials to produce effective laboratory learning. These factors bring about a basis for teaching strategies and assessment that a more appropriate laboratory activity is likely to be an activity that based on the learners' interests, ability and prior knowledge. Such an activity gives the responsibility of learning to the learners by investigating, observing, experimenting in active, collaborative learning environment. The learners need to have conceptual understanding and necessary skills and support from the instructors to explore the natural phenomena. Formative assessment, peer evaluation and communication of what the learners have gained from the laboratories are part of assessment strategies for laboratory work.

Factors for Helping Students Learn in Laboratory Activities

Learning in the laboratory has various goals, such as: development of science process skills, thinking process, content knowledge underlying the laboratory activities, and attitudes towards the science subjects and activities. To help students achieve the learning goals, instructors should consider many factors which influence students learning in the laboratories. The factors are related to content knowledge, procedural and technical skills, social factors, challenge level, time for practice and using thinking process, and the meaningfulness of laboratory activities. Details are discussed as the followings.

Content knowledge

Students need to have sufficient content knowledge for conducting experiments. Toh (1991) and Berry *et al*., (1999) argued that in an open-ended laboratory, students who lack adequate content knowledge may design and follow an inappropriate procedure and may be confused when doing their experiment, and be unable to finish their work because they do not know how to solve their problems. If there are results, these will be useless because their procedure is incorrect. Teachers have to determine how much content knowledge is necessary for students to be able to engage mentally with a particular investigation and to what extent students have acquired this prior to beginning a task.

Procedural knowledge and technical skills

Students need to know about the scientific method which underlies their activities in the laboratory. Lundford (2002) introduced the scientific method to his students before they had participated in an open-inquiry activity and it was proved that students were encouraged to do their experiments because they had understood how scientific experiments were carried out. Hudson (1994) suggested the development of technical skills. These skills can be developed by repetitive practice each of the skills. Instructors should encourage students to practice technical skills in problem-solving activities rather than in isolated tasks. They should use good demonstrations as a powerful teaching tool to give students a mental image of what the action is like and then allow their students to practice until they have mastered the use the skills. Many researchers helped students develop necessary technical skills prior to engaging them in planning their own experiments (Chaplin, Manske and Cruise, 1998; Darling, 2001; Foote and FitzPatrick, 2004).

Social factors

Howard and Boone (1997) found that social factors significantly influenced student learning in an introductory laboratory course in which students spent an extended period for discussion in an informal setting. Working in pairs or in groups was more successful than working as individuals. They also argued that interactions between instructors and students were also important and that "an instructor must make minor corrections to the procedures and devote some attention to unforeseen problems with procedures, potentially at some cost of his or her ability to talk informally with students".

Challenge level

Challenge level must be considered because it has potential to engage students in laboratory activities with intellectual satisfaction (Arce and Betancourt, 1997). Instructors need to match students' levels of conceptual understanding and skills with the levels of difficulty of the experiments. The tasks for students must be set so that they can solve the problem, but not too easily (Arce and Betancourt, 1997; Gardner and Gauld, 1990).

Time for practice and using thinking process

Instructors should provide sufficient time for students to finish their work and use their thinking to design their own investigations, plan, implement and conclude their work (Berry *et al*. 1999). Learning in the laboratory is time-consuming, but it may be more appropriate to spend time for students to drill for practical work individually rather than focus on covering all the content in the curriculum. However, Arce and Betancourt (1997) argued that students should not spend too much time on doing experiments, so they would have time to think about and discuss the results in depth and if more time is available, redesign their experiments.

Meaningfulness of the laboratory activities

This feature can be promoted by helping students understand the purpose and aim of the laboratory activities and giving the ownership of learning to the students. According to Berry *et al*. (1999), students will participate in a laboratory meaningfully when they know and understand the purposes and aims of the activities. Instructors should help students improve their learning by helping the students to identify aims and purposes and understand the difference between them. The awareness of aims will help students make sense of what they are doing and link the knowledge from the activities to other scientific knowledge. Ownership can be enhanced by truly involving students in the process of their learning. If students feel that they are the owner of their learning, they will pay more attention, have more interest and be more mentally engaged with the laboratory activities. Instructors should give opportunities to students to add their ideas in the laboratory work. When the activities incorporate their ideas, students will be more motivated to learn and face problems arising from the laboratory work.

Summary of Chapter II

This literature review covers the history of laboratory teaching and learning from 1960s to present, the characteristic of current practices in laboratory teaching at the tertiary level in western countries and Thailand, the National Education Act, 1999 of Thailand and constructivist theory as well as the research studies that reported perceived purposes, outcomes, teaching and assessment strategies of laboratory work.

The trend of laboratory teaching and teaching strategies that found to be desirable suggests an integration of aspects of science including content, process, and the nature of science through an investigative approach. Favourable assessment strategies for laboratory learning is as a whole-process with appropriate products (conceptual understandings), and process skills demonstrated by learners' presentations and by means of formative assessment by the instructors. The purposes of teaching, the nature of science conceptions, characteristics and practice of science process skills, as suggested by many studies, need to be made explicitly to the learners.

A basis of constructivist ideas suggests taking learners' prior knowledge into account of learning. Thailand National Education Act, 1999, stipulates that, by a learner-centred approach, the learners need to achieve the learning outcomes and competencies for the future careers. Thus, learners' prior biological conceptions, the understanding of the nature of science, attitudes toward biology and the ability to use science process skills are the aspects that need to be considered for designing the Laboratory in Biology course.

Social constructivism suggests that the learning process must incorporate the encouragement to make clear of prior ideas, exchange of ideas and negotiation of meanings while learners are actively engaged with the laboratory learning activities. The social construction of scientific knowledge can be promoted by interactions between learner-learner and learner-instructor. The instructor is an important person to prepare appropriate teaching and learning activities and various instructional materials and acts as a creator of active, challenging and collaborative learning environment and a scaffolder by encouraging them to develop their competence regarding their own interests and potentials.

Overall, this chapter presents a literature review on laboratory teaching and learning and learning theories to help the researcher to synthesize the guiding principles utilized in the development of the instructional set for the Laboratory in Biology course. The review of laboratory work were covered; history of laboratory work, classroom practice and problems in science teaching in Thai context, research on purposes, learning outcomes, teaching and assessment strategies of laboratory work. Learning theories focused was constructivist theory which is central for science learning since the 1980s to present. The literature review suggested some ideas which were further utilized in generating the guiding principles of the instructional set. The next chapter presents and discusses research methodology of the research study.

CHAPTER III

METHODOLOGY

Introduction

This chapter discusses the methodology used to answer the research questions of this study. It includes research paradigms, design and methods of this research study. The construction of instruments used to collect data about pre-service science teachers' learning outcomes in the existing Laboratory in Biology course as well as the outcomes after the instructional set was implemented. Data collection process, data analysis and trustworthiness of this research study are also discussed.

Methodology is a framework describing how a research study is conducted. Systematic and planned data collection, analysis and interpretation of the data are required as powerful tools to effectively answer the questions of researchers (Mouly, 1978). It presents the planning process which a researcher uses to reach the answers for the research questions, covering the outlook on participants, fieldwork, data collection and data analysis (Patton, 1990; Freebody, 2003). Research methodology also describes and analyses the methods used to gather data and guides the way that inferences, interpretations, explanations, and predictions are made (Cohen and Manion, 1994).

Research studies conducted based on different paradigms will use different perspectives of data gathering and analysis although they use the same methods (Patton, 1990). Research paradigms shape the ways to collect and analyze data. This is because each paradigm has different ontological, epistemological, and methodological assumptions and uses different research tools and strategies for interpretation of findings to answer research questions (Guba and Lincoln, 1998). Thus, an understanding of the philosophical foundations of different perspectives will help researchers choose the appropriate research paradigm underlying the methodology to be used (Patton, 1990; Merriam, 1998).

Research Paradigms

A paradigm is a fundamental set of beliefs which presents and guides a refinement of the nature of the world and its parts (Lincoln and Guba, 1985; Guba, 1990; Guba and Lincoln, 1998). Bryman (1988) noted that the term "paradigm" was firstly used by Kuhn (1970) which he referred to the paradigm underlying the scientific investigations in his book "The Structure of Scientific Revolutions". Bryman also defined a paradigm as a cluster of beliefs and dictates which influence what scientists' study, ways of doing research and how the data is interpreted. Thus, in the educational sense, a paradigm influences what educational researchers study, the way of doing their research, the way they interpret the collected data. This section discusses two major paradigms used in educational research, positivism and interpretivism.

Positivists believe that reality is assumed to exist and that it can be objectively studied without being influenced by either the study or the studier. They hold the "etic" or outsider view of their research (Guba and Lincoln, 1998). Researchers who believe in this paradigm, possess an etic perspective in which they perceive the research aims as "[moving] beyond the perspectives of the people being studied and [using] social science concepts, terms… and procedures to describe the people and explain their behaviour" (Johnson and Christensen, 2000). In positivist research, questions and hypotheses are formulated for verifying the results of interactions of independent and dependent variables with appropriate condition controls to collect the data (Lincoln and Guba, 1985).

Positivists use manipulation of reality, in which they believe that it is stable and isolated, with variation in only a single independent variable to examine regularities in, and to form relationships between, some of the constituent elements of the social world (Lincoln and Guba, 1985; Erickson, 1986; Cohen and Manion, 1994; Merriam, 1998). Positivist research possesses unique characteristics of objectivity, measurability, predictability, controllability, and patterning, the construction of the laws and rules of behaviours (Cohen *et al.*, 2000).

There has been much debate on the issue that the positivist research paradigm may not be entirely suitable for social science or educational research. Husén (1997) noted that positivism may not be able to investigate the multifaceted field of educational research. In a classroom, undoubtedly a natural setting, a positivist style of research might not be appropriate to investigate the complexity occurring within the setting (Kelly and Lesh, 2000). Science education research has shifted attention from strict traditional experimental methods to alternative methods for research. A different perspective to the positivist research paradigm, interpretivism is used to create the understandings and reconstruction of classroom phenomena and the degree of its trustworthiness and authenticity have replaced the internal and external validity of positivism (Guba and Lincoln, 1998).

The interpretive paradigm assumes that the understanding of the subjective world of human experiences, in which individuals' interpretations or understandings of the world around them, has to come from the inside, not the outside (Cohen and Manion 1994). Interpretivism assumes that reality is socially constructed, thus the interpretive research goal is to understand what meanings people give to that reality as the inside views of the people (Schwandt, 1994; Cohen *et al.*, 2000; Schutt, 2003). In addition, the goals of interpretive research are to gain an understanding of how people make sense of their world and the experiences they have in the world (Behrens and Smith, 1996; Merriam 1998).

Hence, interpretive researchers must hold "emic" or insider perspectives which consider questions and issues for study that are important to insiders and try to get to know what is inside of the head of the participants (Johnson and Christensen, 2000). The researchers also need to apply the research tools which facilitate getting close to the participants and situations being studied in order to personally understand the realities in the social sense (Goetz and LeCompte, 1984).

These beliefs of the interpretivist paradigm result in a focus on exploring how a particular person, or group of people in a social context, constructs the beliefs in situations occurring in the scene of research investigation (Guba and Lincoln, 1989).

An interpretive researcher does not attempt to manipulate the research setting, but tries to understand the phenomenon which is naturally occurring in the research setting (Patton, 1990). An understanding of a phenomenon is from an appropriate interpretation of the data which is directly gained from the insiders' look and clarification of what and how the researcher interprets the meanings from the language and actions belongs to the participants (Schwandt, 1998).

Interpretivists use an interactive research process, in which they begin to explore and evaluate the questions and interest within a natural setting. They attempt to get to know what the participants think and consequently use hermeneutical techniques which are based on sharing the perspectives on the problem being investigated (Guba and Lincoln, 1989). With the idea that only through the subjective interpretation and intervention in reality can that reality be fully understood, the philosophy of the interpretive research is being conducted in a natural setting. It uses interpretations of an insider's look to reveal what is inside the setting. However, researchers are also aware that these interpretations, although processed by analytical and logical thinking as scientists interpret their experimental findings, come from themselves (Merriam, 1998).

In describing and evaluating how pre-service science teachers learn in a new instructional set of the Laboratory in Biology course based on social constructivist theory and the Thailand's National Educational Act, 1999, this research is undeniably conducted in a complex natural setting. In addition, this research does not aim to manipulate and control the learning environment. Rather, the researcher is interested in the interaction of first year pre-service science teachers with the teaching on the course, and their learning process in the laboratory. Data on the perspectives of the participants are interpreted in order to formulate the research findings. Interpretivism is considered as the appropriate paradigm underlying the research. Observations, interviews and document review will be used to investigate the scene in the Laboratory in Biology Course which will reflect the complexity of the setting. In the next section, the characteristics of interpretive methodology, research design and research methods are discussed.

Interpretive Research

Interpretive research is based on interpretivism. This paradigm has been discussed in the previous section. The characteristics of interpretive research thus reflect the nature of the paradigm. Interpretive research aims at creating an understanding of meaning of the processes and experiences from an inductive, hypothesis- or theory-generating mode of inquiry (Merriam, 1998). It involves rich description and evidence from the investigated phenomenon which the researcher has collected and interpreted from the research participants and the setting. It can be assumed that interpretive research uses a holistic approach, in which the whole phenomenon is investigated, to construct a complete picture of it as a complex and dynamic system.

Interpretive researchers are willing to get close to the sources of data, embed themselves in the setting and “get their hands dirty” by participating where possible in actual program activities, and getting to know the participants at a personal level (Patton, 1990). Building rapport and being in the setting over a period of time to develop proximity to the participants is necessary for enabling the researcher to elicit participants’ thinking and feelings of their experiences confidently (Goetz and LeCompte, 1984).

Patton (1990) argued that interpretive research cannot be completely specified in advance before immersion in the setting of the research. The researcher does not attempt to manipulate the research setting but the research setting is a naturally occurring situation. The design can be specified as an initial focus, identifying the research plan to use observation and interviews, and indicating primary questions to be explored. Its naturalistic and inductive nature makes it almost impossible to specify predetermined operation variables, state testable hypotheses, and finalize either instrumentation or sampling schemes. That it has no predetermined categories of analysis contributes to the depth, openness, and detail of qualitative inquiry.

Raw data from the research setting, such as direct quotations, dialougues and other evidence gathered in the setting such as participants’ work and pictures are significant sources for the interpretation of the research findings. For instance, excerpts from videotapes showing how pre-service science teachers interact and respond to the learning activities and a writing material expressing their feelings and satisfaction, while participating in the Laboratory in Biology course, could be the sources which the researcher can interpret to describe the pre-service science teachers' attitudes towards teaching and learning in the course.

To collect, describe and interpret the data deeply and fully in detail, several methods such as observation, interviews and document reviews are used. Methods are different from methodology. A method refers to techniques or procedures used for gathering data from the research setting and participants, but methodology describes the whole process of conducting the research, including data collection and analysis (Cohen and Manion, 1994). Also, the researcher is regarded as an effective tool for answering the research questions. Apart from being close to the participants, the research is the one who grasps and evaluates the phenomenon being studied. The researcher is the primary instrument which is appropriate to use for interpreting the meaning of various complex social interactions within the educational research contexts (Erickson, 1985; Lincoln and Guba, 1985).

Choosing research design is another important process to answering the research questions. Researchers need to appropriately choose the research design for the research study. This research study employed a case study as it focused on a case of a laboratory section of the Laboratory in Biology course with first-year pre-service science teachers and an investigation of all phenomena occurred in teaching and learning activities and situations during the implementation of the instructional set based on a learner-centred approach. The features of a case study research are discussed in the following section.

Case Study

An appropriate design of research has to be chosen in order to match the purposes of the research. This research study is focused on a particular group of people, at a particular time and place and aims at describing in-depth of how pre-service science teachers learn through an instructional set for the Laboratory in Biology course which follows the National Educational Act, 1999. Thus, a case study design seems the most appropriate to be the research design. Characteristics of a case study are discussed below.

A case study provides a unique instance of real people in real situations, in order to create an understanding of the case more clearly than simply presenting abstract theories or principles. (Cohen *et at*., 2001). It attempts to gain theoretical and professional insights from a full documentation of such particular instances of education experiences (Freebody, 2003). Merriam (1998) noted that a case study design is interested in process rather than outcomes, and in discovery rather than confirmation with in-depth understandings and meanings of the case. A case can be a person, an event, a program, an organization, a time period, a critical incident or problem, or a community (Patton, 1990; Bryman, 2001; Freebody, 2003).

The goal of a case study is to put in place an inquiry in which both researchers and educators can reflect upon particular instances of educational practice (Freebody, 2003)**.** A case study becomes particularly useful where the researcher needs to understand in great depth, and where one can identify cases rich in information and capture individual differences or unique variation from one program setting to another or from one program experience to another (Patton, 1990). It can establish cause and effect in real contexts which are unique and dynamic (Cohen *et al*., 2001).

Merriam (1998) argued that case studies are differentiated from other types of qualitative research in that they have intensive description and analyses of a single case. In addition, unlike experimental, survey, or historical research, a case study does not claim any particular methods of data collection or data analysis. Data collection in a case study can be all of the data gathering methods from testing to interviewing, including both qualitative and quantitative data. Freebody (2003) asserted that a case study does not have so much a pre-set of data collection but it focuses on attempting to document the story of a naturalistic-experiment-in-action. Hitchcook and Hughes (1995) indicate the hallmarks of a case study are that it includes a rich and vivid description of events relevant to the case in a chronological narrative of events which attempt to portray the richness of the case in writing up the report. The researchers are integrally involved in the case so that they are able to provide a blend of description and their own interpretive analysis.

Yin (1984) classified three types of case; critical, unique and revelatory. To investigate a critical case, the researcher has specified a hypothesis to generate an understanding of a particular circumstance. A unique case or an extreme case has unique characteristics which interests the researcher to investigate about it. A revelatory case is where the researcher has an opportunity to observe and analyse a phenomenon without influencing the case.

This research study of pre-service science teachers in the Laboratory in Biology course has a shared characteristic of critical and revelatory cases. It is a revelatory case in that the researcher aims at gathering the entire possible sources of information in order to make an interpretation and construct a whole picture of the class's activities which actually occur in the course. The researcher previously participated in the class as a student. Before going to the class, a view has implicitly been formulated in the researcher's mind that teaching and learning in the course employed traditional laboratory teaching approach as she had experienced. Therefore a hypothesis can be framed that states that designing an instructional set in accordance with Thai National Education Act, may be a possible way to improve the teaching and learning in the course. These point this research study as a critical case.

Case studies have been proven as useful for the studies of education innovations, evaluating programs and informing policy (Cohen *et al.*, 2000). A case study can examine educational processes, problems and programs to provide understandings of what can affect and perhaps make improvement of practices

(Merriam, 1998). It can portray the real experiences by direct interpretation and provide complexity through the embedding of the researcher in the research setting (Adelman *et al.*, 1980, cited in Cohen *et al.*, 2000).

Case studies undeniably have weaknesses. Bryman (2001) pointed at a good illustration of the problems of external validity or generalizability of case study research. It has strength in providing thick description of a particular case. But the findings are unable to be applied or generalized to other cases. Considering the focus of case study research design reveals the significant characteristic of case study research in that they naturally cannot be generalized. It is important to appreciate that case study researchers do not delude themselves that it is possible to identify typical cases that can be used to represent other cases. Bell (1993), Lincoln and Guba (1985) and Merriam (1998) also discussed about the same point of non-generalizability of a case study in that a case study is studying a single case, it cannot generalize from that case to another case which has different characteristics. But by providing a rich description of a case, the researcher can leave the reader to examine what can be applied from the case study to their own situation.

This research study of teaching and learning in the Laboratory in Biology course was a case study as it situated in a laboratory class including pre-service science teachers. It focused on their learning and the instructor's teaching. The boundary of the case was clear, with a focus on the phenomena happening in the teaching and learning in the course during one academic semester of trying out the instructional set, excluding the previous observation to find out the general practice in the course and planning the instructional set. It aimed at gathering data about the learning process of the pre-service science teachers as well as their development of their conceptions, views, skills and attitudes which are viewed as outcomes of the Laboratory in Biology course. The researcher spent time to observe and participate in every class session for the whole semester to gather all of the possible sources of data to construct an understanding of the whole picture of the case.

Data Collecting Methods

This section discusses the main research methods for data collection research of this research studies: observation and interview. These data collection methods are discussed as the followings.

Observation

Interpretive and case study research use observation as an important tool for gathering data as it enables researchers to understand what happens in natural situations (Merriam, 1998; Cohen *et al.*, 2000; Lankshear and Knobel, 2004). Data from observations provides descriptive information in details of what happen in the setting and how the participants interact and react in the situations. Essentially, an observation aims at describing the setting, the activities that take place in that setting, the people who participated in those activities, as well as interpret the meanings of those are observed (Patton, 1990). An observation includes looking, listening, and face-to-face interaction (Punch, 1998). This means that both oral and visual data are important to be the source to describe the context and situations happen in the research studies. It also helps the researcher to gain insight perspectives of participants which they may not feel comfortable to talk freely in an interview situation. (Patton, 1990; Merriam, 1998; Cohen *et al.*, 2000).

According to roles of the observer, Lincoln and Guba (1985), Patton (1990), Bell (1993) and Punch (1998) classified observations in two categories; non-participant observation and participant observation. For non-participant observation, the researcher as an observer comes to the classroom setting and records teacher-student discourse using a structured set of observational strategies (Cohen *et al.*, 2000). It benefits as the researcher can concentrate on what is being observed follow research purposes. However, observations by a stranger who enters the classroom and write down something usually affect participants' behaviours (Patton, 1990; Banister *et al.*, 1994). For participant observation, widely use in educational research, the researcher is a member of the group being studied (Merriam, 1998; Cohen *et al.*, 2000). Participating and interacting with the participant make the researcher obtains inside information with more details and sees what is happening as well as feels it part of the setting.

Participant observation has limitation in that the researcher will not capable to focus on every interesting perspective of participants because they are also participating in the activities or situations being observed. Being close to the participant, the research needs to be aware of personal bias about some participants as well as predetermination of participant's behaviors. Also, participant observation has been critiqued of its subjectivity and unreliable results due to the observer's perceptions and interpretation (Bell, 1993; Banister *et al.*, 1994; Merriam, 1998).

In this study, participant observation is used to gather the data in the every laboratory session to capture how the pre-service science teachers learn and how the instructor teaches during the implementation of the instructional set. The researcher will interact with the participants and use field notes to record preliminary data. Filed notes include a table for collecting the data which is separated into two columns; what are observed and researcher's thought/action about those are observed (Bouma, 2000). Videotape recording is also used to enable the researcher to review the situation occurred and to capture other information which has not been recognized in preliminary field notes and reinterpret the data. The data is given to the instructor to for member checking to enhance the validity of the research findings and the data is consequently used for interpretation of the findings.

Interview

To elicit participant ideas which cannot be observed, interview is regarded as a powerful tool for gathering information in interpretive research. Interview is person-to-person verbal interaction which is normally used in educational research to capture information of interviewees' perspectives (Lincoln and Guba, 1985; Banister *et al*, 1994; Fontana and Frey, 1994; Merriam, 1998; Punch, 1998). It becomes very useful for past events that are unrepeatable (Lincoln and Guba, 1985; Merriam, 1998). Interviewing skill is significant in that it determines the quality of information. The interviewer can both motivate the interviewees to openly express and discuss their interpretations of a situation using their own viewpoints (Cohen *et al.*, 2000) and gain prejudice information due to the interviewees' emotional state and the interviewer's bias (Goetz and LeCompte, 1984; Bell, 1993; Cohen et al., 2000).

How much an interview is effective depends on the quality of the questions. Patton (1990) suggested that being open-ended, natural, singular and clear are the characteristics of good interview questions. The interviewer should avoid three types of question; multiple questions, leading questions, and yes-or-no questions (Merriam, 1998). The interaction between the interviewer and the interviewee is also important; the interviewing atmosphere should be relaxed for the interviewee to feel free to express his/her own perspectives. Responses from the interviewee should be non-judgmental, non-committal and non-threatening (Jones, 2005).

Three types of interviews have been classified according to the degree of interview structure (Patton, 1990; Bell, 1993; Fontana and Frey, 1994; Bryman, 2001). Types of interviews are classified as structured, semi-structured and unstructured interviews, discussed as the followings.

Structured interview has carefully worded questions which ask each participant the same question with essentially the same words (Patton, 1990). It is like an oral form of the written questionnaire or checklist (Bell, 1993; Freebody, 2003). The interviewer has already identified the complete rigid set of questions derived from aspects which the interviewer wants to know about the interviewees (Guba and Lincoln, 1989). Its strengths are those; it has higher validity and reliability than other types of interview (Bryman, 2001); it can save a lot of time and the interviewer cover all of the questions (Bell, 1993); and data analysis can be done easier because every interviewee answered the same question and in the same order (Punch, 1998). However, structured interview is not widely used in educational research in that its structured set of questions are predetermined by the interviewer's framework which may not achieve in accessing interviewees' perspectives; it may not produce normal conversations and the questions may not relevant to the different interviewees (Lincoln and Guba, 1985; Patton 1990; Freebody, 2003).

Semi-structured interview has an outline of a set of guide questions prepare to remind the interviewer to cover all of the interviewing topics (Bryman, 2001). The interviewer can adjust the sequence and language to match the interviewee's answers and contexts (Patton, 1990). It allows the interviewer to access a more in-depth view of interviewee's perspectives than the structured interview. The interviewer has more freedom to create a conversation within a particular subject area, ask questions spontaneously, and be able to establish a conversational style within the focus of the interview. The interviewer can respond to the actual situation which helps in eliciting interviewee's suddenly emerged ideas (Merriam, 1998). However, the interviewers may face trouble in that they cannot to manage the time available and cover all of the topics in the real interview situation (Patton, 1990; Freebody, 2003). Some important topics may be unintentionally omitted and that the interviewer has flexibility in sequencing and wording questions may produce different responses, and it will not be possible to compare those results from different interviewers (Patton, 1990).

Unstructured interview is similar to normal conversation which has natural flow of an interaction emerged from direct context. There are no predetermined topics or wordings before the interview (Punch, 1998). This type of interview can be used when the interviewer has not known much about the phenomena (Lincoln and Guba, 1985). It can be part of ongoing participant observation while the researcher interact with the participant and wants to know what participants are thinking, how and why they have interacted with the phenomena, the interviewee may answer the question without realizing that they are being interviewed (Patton, 1990).

Because of its strength in flexibility, the interviewer can gather in-depth information by responding to a suddenly emerged situation (Lincoln and Guba, 1985; Freebody, 2003). Questions in an unstructured interview are changeable over time. New interview builds on those already completed for expanding information that was picked up previously. It can also move in new directions to elucidate and elaborate from perspectives of various participants (Patton, 1990; Freebody, 2003). Unstructured interview has weakness in its time-consuming nature in that the interviewer may need to have several conversations with various participants to construct the picture of the whole phenomena (Goetz and LeCompte, 1984; Bell, 1993). The quality of data greatly depends on the interviewer’s skills and data from unstructured interview are also difficult to organize and analyze because obtained data may vary by individual differences (Patton, 1990).

Data Analysis Methods

Collected data are processed via data analysis process. This section describes two data analysis methods frequently used in research studies: content analysis and thematic analysis as the followings.

Content Analysis

Content analysis is used for analyzing the data which the researcher has already known the important categories will be prior to the analysis (Ezzy, 2002). It begins with predefined categories, defines then the units of analysis and the categories into which these will be placed. The final stage of content analysis is the interpretation of results it is useful way of confirming or testing a pre existing theory. Content analysis is used widely in studies of student understandings in science concepts, For example, Simpson and Marek (1989).

Thematic analysis

Thematic analysis is used to analyse the data from observations, unstructured interviews during the class sessions. Thematic Analysis has been used in many research studies (For example, Kracker and Pollio, 2003; Goodwin, 2002; Billingsley, 2004; Spencer *et al.*, 2004). Thematic analysis is a form of inductive analysis that no categories of data are predetermined. Rather, the categories are emerged from the data

(Ezzy, 2002). The strategy for this type of data analysis is identifying themes and pattern from the data. The steps of analyzing data by thematic analysis described by Aronson (1994) are:

1) Transcribing conversations and patterns of experiences which can come from direct quotes or paraphrasing common ideas,

2) Relating and identifying all data that relate to intellectual scheme or ideas,

3) Combining and cataloguing related patterns into themes, and

4) Building a valid argument for choosing the themes by relating literature to the analyzed result sand referring back to the literature.

Trustworthiness of Data Collection and Analysis

In interpretive research, the researcher is the powerful tool for both data collection and data analysis as discussed earlier. The quality of data thus directly depends on the process which the researcher has been through. Skills of the researcher also determine the quality of the data which affect on data collection, data analysis and interpretation in both positive and negative (Patton, 1990). Trustworthiness of the research process is considered significant. Guba and Lincoln (1989) proposed the terms used for determining trustworthiness of interpretive research which are paralleling with the terms used in the positivist research; credibility, transferability, dependability and confirmability; parallel to internal validity, external validity, reliability, and objectivity, respectively.

Credibility

Credibility is the degree of confidence that research finding is really gained or drawn from the perspective of the research participants the authentic research contexts (Creswell, 1998, Lincoln and Guba, 1985). It "seeks to demonstrate that the explanation of a particular event, issue or set of data which a piece of research provides can actually be sustained by the data" (Cohen *et al.*, 2000, p. 107). The degree of credibility depends on the skill, competence, and rigor of the researcher (Patton, 1990). Six basic strategies to enhance credibility have been suggested by Merriam (1998); triangulation, member checks, long-term observation, peer examination, participatory or collaborative modes of research, and research's bias.

1) Triangulation; using multiple investigators, multiple sources of data, or multiple methods to confirm the emerging findings.

2) Member checks; taking data and tentative interpretations back to the people from whom they were derived and asking them if the results are plausible.

3) Long-term observation at the research site or repeated observations of the same phenomenon, gathering data over a period of time in order to increase the validity of the findings.

4) Peer examination; asking colleagues to comment on the findings as they emerge.

5) Participatory or collaborative modes of research; involving participants in all phases of research from conceptualizing the study to writing up the findings.

6) Research's bias, clarifying the researcher's assumptions, worldview, and theoretical orientation at the outset of the study.

Transferability

Transferability refers to the degree to which the results can be generalized to the wider population, cases or situations (Cohen, *et al*, 2000). Schofield (1993) noted that clear in-depth in detail of description will help other researchers decide how much the research finding can be generalized to other studies. To enhance the possibility of the results of a qualitative study generalizing Merriam (1998) suggests three strategies for enhancing transferability of research; rich/thick description, typicality or modal category, and multi-site designs.

1) Rich, thick description; providing enough description so that readers will be able to determine how closely their situations match the research situation and whether findings can be transferred.

2) Typicality or modal category; describing how typical the program, event, or individual is compared with others in the same class, so that users can make comparisons with their own situations.

3) Multi-site designs; using several sites, cased, situations, especially those that maximize diversity in the phenomenon of interest; this will allow the result to be applied by readers to a greater range of other situations

Dependability

In interpretive educational research, dependability or reliability will not be made due to the change of human behaviours (Cohen *et al.*, 2000). Dependability refers to how much research findings can be replicated with the same research methodology (Merriam, 1998). Three techniques for enhancing dependability of data were suggested by Merriam (1998); the investigator’ position, triangulation, and audit trail.

1) The investigators’ position; the investigator needs to explain the assumptions and theory behind the study, the group being studied the basis for selecting informants and a description of them, and the social context from which data were collected.

2) Triangulation; using multiple methods of data collection and analysis

3) Audit Trail; the investigator must describe in detail how data were collected, how categories were derived, and how decisions were made throughout the inquiry so that independent judge can confirm the findings of a study by following the trial of researcher.

Confirmability

Confirmability refers to the degree to which the results could be confirmed or corroborated by others (William, 2002). Confirmability pursues data assurance, interpretations, and outcomes of research in that they are not from the subjectivity among different researchers (Guba and Lincoln, 1989). One of the principal techniques for establishing the confirmability of findings is audit trail (Lincoln and Guba, 1985). Thus, strategies for enhancing confirmability is asking other researcher or experts to check or audit the data collection, interpretation and analysis procedures findings and makes judgements about the potential for bias or distortion.

Methodology of This Research Study

In order to answer the research questions, more specific details of the research should be established. In this section, the design of this research study is described accompanied by the instruments and methods used. Data collection, data analysis and trustworthiness are also discussed.

This research study has two phases. Phase I, adopted a survey research design, was to explore the pre-service science teachers' basic biology concepts, science process skills, understandings in the nature of science and attitudes towards biology prior to implementing the intervention. In phase II, the findings from phase I and the information from a literature review (Chapter Two) were used to design an instructional set for the Laboratory in Biology course to help pre-service science teachers to experience laboratory work based on social constructivist theory and Thailand National Education Act, 1999 and achieve the same four learning outcomes explored in the first phase. Then instructional set was implemented by a biology instructor with first-year pre-service science teachers. In phase II, a case study was employed as the research design. Details of each phase are discussed as follows.

Phase I: Exploratory Phase

The first phase was to find out biology concepts and views on the nature of science, science process skills and attitudes towards biology of the first year pre-service science teachers who completed the Laboratory in Biology course in 2004 academic year. The findings of this phase provided the answer for the first research question and served as part of the guiding principles to design an instructional set in the second phase. In this phase, two questionnaires and one inventory were developed to find out the first-year pre-service science teachers' understandings in biological concepts, science process skills, the nature of science and attitudes towards biology.

Data collection of phase I

This section discusses the information of participants participated and the development of three research instruments utilized in the first phase of this study: Biology Concept and Science Process Skill Questionnaire, Views on the Nature of Science Questionnaire and Attitudes towards Biology Inventory. Details are discussed as the followings.

Participants

Thirty-six first-year pre-service science teachers, majoring in teaching physics, chemistry and biology participated in Phase I of this study. All of them participated in the Laboratory in Biology course in the first semester (June-November 2004), 2004 academic year. After they took the final examination, they were asked to give responses for the three research instrument in October, 2004.

Instruments

There were three instruments utilized in phase I. The development of each instrument is shown in the following sections.

1) Biology concept and science process skill questionnaire

To find out pre-service science teachers' understanding of biology concepts in 12 topics taught in the Laboratory in Biology course and their understanding of science process skills, an open-ended questionnaire was developed. The questionnaire was used to capture the pre-service science teachers' conception and misunderstanding of biology concepts after they participated in the Laboratory in Biology course. This could provide the ideas for the researcher to give more consideration in designing the instructional set for the lesson including the concepts which the majority had misunderstanding about. For the concepts which they well-understood, additional activities were considerably added to the lesson other than the existing activities as planned in the original required activities.

An open-end form of questionnaire had been chosen for finding out all possible alternative conceptions relating to the 12 topics taught in the course. In one open-ended question, many alternative conceptions may be revealed. As Sudman and Bradbum (1982) had noted, an open-ended questionnaire allows respondents to answer the question in their own words and also encourage them to give their opinions fully in the language that is comfortable for them. In addition, the respondents would feel free to write their conceptions asked by each question. However, a free-response question is often easy to ask, but difficult to answer, and still more difficult to analyse. Thus, the limitation of open-ended questionnaire is that it difficult for the researcher to make comparisons between respondents, and it takes much longer time to analyze the data. At the same time, with a small number of respondents, an open-ended questionnaire is very useful to provide the details which an interpretive researcher might need to know about the participants (Cohen *et al.*, 2000).

The questionnaire consisted of ten major questions (see Appendix). Each question has two to eight sub-questions. The first eight questions asked about some of the biological conceptions taught in the Laboratory in Biology course. The concepts cover cell structure and function, prokaryotes and eukaryotes, osmosis, cell division, reproduction, photosynthesis, respiration and ecology. The last two questions asked about understanding of science process skills covering formulation of hypotheses, identifying and control variables, designing an experiment, interpreting of findings and drawing conclusions.

The questionnaire was developed by reviewing the Laboratory in Biology Course Manual and literature to make a draft of preliminary questions. The majority of the questions (Question 1, 2, 4, 6, 8), were developed from considering the general questions in the laboratory manual and other biology textbooks and then adding contexts to the questions which were relevant to the Thai pre-service science teachers. The other questions have been based on research papers; Question 7 was adapted from Barker (1985), Question 5 was adapted from Lewis *et al.* (2000). Only Question 3 was developed by adopting the knowledge question type typically found in general biology textbooks to find out basic concepts without adding a context. Question 9 and 10 were also developed by the researcher based on Thai context. The topics asked by the ten questions are identified in Table 3.1.

Table 3.1 Covered topics in biology concepts and science process skill questionnaire

Questions	Covered Topics
1.	Cell structure and function
2.	Prokaryote and eukaryotes
3.	Osmosis
4.	Osmosis (application)
5.	Cell division
6.	Reproduction
7.	Photosynthesis and respiration
8.	Ecology, photosynthesis and respiration
9.	Designing an experiment
10.	Formulation of hypothesis, identifying and controlling variable, interpreting results and drawing conclusions

2) Views on the nature of science questionnaire

Views on the nature of science questionnaire (see Appendix) was developed to assess the first-year pre-service science teachers' views on four aspects of nature of science; definition of science, characteristics of scientific knowledge and methods, characteristics of scientists and interrelationship of science and society. This questionnaire was adapted from VOSTS developed by Aikenhead *et al.* (1987). Thirteen statements about the nature of science have been selected from VOSTS statements. Two items assessed conceptions of the definition of science (Item 1 and 2), 5 items assessed the characteristics of scientific knowledge and methods (Item 3, 4, 5, 6 and 9), 4 items assessed characteristics of scientists (Item 7, 8, 10 and 11) and 2 items assessed the interrelation of science and society (Item 12 and 13). The questionnaire asked pre-service science teachers to read each statement and make decision whether they 'agree', 'not sure' or 'disagree' with the statements. This helps them to set their own position before providing reasons to support their views for each statement in the space under each statement.

3) Attitudes towards biology inventory

A rating scale is powerful and useful in research, especially capturing responses about attitudes, perceptions and opinions (Cohen *et al*., 2000). Attitude towards Biology inventory thus adopted this model. This attitude inventory measured attitudes towards biology in general, attitudes towards laboratory work and attitudes towards learning in the Laboratory in Biology course. The inventory had 10 positive and 10 negative items, totally 20 items; 8 items measured attitudes toward biology, 6 items measured attitude towards laboratory work and 6 items measured attitudes towards learning in the laboratory in Biology course. These items were adapted from many research papers (for example, Ebenezer and Zoller, 1993; Francis and Greer, 1999; Jesky-Smith, 2002; Moore and Foy, 1997; Salta and Tzougraki, 2004). Each item had a five-point Likert scale with categories ranging from strongly agree (5 points) to strongly disagree (1 point). The pre-service science teachers were asked to tick in order to indicate their attitudes towards each statement.

Validity of questionnaires and inventory

To ensure that the questionnaires have been developed to capture the features as required by the research question 1, the validity of these questionnaires and inventory was considered important. The questionnaires and inventory was reviewed by four university science instructors and four science educators. Then each was improved according to the feedbacks and comments. Biology Concept and Science Process Skill Questionnaire was piloted with 15 second-year pre-service science teachers who had completed the Laboratory in Biology course in 2003 academic year. Views on the Nature of Science Questionnaire and Attitude towards Biology Inventory were piloted with 19 third year pre-service science teachers. These responses were used to improve wordings in questions which consequently made the question clearer to the respondents. The pilot results of the inventory were used to calculate the reliability of the whole inventory. The reliability coefficient (Cronbach's alpha) was 0.76. Then the questionnaires and inventory were administered to the participants of the study.

Data analysis of phase I

Data from the questionnaire for finding biology concepts and science process skills are analyzed by content analysis method. The expected scientific concepts were generated to answer each question in the questionnaire. These answers were validated by four biology instructors and four science educators. Categories of responses have been predetermined before analyzing the responses. These categories are adapted from Westbrook and Marek (1982), as shown in the following section.

Categories of student understandings

1) Sound Understanding: SU

The students' response is scientifically accepted theories and explanations and expresses a complete understanding of the concept

2) Partial Understanding: PU

The students' response contains parts, but not all of the information necessary to convey a complete understanding. No incorrect information occurs in the response

3) Specific Misunderstanding: SM

The students' response contains only misunderstandings

4) Partial understanding and Specific misunderstanding: PS

The students' response contains correct information, but also indicates a misunderstanding concerning some aspects of the concept

5) No Answer: NA

The students' response consists of 'I don't know', the question repeated, irrelevant remarks or the page left blank

Responses in the Views on the Nature of Science Questionnaire are analyzed by thematic method. All of the responses were read then grouped and generate the theme to each group of answers. Percentage of answers in each group also presented.

Responses from the Attitudes towards Biology Inventory were analyzed by rating scale analysis. The responses were assigned point values, shown in Table 3.2.

Table 3.2 Point values for positive items and for negative items of the inventory

	Positive Items	**Negative Items**
Strongly agree	5	1
Agree	4	2
Not sure	3	3
Disagree	2	4
Strongly disagree	1	5

The point values of each item are summed up and calculated for mean and standard deviation by Microsoft Excel. The mean scores are used to determine the attitudes towards biology of pre-service science teachers. The standard deviation is for investigating the distribution of the scores which indicate the differences attitudes of participants towards attitude statement in each item.

The meaning of the attitude score ranges are shown as the followings.

> 4.50	highly positive
3.51-4.50	positive
2.51-3.50	moderate
1.51-2.50	negative
<1.50	highly negative

Phase II: Development and Implementation Phase

In the second phase, an instructional set for the Laboratory in Biology course were developed and evaluated by experts. After it was improved, the instructional set was implemented in the Laboratory in Biology course by two experience biology instructors. The teaching and learning process were monitored by the researcher. After the implementation was finished, the pre-service science teachers' learning outcomes after learning were investigated. They were asked to give responses to the Biology Concept and Science Process Skill Questionnaire, Views on the Nature of Science Questionnaire and Attitudes towards Biology Inventory. The instructors were asked to give comments and suggestions to the instructional set. "Summary of Experience in the Laboratory in Biology 424112" worksheet and follow up interviews of 7 selected pre-service science teachers according to their levels of achievement were conducted for them to illustrate their ideas given the worksheet. Details of the process of development of the instructional set is presented and discussed extensively in Chapter 5. The next sections describe the participants, context and data collection of phase II.

Participants

1) Instructors

Two instructors participated in the research study. Ethically, pseudonyms (Vipa and Darin) are used instead of their real names. Vipa implemented the first two weeks of the semester and Darin implemented from the third week to the end of the semester. Their backgrounds are detailed as follow.

Vipa

Vipa, an associate professor aged 47, started her teaching career 23 years ago. She had 20-year experiences in teaching the Laboratory in Biology course and 4-year experiences in teaching first-year pre-service science teachers in the Laboratory in Biology course. She graduated with a bachelor degree in biology from an open university. She continued her further study and got a master's degree in zoology from a public university. She received these two degrees in the country. She also had a doctorial degree in aquatic science from an overseas university. She was an expert in ecology. She had never had any opportunities to be educated or trained in the field of education.

Vipa was responsible for teaching 8 courses; Laboratory in Biology, Museum Collection, Ecology, Developmental Biology, Biology of Freshwater Mussels, Advanced in Biology of Freshwater Mussels, Research Technique with Freshwater Mussels and Special Problems. In the semester of implementation of the instructional set, she also taught Ecology, Developmental Biology and Special Problems. She had other work than teaching including being an expert of a university's institute of research and development, and validating research papers to be published in an international journal. She was also in the department's committee such as graduate school chair committee, educational insurance committee, zoology museum committee, academic service committee, etc.

Darin

Darin was a 52-year-old associate professor. She started her teaching career 26 years ago and it was the same time at which she started teaching the Laboratory in Biology course. She had 5-year experiences in teaching first-year pre-service science teachers. Darin had a bachelor degree in biology. She then received a bound-scholarship to do a master's degree in zoology and after graduated she would turned to be a university instructor. She had a 5-day teacher training before she began to do her master's degree. She also participated in several educational trainings and seminars but it was very long time ago and she could not identify topics or explain activities in the trainings and seminars. She was an expert in cells, cell division and animal tissues.

Darin had responsibility to teach 6 courses; Laboratory in Biology, Principles of Biology, Cell Biology, Microanatomy, Comparative Histology and Histochemistry. In the semester of implementation of the instructional set, she also taught Microanatomy. Each year, she was required to publish two research papers in the international journals. She was also an advisor of graduate students and department's research committee, graduate study committee and so on.

2) Pre-service science teachers

There were twenty-nine first-year pre-service science teachers participated in the class during the implementation of the instructional set. There were twenty-five female and four male pre-service science teachers. They all had a major in teaching science with a science minor in chemistry (11), biology (9) and physic (7). The other two first-year pre-service science teachers had not chosen a minor at the time of the study. These pre-service science teachers were from every region of the country: central (14), south (6), northeast (5), north (2) and east (2). Their high-school GPA ranged from 2.98 and 3.8. Their average of biology grades in the 10-12 year were in a range 2.00 to 3.97. After the midterm examination of the implementation semester, three of them dropped out the course due to their very low marks.

Context of the Study

The Laboratory in Biology course is a requirement subject of science students' and pre-service science teachers' study programs. About 500 students enrol in the course each semester. There are up to fifteen laboratory sections in a semester and more than ten instructors participate in the teaching. Normally, each section has about 40 students from two or three different majors according to the department assigned. The summative assessment of the course comprised midterm and final examinations in which all students were assessed their understanding in biology. Student final grades were entirely from these examinations.

In other semesters, first-year pre-service science teachers were assigned to be in the laboratory section which included first year science students. The instructional set was specifically designed to benefit first-year pre-service science teachers as it was designed to help the first-year pre-service science teachers to achieve both the original laboratory learning outcomes and others which would facilitate them in their future teaching career. In addition, the instructional set also targeted to give them an experience of learning through a learner-centred approach while learning science in the university. As a result, the first-year pre-service science teachers who are the focus of this study were assigned to be in the laboratory course without first-year science students.

The laboratory classroom had four large laboratory tables, each with many stools. It was a clean air-conditioned room. There were cupboards and sinks near the windows. The students worked in groups of three or four. Each group had a locker for storing often-used apparatus such as slides, glasses, droppers, cylinders, etc. The laboratory materials and instruments were prepared by two professional laboratory boys. They prepared the samples of organisms used in the laboratory activities, chemicals (such as stock solution, alcohols, acids and petroleum ether, etc) and laboratory apparatus (razors, pipettes, Dissolved Oxygen Bottles, etc). There were a computer and a microscope, both of which linked to the LCD enabling an image to be projected onto a screen at the front of the class. A slide projector was also set up and a whiteboard located at the front of the class. Figure 6.1 depicts the laboratory classroom setting.

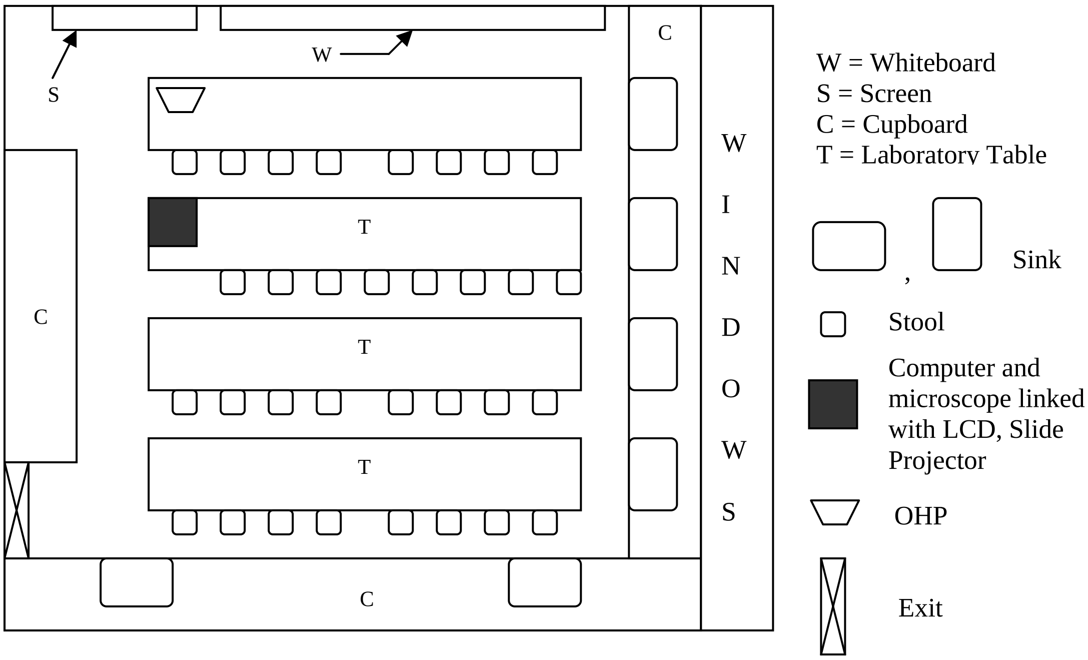

Figure 3.1 Laboratory classroom setting

Data Collection of Phase II

During the implementation of the instructional set, unstructured interviews were used to capture pre-service science teachers' thinking, perspectives, and feelings while they were interacting with the teaching. The researcher approached to the groups/ individual person to interview about what they were thinking, feeling, and even doing in the laboratory activities. There was no schedule of group/person to be interviewed in each class session. The researcher would select the situation to be interviewed according to interest and suddenly emerge situations. This strategy unquestionably possesses bias of the researcher but it would help the researcher gain in-depth reasons behind the actions which had been observed. The interview conversations were audiotape recorded to be consequently transcribed and analyzed.

Data Analysis of Phase II

Data from documents such as students' worksheets and the questionnaires and inventory after learning were analyzed by methods discussed in data analysis of Phase I. The results help in determining the achievement of pre-service science teachers' learning with the new instructional set. The videotapes of observations and audiotapes of unstructured interviews are transcribed and analyzed by thematic analysis. Data from field notes and student thinking books will also be analyzed by the thematic method. These data provide fully description of the laboratory class setting and situations occur while implementing the instructional set and reveal pre-service science teacher's interaction and attitude towards the instructional set.

Trustworthiness of This Research Study

To ensure the credibility of this research study, data from several sources were utilized for triangulation; observations, interviews and document data. Observational results were member checked by the instructor. Results from interviews were repeated to the interviewees at the end of each interview. The researcher used participant observation to gain in-depth data and observe the class for the whole semester from the first to the last class session. In analyzing data, researcher needed to eliminate biases which possibly occurred by consider the purpose and research questions. In addition, the credibility was also increased by validating the findings by science educators.

This research study focused only one case study in teaching and learning in the Laboratory in Biology course with one instructor and first-year pre-service science teachers participated in the classroom. The research findings might not be transferred to use in different contexts. However, this study provided fully in-depth description of the setting and laboratory activities happened while implementing the instructional set.

Dependability of this research study was enhanced by providing clear descriptions of research methods used to collect data, the context of the study and the process to analyze and triangulate the collected data. The research also needed to describe changes which occurred in the setting and how these changes affect the way of the research study, for instance, describing the improvement of the instructional set after implementation to match the particular group of pre-service science teachers who enrolled in the course in the first semester of 2005 academic year.

To ensure the comfirmability of the study, the results of pre-service science teachers' achievement were reviewed by research supervisors and experts. Data from videotapes of observations and audiotapes of interviews were independently transcribed and analyzed. These interpretation and analysis were compared by the researcher and also reviewed by research supervisors and experts.

Summary of Chapter III

To study the teaching and learning in the Laboratory in Biology course including pre-service science teachers, interpretive research, under the interpretive paradigm, was used to gather the complex multifaceted context of the laboratory classroom. A case study design was applied to answer the research questions of the development and implementation of the instructional set for a particular group of students participate in the course. Questionnaires were used to find out students concepts, skills and attitudes in Phase I which provide the needs and directions for improvement of teaching to match the learners. Results from Phase I, accompanied information from a literature review of learning theory, Thailand National Education Act, 1999 and teaching and learning of laboratory work, guided the development of the instructional set.

During the implementation, observations and unstructured interview were to collect the data. The observational data were collected in field notes and videotapes. Unstructured interviews were also used during the laboratory sessions to investigate learning process and attitudes of pre-service science teachers while learning from the instructional set. The document data and responses of questionnaires inventory after learning were for investigating the first-year pre-service science teachers after learning through the instructional set. Thematic and content data analysis methods were mainly used to analysed data from both Phase I and II.

CHAPTER IV

RESULTS AND DISCUSSION OF PHASE I

Introduction

Three instruments, Biology Concept and Science Process Skill Questionnaire, Views on the Nature of Science Questionnaire and Attitudes towards Biology Inventory, were developed to capture understandings in biological concepts, science process skills, the nature of science and attitudes towards biology of first-year pre-service science teachers. These instruments were administered to the participants in October, 2004. There were 36 pre-service science teachers participated in Phase I of this study. This chapter presents and discusses the findings of Phase I as the followings.

Biology Concepts

Concepts of cell structure and function, prokaryotes and eukaryotes, osmosis, cell division, reproduction, photosynthesis and respiration, and ecology were asked by the multiple-choice and open-ended question formats in the biology concept part of Biology Concepts and Science Process Skills Questionnaire. Table 4.1 summarized percentage of responses from the open-ended question format.

From Table 4.1, it was found that the majority of the pre-service science teachers had partial understanding in most concepts. No scientific understanding found in three concepts; cell division, sexual reproduction and meaning of an ecosystem. Percent responses with more than 25% of specific misunderstanding were found concepts of osmosis, application of osmosis, meiosis and genetic information, and ecosystem. The pre-service science teachers were likely to give no responses for osmosis, cell division, reproduction and photosynthesis in that they could not give more explanation of their responses and repeated what already given in the questions. Responses of the pre-service science teachers' to all questions in details are presented and discussed under the names of each biological topic as the followings.

Table 4.1 Pre-service science teachers' responses in open-ended questions of each concepts (Phase I)

(n=36)

Concepts	**Categories of Responses (%)**				
	SU[1]	**PU**[2]	**PS**[3]	**SM**[4]	**NA**[5]
1. Cell structure and function	6	64	19	3	8
2. Prokaryotes and eukaryotes					
2.1 Prokaryotes	30	39	11	17	3
2.2 Eukaryotes	28	53	6	11	3
3. Osmosis	33	17	6	28	17
4. Application of Osmosis	33	25	6	33	3
5. Cell division					
5.1 Organisms having mitotic cell division	-	58	6	14	22
5.2 Organisms having meiotic cell division	-	39	19	22	19
5.3 Mitosis: genetic information in daughter cells	-	25	-	19	56
5.4 Meiosis: genetic information in daughter cells	-	47	-	28	25
6. Reproduction					
6.1 Sexual reproduction	-	56	8	6	31
6.2 Asexual reproduction	67	-	6	17	11
7. Photosynthesis: starch test	6	75	-	3	17
8. Ecosystem: meaning	-	72	-	25	3

[1] Scientific Understanding

[2] Partial Understanding

[3] Partial Understanding and Specific Misunderstanding

[4] Specific Misunderstanding

[5] No Answer

Cell Structure and Function

The pre-service science teachers were given Figure 4.1. Supposing that they were biology teachers and one student drew the picture as Figure 4.1 to illustrate his idea of a cell, they were asked to check the student drawing whether it was correct or incorrect. If it was incorrect, they also needed to indicate how they would explain to the student. Most of the pre-service science teachers could identify the erroneous labelling of cell wall and cell membrane and about half of pre-service science teachers could identify the erroneous labelling of chloroplast and mitochondria. Nucleus and nucleolus were correctly labelled but few pre-service science teachers identified them as incorrect labelled. Their responses are shown in Table 4.2.

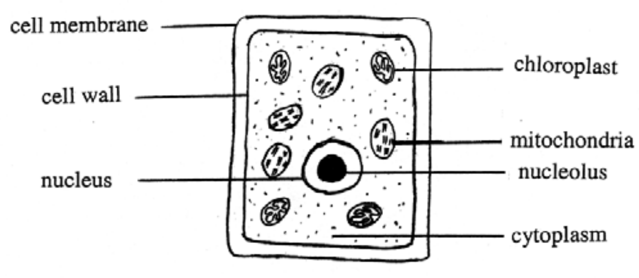

Figure 4.1 Cell structure

Their reasons for identifying the wrong labels in Figure 4.1 were categorized, shown in Table 4.1. Only six percent of pre-service science teachers could correctly identify the position of cell wall, cell membrane, chloroplast and mitochondria and also explain the characteristics and functions of these cell structures. This response was categorized as scientific understanding (SU). The majority (64%) of pre-service science teachers had partial understanding (PU) in that they could identify only part of the response of the SU. Most responses in the PU category only explained the structure and function of cell wall and cell membrane.

Table.4.2 Identifying the incorrect labelling of the cell in Figure 4.1 (Phase I)

(n = 36)

Cell Structure	%Responses
Cell wall	92*
Cell membrane	92*
Chloroplast	50*
Mitochondria	58*
Cytoplasm	0
Nucleus	3
Nucleolus	6

* correct answers

Nineteen percent of pre-service science teachers had partial understanding with specific misunderstanding (PS). These pre-service science teachers could identify the correct positions and correctly explain the structure and function of cell wall and cell membrane. Misunderstandings were also found in that they had terminology confusion between cell and organelle (11%). Six percent noted that nucleus and nuclear membrane were swapped labels and three percent thought the cell membrane must be absent from the picture. Three percent of the pre-service science teacher's had specific misunderstanding (SM) notifying that cell membrane was the outmost part of the cell and nucleolus must not be seen. Another three pre-service science teachers (8%) did not explain their answers so their responses were filled into the no answer (NA) category.

From overall responses of this question, it was found that most of the pre-service science teachers could explain structure and function of the cell wall and cell membrane. They had more difficulties to explain structure and function of chloroplast and mitochondria. This might because they had learned about cell wall and cell membrane before other cell structure and they repeatedly learned about these two cell structure since the secondary level. Terminology confusion was previously found in names of 'very small structure' such as Arnold (1983, cited in Driver *et al*., 1994) found that Scottish secondary students were confused the terms between 'cell' and 'molecule'. In this study found that Thai pre-service science teachers had terminology confusion between 'cell' and 'organelle'.

Prokaryotes and Eukaryotes

Examples of organisms were given; bacteria, mushroom, blue green algae, starfish, hydra and fern. The pre-service science teachers were asked to categorize these organisms as prokaryotes or eukaryotes and identify the criteria of their categorization. Three percent did not give any responses to the item. Percent of pre-service science teachers' responses categorizing the given organisms as prokaryotes or eukaryotes is shown in Table 4.3.

Table 4.3 Categorizing organisms as prokaryotes or eukaryotes (Phase I)

(n = 36)

Organisms	**Prokaryotes**	**Eukaryotes**
Bacteria	89*	8
Mushrooms	39	56*
Blue Green Algae	53*	36
Star Fish	11	83*
Hydras	28	61*
Ferns	6	86*

* correct answers

The majority of the pre-service science teachers could correctly categorize bacteria as a prokaryote and star fish and ferns as eukaryotes. About half could correctly categorize mushrooms and the blue green algae. A Difficulty was found in categorizing mushrooms, blue green algae and hydras which were often described as low-order organisms among the respondents. Considering their criteria to categorize an organism as a prokaryote, thirty percent of them had scientific understanding (SU) in that they noted the organism must have no nuclear membrane and membranous organelles. Thirty-nine percent had partial understanding (PU) in that they could identify either the absence of nuclear membrane or membranous organelles in prokaryotes. Eleven percent showed partial understanding with specific misunderstanding (PS) in that they included incorrect characteristic of prokaryotes; have no cell membrane and organelles. Seventeen percent had specific misunderstanding (SM); they notified that prokaryotes had no cell membrane, were liked dots seen by a light microscope, had nucleus and nuclear membrane, and had no cell wall.

Consider their criteria to categorize an organism as a eukaryote. Twenty-eight percent of the pre-service science teachers had scientific understanding (SU) in that they described eukaryotes as having nuclear membrane and membranous organelles. Fifty-three percent had partial understanding (PU); 44% could only notify that eukaryotes must have nuclear membrane, and 8% could only notify the characteristic of having membranous organelles. Six percent of them, showing partial understanding with specific misunderstanding (PS), notified that eukaryotes must have nuclear membrane. Their misunderstandings were found in that three percent noted eukaryotes must have cell wall and three percent noted eukaryotes must have glucose as a component in the cell wall. Eleven percent of the pre-service science teachers had specific misunderstanding (SM), categorizing organisms as eukaryotes where they had cell membrane (3%) were multicellular (6%) and their organelles were separated from each other (3%).

To categorize organisms as prokaryotes or eukaryotes was to consider the absence or presence of nuclear membrane and membranous organelles. Several pre-service science teachers had misunderstanding by considering the presence cell membrane, and noted the absence of cell membrane in some organisms. This confirms the difficulties in learning about cell structure. Other characteristics of prokaryotes and eukaryotes introduced by the pre-service science teachers were mostly incorrect. This might be possible that the pre-service science teachers thought being small in size and unicellular were features of prokaryotes, which is true but not for all. Having cell wall might refer to plant cells which easily categorized as eukaryotes as discussed above.

Osmosis

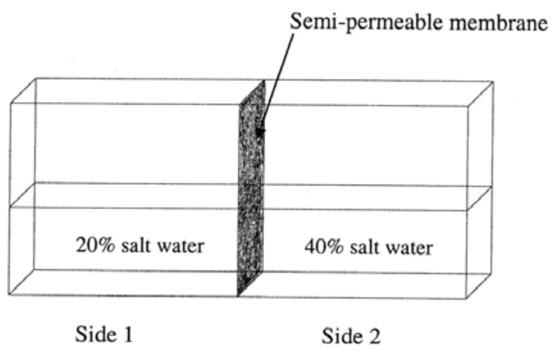

Figure 4.2 Osmosis experiment

An osmosis experiment (Figure 4.2) was given to the pre-service science teachers in the first sub-item. Considering that the salt could not get through the semi-permeable membrane, they were asked to identify the changes would be happen after one hour from the beginning of the experiment. The answer of this sub-item required the identifying of changes in concentration and volume of solution in both sides of the container that in Side 1, the concentration would increase and the volume would decrease and, in Side 2, the concentration and volume would change in the opposite way of Side 1. Long enough, the concentration of salt solution in both sides could be the same.

The results found that fifty percent of the pre-service science teachers correctly identified a change and reason of the given osmosis experiment. However, as shown in Table 4.1, only thirty-three percent of them had scientific understanding (SU) by answering that the volume of the solution in Side 1 decreased (28%), concentration of solution in Side 1 increased (3%), and the concentration of solution in both sides was the same (3%). Their reasons were; water moved through the semi-permeable membrane from the area which had lower concentration to higher concentration (25%), the concentration of salt water in Side 1 was less than in Side 2 (6%) and water moved from high osmotic pressure solution to low osmotic pressure solution (3%).

Seventeen percent had partial understanding (PU) but showed very little understanding. Eleven percent of them answered a correct change, either volume of solution in Side 1 decreased or concentration of both sides was the same with the same reason that osmosis occurred, without more explanation. Another 6% did not specify a change but identified the correct osmosis principle in their responses. Six percent of the pre-service science teachers showed their partial understanding and specific misunderstanding (PS). They correctly answered that the concentration of Side 2 decreased. But their reasons included misunderstanding that there was no particle movement when it reached equilibrium and low-concentration solution had high osmotic pressure.

Twenty-eight percent showed specific misunderstanding (SM). Six percent of them answered that concentration of solution in both side was the same and another six percent answered that volume of solution in Side 1 increased, they all gave the same reason that water moved through the semi-permeable membrane from the area which had higher concentration to lower concentration. This was correct about diffusion but not osmosis because osmosis considers water/solvent concentration, not the solute concentration. Six percent answered that no changes occurred because salt could not get through the membrane. Three percent answered that volume of solution in both side was the same with the reason that salt could not move through the semi-permeable membrane. Six percent showed a difficulty in understanding a semi-permeable membrane property, they gave the reason that higher concentration solution pushed the membrane towards the lower concentration and a change could occur only if the membrane was torn. Seventeen percent of pre-service science teachers did not respond to this item, so their responses were categorized as no answer (NA).

Half of the pre-service science teachers could correctly identify the correct change of the given osmosis experiment but only about one forth could correctly explain the correct reason. This suggests that correctly identifying of changes or experimental results did not ensure that the learners had an adequate understanding of the osmosis concept. In addition, some pre-service science teachers' responses presented wrong information about osmosis (such as the concept of osmotic pressure) and showed their misunderstanding of the osmosis concept and having very little understanding of the property of a permeable membrane. Besides, a misunderstanding that no particle movement occurred after reaching equilibrium found by many researchers (e.g. Odom, 1995; Odom and Barrow, 1995; Odom and Kelly, 2001; Sanger *et al*., 2001) was found consistent by three percent of the pre-service science teachers who responded to the questionnaire of this study.

Application of Osmosis

The pre-service science teachers were given the situation where a plant's root had been placed in 30% salt water for 30 minutes and a girl prepared a wet mount slide of the root and observed the root cell under a light microscope. They were asked to draw a picture of the root cell to illustrate the changes, if any, which would occur. They were also asked to explain why the appearance of the cell had changed or had not changed according to their drawings. The expected drawing was a shriveled cell where the volume of cytoplasm decreased and the cell membrane split off the cell wall. The cell wall, hard part of the plant cell, would remain its shape. The reason for this was drawn from the osmosis concept that with the salt solution having higher concentration comparing to the root cell, water in cytoplasm moved out resulting in cell shrivelling. Each pre-service science teacher drew a cell to response to the question. But, one pre-service science teacher (3%) did not give a reason for his drawing of a cell in normal shape, thus his response was categorized as no answer (NA).

Six pre-service science teachers (17%) drew swollen cells. All of them gave the same reason that water from outside moved into the cell. Four of them also gave more explanation that concentration of the solution outside the cell was more than inside the cell. This was the same misunderstanding of the osmosis that water moved from high to low concentration. Three percent of these pre-service science teachers also showed a misunderstanding that the process or phenomenon of cell swelling was called 'hypotonic solution'. Hypotonic solution means a solution with lower concentration comparing to a concentration-known solution. In this case, cytoplasm was a hypotonic solution comparing to 30% salt water. Therefore, all these 17% of the responses showed specific misunderstanding (SM).

Three of the pre-service science teachers (8%) who drew shrivelled root cells also showed specific misunderstandings (SM); two of them noted that concentration in the cell was more than outside the cell so water moved out of the cell. The other pre-service science teacher, who drew a shrivelled root cell, had correct concept of osmotic process but explained that the cell would burst then shrink. This was much possible that the pre-service science teacher used the experience in class when observing red blood cells in a hypotonic solution. The cells first appeared swollen and then burst resulting in cell leakage and shrinkage. It might demonstrate a robust memory from practice which suggested a more focus on the laboratory results and post-lab discussion. Learners might experience obvious experimental results and have a correct concept but could not make a correct relation of the results and the concept.

Twenty nine pre-service science teachers (81%) drew shrivelled cells. One of them (3%) showed a misunderstanding of cell structure in her drawing of a shrivelled cell by presenting the cell membrane as the outermost part of the cell with the cell wall inside it. She also demonstrated the same misunderstanding of cell structure and function as found in the first question of the questionnaire. This misunderstanding made her drawing have shrivelled cell wall and structured cell membrane. Thus, her response was categorized as a specific misunderstanding (SM). Two pre-service science teachers' (6%) drawings also illustrated the shrinkage of cell wall indicating their misunderstanding of the hard and stiff property of cell wall. Hence, their responses were also in the specific misunderstanding category (SM).

Twenty six pre-service science teachers drew the root cells with structured cell wall which were considered as correct drawings. Considering their reasons, twelve pre-service science teachers (33%) had scientific understanding (SU) that the concentration of the solution outside the cell was more than inside the cell so water in the cell moved out. Nine of them (25%) had partial understanding (PU) in that they noted only water moved out of the cell and salt water made the cell shrivelled. Although these showed very little understanding, they did not include any misunderstanding in their responses. Two of them (6%) showed partial understanding with specific misunderstanding (PS); they noted correct reasons including the terminology confusion that the term 'hypertonic solution' was used to call the condition, or a phenomenon. All percentage of responses in each category of understanding was summarized and shown in Table 4.1.

To assess the application of the osmosis concept, only asking learners to draw pictures to illustrate their understanding seemed not to be enough, they must include the reasons to show whether they really understood the concept. Although 81% of the pre-service science teachers could draw correct cell appearance when putting the cells in 30% salt water but only one third could gave the correct reason for their drawings. The drawings could also capture a misunderstanding of cell structure (wrong labels of cell wall - cell membrane). The incorrect understanding of the osmosis concept that water moved from the higher to the lower concentration solution was also constantly found by six percent of the pre-service science teachers.

Cell Division

The pre-service science teachers were given Figure 4.3. Division A illustrates mitosis and Division B illustrates meiosis. They were asked to give examples of organisms and identify cells having mitotic and meiotic cell division and the amount of genetic information after cell division. Thirty-four of them (94%) responded to the item but the other two (6%) did not give any responses.

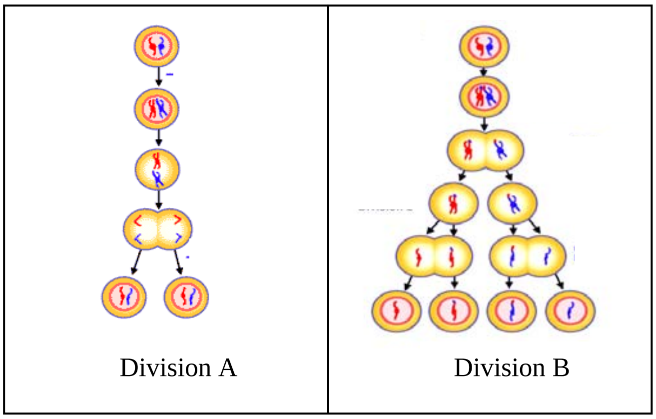

Figure 4.3 Cell division

Organisms having mitotic and meiotic cell division

The pre-service science teachers were asked to give examples of organisms having cell division as shown in Figure 4.3 namely Division A (mitosis) and Division B (meiosis). Most of them gave more than one example. Their responses are shown in Table 4.4. Only 6% of them could identify correctly that all types of organisms had mitotic cell division. The first three organisms which they were identified that having mitotic cell division were plants (27%), animals (24%) and organisms having asexual reproduction (20%). However, excluded of the responses shown in Table 4.4, five of the pre-service science teachers (14%) did not identify organisms but they noted cell types, such as somatic cells and did not specify types of organisms in that they answered that all organisms which have cell division for growth had mitotic cell division, for instance. The item also asked them to give reasons for notifying these organisms as having mitotic division. Most of them gave one or more reasons for their responses. The expected reasons were that because Division A (Figure 4.3) was mitosis, which is for increasing the number of cells resulted in growth and maintaining the body (thus it occurs in all types of organisms).

Table 4.4 Example organisms having mitotic and meiotic cell division (Phase I)

(n=34)

Organisms/ Types of Organisms	**% Responses**	
	Mitosis	Meiosis
All type of organisms	6*	-
Organisms having asexual reproduction	20	-
Organisms having sexual reproduction	3	20*
High order organisms	3	6
Low order organisms	9	-
Unicellular organisms	3	3
Multicellular organisms	3	3
Prokaryotes	9	-
Eukaryotes	6	6
Human	18	24
Animals	24	35
Plants	27	27
Bacteria	9	-

*correct answer

Analysis of their responses in this item, summarized in Table 4.1, none of their responses were in scientific understanding. Twenty one pre-service science teachers (58%) showed partial understanding (PU) by identifying part of the expected reason in their responses. Most of the responses in the PU category (41%) indicated that it was mitotic cell division with features of mitosis such as it was for growth and it occurred in somatic cells. Two pre-service science teachers (6%) had partial understanding with specific misunderstanding (PS). They included their misunderstanding that mitosis was for cell enlargement and a production of sex cells of high order plants. Five of them (14%) noted specific misunderstanding (SM) that; mitosis occurred in both somatic cells and sex cells, in the organisms having nuclei, in cells which did not need fertilization, it was for only reproduction and it was the same as asexual reproduction. Eight of them (22%) did not give any reasons.

Similarly to mitosis, the pre-service science teachers were asked to give example of organisms having meiotic cell division (responses are also shown in Table 4.4). Seven of them (19%) could correctly identify that all sexually reproducing organisms had meiosis cell division. The most three frequently answered were animals (35%), plants (27%) and human (24%). Eight out of thirty-six science student teaches (22%) responded that meiosis occurred in sex cells in which they did not respond to the questions asking about types of organisms and their response also demonstrated the misunderstanding of meiosis. According to scientifically accepted conception, meiosis produces, does not divide, sex cells. They were also asked to give a reason for why they notified the organisms as example of organisms having meiotic cell division. None of them gave the expected reason that Division B (Figure 4.3) was meiosis which divided germ cells and produced sex cells (so it was required by all organisms having sexual reproduction).

Fourteen of them (39%) had partial understanding (PU) in that they could provide part of the reason. Most of the responses in the PU category could only indicate that it was meiotic cell division. Seven of them (19%) had partial understanding with specific misunderstanding (PS) in which they identified part of the correct reason with either misunderstandings; meiosis occurred in sex cells or divided sex cells, or it was exactly the same as sexual reproduction. Eight of them (22%) had specific misunderstandings (SM) in that they notified; the misunderstanding previously presented in PS category, meiosis was mainly for sexual reproduction (actually, all meiosis was for sexual reproduction), and it was for increasing the number of cells (which is mitosis conception). Seven of them (19%) did not provide any reasons (NA). The summary of the percent responses in each category is shown in Table 4.1.

Interestingly, buried in the responses of sixteen pre-service science teachers (44%), they gave reasons which were not responded to the question asking why they thought their example organisms had mitotic cell division?. These reasons were; it occurred in somatic cells and the numbers of chromosomes were same after cell divided. Similarly, eight pre-service science teachers (22%) gave reasons not responded to the question asking why they thought their example organisms had meiotic cell division?. They all gave the same reason that the number of chromosomes was reduced in half. These reasons were correct about mitosis and meiosis but did not respond to the questions asked. This might illustrate the little understanding of the concepts so that they could not give appropriate reasons for the questions and memorization of the cell division concepts where they shortly answered what they had learned about mitosis and meiosis even their answers did not respond to the questions.

Cells having mitotic and meiosis cell division

Six cell types; a shoot apical meristemic cell, a root apical meristemic cell, an intestinal epithelial cell, a skin cell, an oocyte and a spermatocyte, were given. The pre-service science teachers were asked to identify cells in which mitosis and meiosis could occur. No reasons were required. The results are shown in Table 4.5.

Table 4.5 Identifying cells having mitotic and meiosis cell division (Phase I)

(n=34)

Cell types	**% Responses**	
	Mitosis	**Meiosis**
A shoot apical meristemic cell	91*	9
A root apical meristemic cell	91*	9
An intestinal epithelial cell	91*	3
A skin cell	82*	15
An oocyte	9	85*
A spermatocyte	3	91*

* correct answers

From table above, the majority gave correct answers. Ninety-one percent of the pre-service science teachers identified that mitosis occurs in the shoot, root apical meristemic cells and intestinal epithelial cell. Eighty-two percent identified the skin cell as having mitotic cell division. The oocyte and the spermatocyte were chosen to be the cells in which meiosis occurred by 85% and 91% of them, respectively. Seventy-two percent of the pre-service science teachers could appropriately identify that mitosis could occur in the four of the given cells; the shoot and root apical meristemic cells, the intestinal epithelial cell and the skin cell. Sixty-nine percent could appropriately identify that meiosis occurred in both oocyte and spermatocyte. To answer this question, the pre-service science teachers needed to be able to identify the given cells as somatic cells or germ cells and have the idea that mitosis divides somatic cells and meiosis divides germ cells. The majority of the pre-service science teachers did not have difficulties to identify the oocyte and spermatocyte as germ cells, and shoot and root meristematic cells and intestinal cell as somatic cells. But they seemed to have more difficulty to identify a skin cells as a somatic cell.

Amount of genetic information in daughter cells

The pre-service science teachers were asked to identify the amount of genetic information in a daughter cell compared to the mother cell, if it would be less, the same or more, after mitotic cell division had finished. The correct concept was the genetic information remained the same. They were also asked to provide a reason to support their responses. Nine pre-service science teachers (25%) had partial understanding (PU) in that they gave the reasons that chromosomes had been duplicated and shared by half in the daughter cells. None of them included a need to maintain amount of genetic information in order to make the daughter cells normally function in the reasons, thus no scientific understanding (SU) was found in this sub-item.

The responses of the eighteen pre-service science teachers (56%) were categorized as no answer (NA) because the majority (38%) repeated the question and did not provide any reasons which responded to the question. The examples of the repeated answers were: the number of chromosomes or the amount of genetic information remained the same; the daughter cells had the same characteristic/genetic information as the mother cell; and the mother cell divided into two cells. Another seventeen percent did not give reasons for the item. Seven of them (19%) had specific misunderstanding. Three of them (8%) noted the reasons that the cell duplicated itself and chromosomes did not divide. Another two of them (6%) erroneously identified the amount of genetic information after mitotic cell division had finished; one answered less and the other answered more. For the reason, both of them noted that it was mitosis and it was for growth or increasing the number of cells. The one who answered that it would be more genetic information after mitosis also added that chromosomes had been duplicated resulted in the more genetic information.

Similar to mitosis, the pre-service science teachers were asked to identify the amount of genetic information in a daughter cell compared to the mother cell, if it would be less, the same or more, after meiotic cell division had finished, and provide a reason to support their answers. The expected answer was less due to the process of sharing chromosomes in the daughter cells and a purpose to reduce half of original amount of genetic information (2n → n) to combine with a sex cell from the opposite sex (n chromosomes) during fertilization. This makes the organism remain the characteristics of the organism with 2n chromosomes in the somatic cells. None of the pre-service science teachers could give the complete reason thus no scientific understanding (SU) was found in this item. Seventeen of them (47%) showed partial understanding, they answered one of the following reasons: the number of chromosomes or the amount of genetic materials was reduced by half; a daughter cell had n chromosomes would combine with another sex cell from the opposite sex; and chromosomes and chromatids had been shared by half.

Ten of them (28%) had specific misunderstanding (SM). Two of these pre-service science teachers answering that the genetic information would be less after meiotic cell division because the chromosomes was shared by half two times. Three of them (8%) answering that the genetic information would be the same, only gave the reason that it (Division B, in Figure 4.3) was meiosis. The other five of them (14%), noting more genetic information after meiosis, gave the reasons that; meiosis resulted in the increase of genetic variation (6%), the daughter cell had 2n chromosomes (3%), meiosis was for the increase of cell size (3%) and no reasons (3%). These ten pre-service science teachers showed a difficulty in understanding the process and purposes of meiotic division, and a confusion of terms ‘genetic information’ and ‘genetic variation’. Nine of the pre-service science teachers’ (25%) responses were in the no answer category (NA). Eleven percent of them gave the reasons which was true about meiosis but did not respond to the question, which were: the cell divided into 4 cells, meiosis resulted in the increase of genetic variation, chromosomes had been duplicated, and there was coupling of homologous chromosomes. Another 14% did not give any reasons for the item.

Lewis, *et al*. (2000) found that the majority of English pre-service science teachers did not have basic concepts of mitosis and meiosis in that they could not identify cell types having mitotic and meiotic division and amount of genetic information or number of chromosomes after cell division. In contrast, most of Thai pre-service science teachers who responded to the questionnaire of this study could identify the correct answers of all these concepts about cell division. But the majority could not give appropriate reasons for their answers. It was found that many of them gave the reasons to support their answers but only mentioned to some correct concepts of cell division. As a result, their responses showed surface understanding and memorization of the concepts. In addition, many of them were likely to repeat the questions and some of them did not give any reasons. Difficulties in giving reasons for cell division were previously found among Israeli secondary science student and pre-service science teachers by a study by Marbach-Ad and Stavy (2000).

Reproduction

Two situations of reproduction in banana trees were given to the pre-service science teachers as banana trees were native trees and well-known for all Thai people. Giving a situation about a banana tree having flowers and fruits on it, and asking the pre-service science teachers to identify how the seeds were developed in the banana fruits. The expected answer was the seeds were from sexual reproduction occurring in the banana flowers' ovaries in which meiosis occurred to produce sex cells; pollen and ovum (located in an ovule). When two opposite sex cells combined, they produced zygote that would become embryo. Ovules were induced to develop to be the seeds. Table 4.6 shows percent of all pre-service science teachers' responses to this question, noted that some of them gave more than one response.

None of the pre-service science teachers could identify the complete expected answer. From Table 4.6, Response 4, 6, and 7 showed very little understanding of sexual reproduction but they did not demonstrate any misunderstandings. Response 5 and 8 were misunderstandings because having seeds is normal characteristics of flowering plants (such as banana tree) but most bananas do not have seeds due to parthenogenesis. If fertilization occurs, it normally produces seeds in fruits. This question investigated the concept of sexual reproduction. As shown in Table 4.1, none of them had scientific understanding (SU). Fifty-six percent had partial understanding (PU) but they showed very little understanding; they only indicated that seeds were from fertilization and developed from ovules. Six percent had specific misunderstanding (SM) notifying that having seeds was abnormal characteristic of a banana tree. Eight percent had partial understanding with specific misunderstanding (PS) in that they gave mixed responses of a correct understanding (seeds were from fertilization) and the same misunderstanding found in responses in the SM category. Thirty-one percent were in the no answer (NA) category because they provided no responses or gave no reasons to the question.

Table 4.6 How banana seeds were developed (Phase I)

(n=36)

	Responses	% Responses
1.	Seeds are from sexual reproduction	6
2.	Male and female sex cells combined in fertilization	14
3.	Seeds were developed from ovules or ovary	28
4.	Seeds were from fertilization	14
5.	Having seeds was the abnormal characteristic of the banana tree	14
6.	Seeds were from the banana	6
7.	Seed were from a number of very small cells divided in the banana	3
8.	Seeds were from mutation or former banana trees in the same area	3
9.	No answers	31

Giving another situation that a few small banana trees had been found near another big mature one, the pre-service science teachers were asked to identify the possible origins of the small banana trees. The expected answer was the small trees were from asexual reproduction, specifically named budding. Twenty-four of the pre-service science teachers (67%) had scientific understanding (SU) of this concept and some of them (11%) also added that the buds were from mitotic division. A specific misunderstanding was found from six pre-service science teachers (17%). They answered that the small banana trees were from the seeds found in the fruit of the mature banana tree. This was impossible because banana seeds needed long dormancy period and the hard and thick tegument of the seeds obstructed seed germination, it might take more than one year for a seed to grow to be a banana tree. Also, the seeds did not easily fall from the tree and grow due to the fleshy characteristic of the banana fruit. Two of them (6%) gave mixed responses of correct understanding and misunderstanding (PS) that the buds were both from asexual reproduction and the banana seeds. Another four of them (11%) gave no responses for this item.

For them, asexual reproduction in banana seemed less problematic than sexual reproduction. It was possible that banana buds were easier seen in nature than banana seeds and they had an adequate understanding of asexual reproduction. Asking students to explain how seeds were developed by an open-ended question, none of the pre-service science teachers illustrated their understanding of seed development process but revealed very little of their understanding. Most of them answered that seeds were from ovules and seeds were from fertilization, in which they had learned since primary school. The concept of seed development is taught in secondary and first-year university level, but none of them responded about.

Photosynthesis and Plant Respiration

Plant’s energy resource and light condition for photosynthesis

A multiple choice question format was used for asking the pre-service science teachers to choose the plant energy resource. Three percent did not respond to this item. Thirty-two of them (89%) could correctly indicate the sun as the only energy source for all plants. Two of them (6%) indicated water and carbon dioxide and one of them (3%) indicated more than one source of plant energy; soil, water, sunlight and carbon dioxide. The idea that, other than the sun, plants got energy from water and carbon dioxide was previously found in a majority of Thai secondary students by a study of Kijkuakul and Yutakom (2004).

Four light conditions were given; in sunlight, in light from a bulb, in light all time and in the dark. The pre-service science teachers were asked to identify in which condition(s) plants could photosynthesize. They responded that plant could photosynthesize in sunlight (89%), light from a bulb (56%), and light all time (69%). Only thirteen of them (36%) could indicate that plants could use both sunlight and light from a bulb to photosynthesize and plants could photosynthesize during any time that there was light in which they chose all of the first three choices. Unexpectedly, two of them (6%) indicated that plants could also photosynthesis in the dark. These pre-service science teachers might infer to their understanding of the dark reactions in the photosynthetic process in which plants did not require light after they synthesized the products from the light reactions. One of the pre-service science teacher (3%) did not respond to this item.

Plant food

Different substances were given to the pre-service science teachers; soil, water, chlorophyll, carbon dioxide, oxygen, carbohydrate, fertilizer and light. The pre-service science teachers were asked to identify plant food from these given substances. Most of them identified more than one substance. Their responses are shown in Table 7.

Table 4.7 Plant food

Substances	**% Responses**
Soil	47
Water	83
Chlorophyll	6
CO_2	42
O_2	17
Carbohydrates	25*
Light	19
Fertilizer	75

* correct answer

All of the given substances were chosen as plant food. Twenty five percent chose carbohydrates but only 6% could correctly identify only carbohydrates as plant food. Water, fertilizer and carbon dioxide were three most frequently chosen substances by the pre-service science teachers as plant food by 83%, 75% and 42%, respectively. This showed that the majority of them had the idea that plants obtained food from the environment in which this finding is consistent with the results of the studies by Bell (1985) and Leach *et al.* (1996).

Plant respiration

Asking the pre-service science teachers to identify the period of the day the plants respire, four choices were given, in day, at night, both in day and at night and plant did not respire. No reasons were required. Twenty one of them (58%) could answer correctly that plants respired both in day and at night. Three of them (8%) noted plants respired only in day. Eleven students (31%) noted only at night. The finding that plants respire only at night was also found in the studies by Kao and Su (2004) and Sander (1993). One pre-service science teacher (3%) did not respond to this item.

Starch test

The pre-service science teachers were asked to give reasons for the disappearance of starch in a plant's leaf after keeping the plant in a dark cupboard for 48 hours and reappearance of starch after placing the plant in the area exposed to light for another 48 hours. All of percent responses in each category are shown in Table 4.1. Six pre-service science teachers (17%) did not respond to the question, thus their responses were in the no answer category (NA). Only two of them (6%), having scientific understanding, could give the adequate reason for this phenomenon. They noted that plant placing in the dark could not photosynthesize so it used its stored food (starch) in its leaves, and after 48 hours the food in the leaves was used up, so a starch test gave the negative result. Placing the plant in the light enabled it to photosynthesize again. So, the starch was restored and reappeared in its leaves.

The majority (75%) responded part of the reason of those who had scientific understanding (such as plant needed light to make starch, or plant could not photosynthesize without light, or light influenced the production of starch). Obviously, their responses did not demonstrate the whole understanding but partially explain why the starch appeared or disappear in different light conditions. Thus, their responses were categorized as partial understanding (PU). One of them (3%) expressed a specific misunderstanding (SM) that in the dark, starch transformed into sugar, and in the light, sugar transformed into starch.

Showing in responses of this item of seventeen pre-service science teachers (47.22%), they noted that starch or carbohydrate was plant stored food and produced by photosynthesis. As most of these pre-service science teachers had misunderstanding of plant food in the previous sub-item, this could be said that they did not have an adequate understanding of photosynthesis, the plant producing food process, which synthesizes a carbohydrate, glucose. Glucose is stored in a starch form. This demonstrated the memorization of fragments of knowledge in that they could not identity the product of photosynthesis and plant food as the same substance. The similar result was formerly found in Thai secondary students by Kijkuakul and Yutakom (2004) and New Zealand students by Barker and Carr (1989).

Ecology

The pre-service science teachers were asked to decide whether a sealed bottle with water, soil, weeds, and snails from a pond placed exposing to the sunlight was an ecosystem and biological processes occurred. To consider whether it was an ecosystem, a combination of structure, function and interrelationship must be addressed. Structure of an ecosystem refers to abiotic and biotic components found in the ecosystem. Function refers to nutrient cycle and energy flow. Interrelationship is interaction of the structure of the ecosystem resulting in its function. The expected answer was that the sealed bottle was an ecosystem. The appropriate reasons should mention abiotic components and organisms with their niches as structure, nutrient cycle and energy flow as function and interrelationship between environment-organisms and organism-organisms.

Twenty-seven pre-service science teachers (75%) indicated that the given sealed bottle was an ecosystem, while the rest (9 pre-service science teachers, 25%) noted it was not. The pre-service science teachers who noted the seal bottle was not an ecosystem gave the reasons that it lacked gaseous cycles (19%) and there were no decomposers (11%) [6% of them gave both reasons]. These two reasons were specific misunderstanding (SM). Decomposers could be naturally found in pond water. A gaseous cycle could occur because there were some weeds and snails. Carbon dioxide was produced from the organism respiration. The weeds photosynthesized because there were essential abiotic components and light in the sealed bottle. Oxygen was produced from the weeds' photosynthesis. The snails could share the oxygen for their respiration and produced carbon dioxide for weeds' photosynthesis. This finding showed that these pre-service science teachers thought that an ecosystem must not be a closed system. It must contact to an open environment to keep the gaseous and nutrient cycles flow. In addition, an ecosystem must have decomposers.

Twenty-six pre-service science teachers (72%) who answered that the sealed bottle was an ecosystem had partial understanding (PU). They could describe briefly about the structure, function, and interrelationship in the given sealed bottle. For all these pre-service science teachers, biotic components seemed to have more priority than abiotic components in an ecosystem. Twenty-two of them described only the interrelationship between organism-organism in the sealed bottle. Four of them considered an ecosystem as it had organisms living in the same area. The other pre-service science teacher (3%), also answered that the sealed bottle was an ecosystem but did not give reasons to extend her ideas about an ecosystem, thus her response were categorized as no answer (NA).

The subsequent sub-question asked to the pre-service science teachers to determine whether the weeds and the snails could survive in the sealed bottle for one month. Fifteen of them (42%) answered that the organisms could survive. Two main reasons were given for the survival; the organisms in the bottle had all the factors needed for their living (17%), and there were nutrients, energy and gas cycling in the bottle (14%). One of them mentioned that there was organism adaptation to the environment to make them survive in the limited resources. Another noted that food and essential resource were provided; the weed could photosynthesize and the snails ate the weeds. One of them considered that the weeds and snails would survive but was not confident whether the weeds could photosynthesize or not. The other did not give reasons to support the answer.

Eleven of them (30%) answered that the organisms could not survive for a month in the bottle. Five of them noted that there was no gaseous cycling and not enough air in the bottle and six of them specifically mentioned the lack of oxygen in the bottle. Another ten pre-service science teachers (28%) were not sure if the organisms could survive for one month in the bottle. Four of them were not sure that the weeds could produce enough oxygen in the bottle for one month, three of them were not sure that the organisms could be alive without contacting with the air outside the bottle and two considered that the environment in the bottle would decay and could not supply the organisms for the whole month. The other pre-service science teacher noted that surviving for one month was too long but did not give more explanation.

Considering their responses across these first two sub-items discussed above, the majority considered the given sealed bottle as an ecosystem in that they thought it had living organisms and could identify the interrelationship between the organisms. Asking them to consider whether the organisms could survive in the seal bottle for a month, the pre-service science teachers were aware of the sufficient of gases in order to make the organisms survive. Without a contact to the open environment, the first thought of some of the pre-service science teachers, organisms would die due to insufficient of oxygen.

The pre-service science teachers were asked to identify whether there were producers, consumers and decomposers in the given sealed bottles. These niches were expected to be all chosen to appear in the sealed bottle. One pre-service science teacher did not respond to this item. The thirty-five pre-service science teachers (97%) chose producers. Thirty-four of them (94%) chose consumers. Only fourteen (39%) chose decomposers. This meant that twenty-one (58%) thought that decomposers were not found in the bottle. However, all of the pre-service science teachers who chose decomposers also succeeded to identify that all three niches were in the bottle.

Asking whether the weeds in the bottle could photosynthesize or not, the majority of the pre-service science teachers (89%) answered that the weeds could do so. They gave the reason that the weeds received sufficient materials for photosynthesis such as light, carbon dioxide and water. Four pre-service science teachers (11%) answered that the weeds could not photosynthesize because the bottle was sealed in which they could not get carbon dioxide and oxygen (8%) and light could not get through the bottle (3%).

The pre-service science teachers were asked to determine if the weeds could respire in the sealed bottle. They were left a blank to provide their reasons to support their answers. One of them (3%) did not give any response to the question. Seven of them (19%) answered that the weeds could not respire and all of them gave the same reason that there was no oxygen in the bottle. Twenty eight of them (78%) noted that the weeds could respire in the bottle with various reasons. The majority of the pre-service science teachers (31%) answered that the weeds could respire because photosynthesis could also occur. This could be interpreted that they considered respiration and photosynthesis occurred as continuum and related processes. Photosynthesis produced oxygen which could be used for respiration, and the respiration produced carbon dioxide which could be used for photosynthesis. Eleven percent thought it was natural that every organism must respire all time and everywhere. Eight percent noted that the weeds had enough resources provided in the sealed bottle. Eight percent thought there was oxygen in the sealed bottle but three percent thought the weeds could respire for a while then they would stop because oxygen were used up.

Misunderstanding was found in that six percent noted that there was no carbon dioxide, six percent mentioned that respiration occurred only at night, and three percent noted that photosynthesis was the same process as respiration. The ideas that plant respired only at night was previously found in the former item had been confirmed in this item and the misunderstanding was found by Kao and Su (2004) and Sander (1993). The idea that photosynthesis was the same as respiration was also found in the studies by Amir and Tamir (1994) and Eisen and Stavy (1993). Three percent did not give a reason for this item.

In brief, it was found that the biology concepts of the science student who participated in the Laboratory in Biology course in the regular style in the first semester of 2004 academic year were mostly partial understanding. It was also found that the respondent gave more responses the multiple choice questions than open-ended questions and they were likely to give very short reasons to support their answers for an open-ended question. Hence, little understandings were captured thus their responses were categorized as partial understanding. Various misunderstandings were found in every topic. More than twenty five percent of misunderstanding were found in three topics; osmosis, meiosis and ecology. The misunderstandings found in this study were similar to those previously found by many research studies around the world. In addition, some of their given reasons for some items showed a memorization of concepts and fragmental understanding in that they noted correctly about the concepts but their responses were not responded to the questions.

The pre-service science teachers who completed the questionnaire had participated in a fundamental biology course and the Laboratory in Biology course. This study showed that they mostly partially understood basic biological concepts and they were some misunderstandings found. This can be implied that the fundamental biology course and the Laboratory in Biology course did not successful in promoting the understandings in biological concepts.

Understandings in Science Process Skills

The pre-service science teachers’ science process skills were measured by the two items of the science process skill part in the Biology Concepts and Science Process Skills Questionnaire. These two items had a difference in that the first item asked them to design an experiment in a blank with response to a given situation and the second item gave experimental results in graphs and asked them to identify the appropriate question, hypothesis, variables, results in wordings and conclusion. The science student responses are presented and discussed below.

Designing an Experiment

The thirty-six pre-service science teachers were given the situation that each of them was a member of a group of Thai scientists who had invented three medicines that showed potentials to cure the bird flu disease which was a serious outbreak in chickens in Thailand in 2004. Each of them was asked to design an experiment to test the efficiency of these three medicines. The independent variable was already given in the question but they needed to identify the dependent variables and explain their procedure to test these medicines. The question was:

> A group of Thai scientists discovered three new medicines for curing chickens that are infected by bird-fever virus in their laboratory. They would like to test their medicines in a chicken farm. One of the volunteering farm owners has 1,200 infected chickens. If you were a scientist in the group and the other members would like you to propose an experiment to test the medicines, what experiment would you do?
>
> Please write a plan for an experiment to help you find out the efficiency of the medicines.

This item tried to find out how the pre-service science teachers would design an experiment. The expected answer consisted of an appropriate hypothesis, experimental design including steps of procedure, a control group and replications, identification of controlled variables, duration of the experiment, data collection, and the brief explanation of how to make a conclusion from possible results. The design of the expected experiment begins with randomly dividing 600 chickens into 4 groups (resulting in 150 chickens per group) as replication 1. Three groups would be tested by each medicine and the other group was a control group. Each group of the chickens would be fed in separated areas, but each area must have same environment such as same temperature, moisture, ventilation and using same type and amount of chicken food, etc. Then, experiment would be conducted over a proper period of time, for example, one month, to see the efficiency of each medicine comparing to the control group. The data could be collected at the end of each week by counting the number of chickens which survived or died, and a test of chicken health (strength, alertness, color and polish of feathers, etc.) could also be included. The other 600 chickens would be for replication 2 with the same experimental procedure as replication 1.

Thirty-five pre-service science teachers gave response of this item but none of their responses was equivalent to the expected answer. The other student gave no responses to this item. Only three of them (8%) formulated the hypotheses for their experiment. But none could formulate appropriate hypotheses. One of them used a question as a hypothesis: ‘which medicine could cure the infected chickens the best?’. Another noted a prediction as a hypothesis by writing that ‘the chickens in the first group will get well’. This pre-service science teacher did not identify independent variable and the treatment for the first group of chicken elsewhere in her response. The other pre-service science teachers used if-then hypothesis form but she could not make a logical statement. She wrote ‘If these three medicines could cure the chickens, then the three medicines had the efficiency to cure the chickens’.

Thirty-three pre-service science teachers (92%) described their designs of experiments. Their designs included dividing the chickens into 3, 4, 6 and 8 groups and treating each group with different medicines. None of them responses included experimental replication. They proposed five experimental designs which can be presented in Table 4.8 below.

Table 4.8 Experimental designs (Phase I)

(n=33)

Designs	Descriptions	% Responses
Design 1: three - group design	treating each medicine with each group of the chickens	76
Design 2: four - group design	treating each medicine with each group and one control group	12
Design 3: six - group design	treating each medicine with each group and three control groups	6
Design 4: six - group design	three groups in the natural setting, and three groups in a closed area, treating each medicine with each group	3
Design 5: eight - group design	one control group and the other seven groups would be treated with medicine 1, 2, 3, 1+2, 1+3, 2+3, and 1+2+3, respectively	3

From the table above, 72% of the pre-service science teachers proposed the three-group design (Design 1). The design was not appropriate due to a lack of a control group and experimental replication. Design 2, proposed by 12% of them, also was not appropriate because it did not include the experimental replication. Design 3 utilized three control groups and three experimental groups treated by each medicine. One control group was considered appropriate, having three control groups was not necessary. Design 4 separating the chicken into six groups and two different experimental cites were identified; the natural setting and closed area. This could be explained as a Thai chicken industry company announced that their chickens were fed in a closed area and guaranteed that the chickens were disease-free. Experiments in the closed area might illustrate a control of effects of the environment. Design 5, having one control group and seven experimental groups, illustrated the ideas of mixing the medicines to test whether the mixtures could have more efficiency to cure the disease. This might show the creativity but no experimental replication was included.

Three pre-service science teachers (8%) indicated the duration of their experiment and their experiment would be lasted by 2 weeks to 3 months. Eleven pre-service science teachers (31%) identified the controlled variables such as the type and amount of chicken food must be the same and all of the chickens must be fed in the same environment. Two of them (6%) noted that their experiments needed controls but they did not clearly identify what their controls were. Twenty-five pre-service science teachers (69%) noted how they would collect data. Six of them identified that they would count the number of chicken which survived or died and observe the symptoms of the chickens. The other nineteen of them only indicated that data would be collect, without more explanation.

Thirteen pre-service science teachers (36%) noted the word “conclusion” in their responses; only three (8%) identified the means they would draw a conclusion of their experiments by comparing of the efficiency of the medicines; the more number of survived chickens expressed the more efficiency of the medicines, or the medicine which could be able to cure more chickens would have the best efficiency. The other ten pre-service science teachers (28%) only indicated conclusion as the last part of their experiments. Two pre-service science teachers (6%) prepared a table for data collection but it was not appropriate because they both proposed the three - group experimental design which did not include a control group and experimental replication (Design 1).

Specific Science Process Skills

The pre-service science teachers were given a diagram of four graphs indicating the rate of activity of four enzymes in different pH levels (Figure 4.4).

They were asked to identify a question, a hypothesis, variables, results and a conclusion of the experiment. There was one pre-service science teacher answering all of the questions relating to enzyme inhibitors. The first sub-item asked them to identify the question of the experiment. Six of them (17%) identified either expected questions that does pH affect the rate of enzyme activity? or how does pH affect the rate of enzyme activity? The questions which other pre-service science teachers responded were what is the optimum pH of each enzyme? (31 %), what are the pH levels in that enzymes can work? (8%) and what is the pH of each enzyme? (14%). Ten pre-service science teachers (28%) did not respond to this sub-item in a form of question. Their responses were much like the variables or conclusions of the experiment, such as enzymes could function differently depending on pH levels, pH levels affect enzyme activity, optimum pH for enzyme activity and rate of enzyme activity.

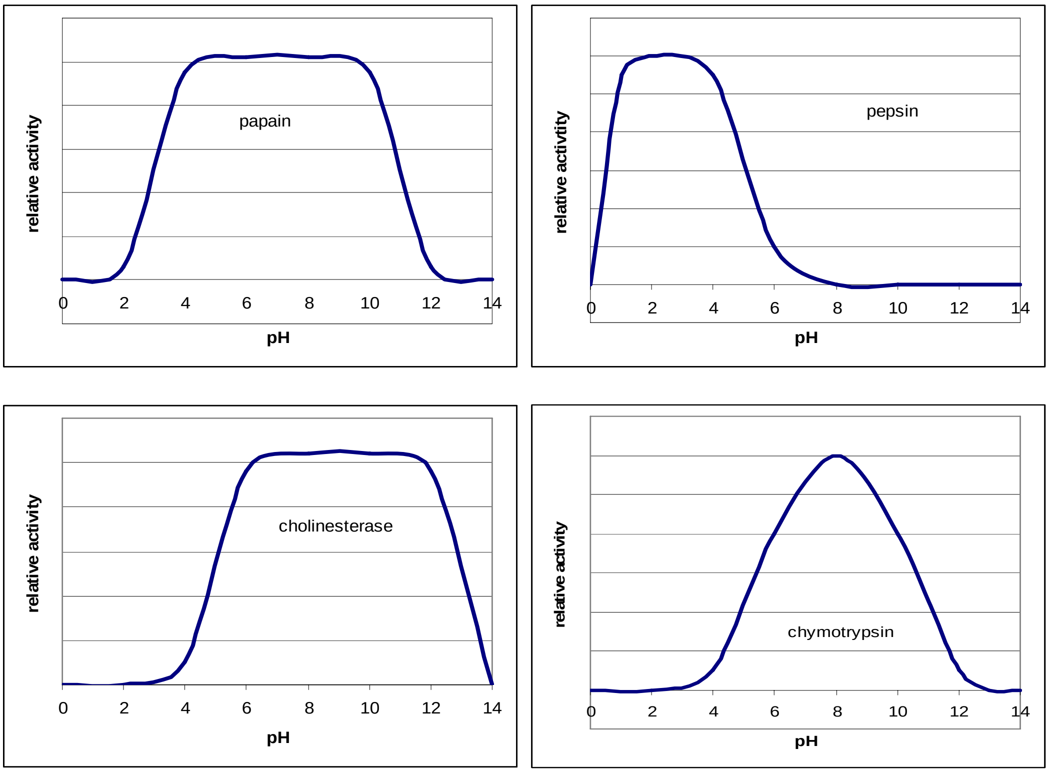

Figure 4.4 Graphs of enzyme experiments

Sub-item 2 asked the pre-service science teachers to formulate an appropriate hypothesis of the experiment. Excluding one pre-service science teacher who gave no response, the majority (24 pre-service science teachers, 67%) formulated their hypotheses that each enzyme has specific optimum pH (53%) and pH affected the rate of enzyme activity (14%). However, other pre-service science teachers indicated inappropriate hypotheses; four of them (11%) wrote that each enzyme had different pH and one of them (3%) wrote enzyme inhibitors affected the pH level. Another four pre-service science teachers indicated the results of the experiment as their hypotheses such as Papain effectively functioned at pH 4-10, pepsin effectively functioned at pH 2-4, cholinesterase effectively functioned at pH 6-12 and chymotrypsin effectively functioned at pH 8'

The pre-service science teachers were asked to identify the independent variables of the experiment in sub-item 3. Twenty-four of them (67%) identified the names of the given enzymes and seven of them (19%) identified the pH. Only one pre-service science teacher (3%) could identify correctly that both enzymes and pH were the independent variables of this experiment. Three of them (8%) did not give identify the dependent variable of the experiment. Eighteen pre-service science teachers (50%) correctly indicated that the rate of enzyme activity was the dependent variable in sub-item 4. Another thirteen of them (36%) noted pH, two of them (6%) noted names of the give enzymes and another two of them (6%) noted the enzymes activity at different pH.

Sub-item 5 asked the pre-service science teachers to identify the controlled variables of this experiment. Most of them identified more than one controlled variables in their responses. The three most frequently identified controlled variables were temperature (42%), the amount of enzymes (39%), and experimental cite (28%). Other controlled variables found in some pre-service science teachers' responses were the concentration of enzymes (14%), concentration of substrates (3%), pressure (3%), and experimental apparatus (3%). However, some pre-service science teachers identified wrongly that pH (22%), time (11%), rate of enzyme activity (6%) and light (3%) as controlled variables of the experiment. However, totally, 53% of them could identify correct controlled variables without the wrong ones. To have a skill at identifying variables, a pre-service science teacher needed to correctly identify all three variables: independent, dependent and controlled. From the responses to subitem 3-5, it was found that only one pre-service science teachers could correctly identify all three variables: It could be referred that this pre-service science teacher was the only one who completely have the skill at identifying variables.

Sub-item 6 asked the pre-service science teachers to identify the results of the experiment. Excluding one pre-service science teacher who did not give a response for the item, their responses could be summarized in five groups as the followings:

- **Group 1**: noting that each enzyme had different optimum pH (33%)

- **Group 2**: noting that each enzyme had different optimum pH in range of acid, or base (not specifying the exact pH values) (25%)

- **Group 3**: identifying optimum pH of each enzyme using the exact pH from the graphs; this group of students can be separated into 2 sub-groups

Sub-group 3.1: correctly identifying optimum pH of each enzyme from the graphs (19%)

Sub-group 3.2: incorrectly identifying optimum pH of each enzyme by identifying the range of pH values in which each enzyme could function (11%)

- **Group 4**: explaining the shapes of the graphs (6%)

- **Group 5**: noting that some enzymes could work fast and some could work slowly (3%)

Hence, the responses Group 1, 2 and 3.1 were correct answers with different depths of interpreting the results from the given diagram (total = 78%).

In sub-item 7, the pre-service science teachers were asked to draw a conclusion. Twenty-seven of them (75%) could conclude the results correctly that enzymes could work effectively at different pH. Four pre-service science teachers (11%) concluded that pH caused different rates of enzyme activity. Other five pre-service science teachers responses were; each enzyme had different optimum pH in ranges of acid, or base (3%), two enzymes (papain and cholinesterase) yielded similar results (as seen from the shapes of the graphs) and the other two yielded different results (3%), each enzyme had different pH (3%), and each enzyme could function differently with enzyme inhibitors (3%). The other pre-service science teacher (3%) gave no responses to the item.

Table 4.9 Percent correct responses to specific questions for science process skills (Phase I)

(n=36)

Science Process Skills	% Correct Responses
Posing questions	47
Formulating hypotheses	67
Identifying independent variables	3
Interpreting the results	78
Drawing a conclusion	75

From the table above, the majority of the pre-service science teachers could give correct answers for formulating hypotheses, identifying controlled variables, interpreting the results and drawing a conclusion. About half of them could correctly identify the dependent variable of the experiment and provide appropriate questions for the experiment. Very few of them could identify the independent variable.

Giving a blank for them to write down their experimental plans, none of them posed questions and formulated appropriate hypotheses for the experiment. Most of them were likely to start at the steps of procedure. These could reflect a flaw of guided inquiry, could be seen in the old series of IPST textbooks. These textbooks were widely used in science classes in the secondary school level before Thailand learning reform in 1999. By guided inquiry, students came up with questions to testify by questioning or introducing by teachers. Then, all of students followed predetermined steps of procedure to get experimental results. The last step of procedure in the textbooks was to record the experimental results and draw a conclusion. Enabling students to focus on the correct types of results, teachers needed to ask questions and highlight the expected outcomes which students would get from doing experiments. Then the class discussed to draw a conclusion, and answered post-lab questions. The correct experimental results were likely to guided by, or come from, the teachers.

The findings of pre-service science teachers posing of questions and formulating hypotheses for an experiment in this study can be discussed in two ways. Firstly, for students, questions and hypotheses seemed less important. As the science activities always asked students to conduct experiments according to steps of procedure after questions and hypotheses had already been shown to them. This makes science experiments seem to begin at the procedures. Secondly, to identify questions and testable hypotheses were ignored by teachers for reducing time in teaching due to many student ideas which could be introduced in the class and needed more time to justify the appropriate ones. One possible way to solve the problem about time constraint is to give students clear and simply science (Nott and Wellington, 1996). Providing ready-to-test questions and hypotheses and ask students to conduct scientific experiment following steps provided seem to relieve the constraint.

Replication is important in doing experiments but had not found in any responses. Activities in IPST textbooks do not always ask students to repeat the experiments because every group in the class does the same experiment. Each group counts as one replication. Unsurprisingly, not having replications in experiments could to be excluded from student own experimental designs.

The majority of students did not identify how they would collect and interpret their experimental results and draw conclusions. In the old series of IPST textbooks, the last two steps of doing an experiment are 'collect the data' and 'draw a conclusion'. Undoubtedly, some students copied these steps and responded in the questionnaire without explaining 'what data to collect' and 'what evidence' which they would consider to conclude the results. This finding is consistent with a study by Germann and Aram (1998) with American students. They found that the majority could not provide specific evidence for their conclusion. Possibly, from student learning experiences, teachers did not give enough time and opportunities to students to think about how to deal with these two steps and also directly tell them the most effective way to do so.

Providing specific questions related to science process skill, they could respond better than giving them a blank. The majority could give appropriate responses for identifying hypotheses and controlled variables, interpreting the results and drawing a conclusion. The only skill in which they seem to have more difficulties was identifying independent variable. Most of the students identified only one independent variable; about two thirds identified enzymes and one fifth identified pH. But this experiment has two independent variables, pH and enzymes. This showed that the majority thought an experiment could have only one independent variable. These students who identified only one independent variable, enzymes or pH, put the other as dependent or controlled variables. Only one six of the students could pose expected questions for the experiment. However, another eleven students brought their conceptions of optimum pH in their experimental questions, which were also counted as appropriate.

It was obvious that students' conceptions about enzymes had been shown in their responses. The majority could identify correct hypotheses, results and conclusion of the experiment. Many of them introduced optimum pH since they wrote their hypotheses. The term 'optimum pH' could also be emerged in the conclusions after they found the pH values or pH ranges which the four enzymes could function most effectively. Having the term 'optimum pH' in their hypotheses demonstrated their correct science concepts about enzymes. Their responses of controlled variables also demonstrated their scientific concepts of factors affecting an enzyme activity such as temperature, concentration of enzymes and substrates.

Learning experiences also showed a strong effect in responding to the questionnaire by one student. This student responded all of the questions in item 10 with the idea that enzyme inhibitors were added into the experiment. Factually, the given experiment in this item does not refer to any inhibitors. But all of the students had learned and carried out two experiments about enzyme inhibitors when they learning in the fourth week in the Laboratory in Biology course. It was more likely that the student had a very strong experience of learning in enzyme inhibitors and responded to the items and interpreted the questions according to his understanding.

Overall, the findings of student science process skills in this research are quite similar to a study with Jamaican students by Beaumont-Walters and Soyibo (2001).

They found that the Jamaican students could perform better in interpreting data than formulating hypothesis and identifying independent variables. Implications of this study suggest explicit teaching of integrated science process skills (Germann, *et al*. 1996). It was found that after students are engaged in science activities with the explicit teaching of science process skills, their competency can be increased (Roth and Roychoudhury, 1993; Tobin, 1986). Teaching of science following the old series IPST textbooks had already succeeded in promoting student ability to interpret data and draw conclusions by explicit teaching of these skills. It is necessary and potential to promote other science process skills in which students lacked such as posing questions, identifying independent variables and designing experiments by explicit teaching of these skills.

Understandings in the Nature of Science

In this section, the views on the nature of science of the thirty-six first-year pre-service science teachers, who responded to the Views of Nature of Science Questionnaire, are presented and describe. These pre-service science teachers were asked to explain their views towards 13 given statements about science. The pre-service science teachers' views on the nature of science are presented in four main aspects; definition of science (Item 1 and 2), characteristics of scientific knowledge and methods (Item 3, 4, 5, 6 and 9), characteristics of scientists (7, 8, 10 and 11) and influence of science and society (Item 12 and 13), as the followings.

Definition of Science

Item 1: Science is a body of knowledge, such as principles, laws, and theories, which explain the world around us (matter, energy, and life).

When defining what science is, product and process of science should be informed. Observation, experiments and thinking processes are viewed as processes of science. The statement of Item 1 presents the view of science as a product which is only part of the definition of science. Twenty-one pre-service science teachers (58%)

agreed with the statement and extended their science as a product, such as ‘Science is whatever that is logically explained’ and ‘Science is an academic subject’. Four of these students also expressed the views of science as a truth in which they responded that ‘science is whatever that is true’. Other fifteen pre-service science teachers (42%) viewed science as both a process and a product which could be capture from their responses that ‘Science also related to scientific methods and experiments’ and ‘Science also related to thinking processes.

Item 2: Science is exploring the unknown and discovering new things about our world and universe and how they work.

The pre-service science teachers responded variously in this item. The majority of them (44%) responded that science was for ‘seeking of new knowledge’ and ‘improving existing knowledge’. Six of them (17%) noted that science is related to ‘development’. Five of them (14%) noted that science was for ‘benefit of humankind’. Four of them (11%) explained that science was from ‘human curiosity’ and three of them (8%) described science as ‘a continuous process’. Two pre-service science teachers (6%) did not give responses for this item.

In brief, science was views as a product by the majority half of the pre-service science teachers. Item 1 revealed their agreement that science was a product by about sixty percent of them. About forty percent of the pre-service science teachers obviously showed the idea that science was both product and process and explained in their reasons. Item 2 was to probe if they had the idea that science as a process, but it showed the pre-service science teachers’ ideas of what science was for or the aims of scientific activities; they thought science could produce the better knowledge and development for humankind.

Characteristics of Scientific Knowledge and Methods

Item 3: Science can investigate the supernatural and can possibly explain it.

Ten pre-service science teachers (28%) agreed with this statement and extended that scientific experiment could do so. One respondent in this group indicated that 'Science could explain everything'. Others (72%) gave the opposite opinion. Six of them (17%) disagreed with this statement and provided reasons that 'the supernatural could not be explained by science because it was unsure and illogical'. Sixteen pre-service science teachers (44%) expressed the views of the beliefs which indicated the limitation of science that 'Many things are still not provable such as ghosts and spirits.' Another four pre-service science teachers' (11%) responses showed that they believed that the future progression of science would make the explanation of the supernatural become possible.

Item 4: Science is understandable.

Thirty-five pre-service science teachers (97%) agreed with this statement. Twenty of them asserted that science was from human understanding; reasoning, thinking process and experiments; seven indicated science was everything around them and three noted that science related to concrete and absolute facts. The other four who also agreed with this statement considered the effects of positive attitudes toward science and intention; the one with a positive attitude and paid enough intention for science would make the person understand it. One pre-service science teacher (3%), responding that 'Some topics in science are hard to understand and have ambiguous assumptions', demonstrated an unsure position. The other did not give response for this item.

Item 5: Scientific knowledge has always changed with time.

Thirty-five pre-service science teachers (97%) agreed with the statement and gave more explanation that ‘science can change with better verified explanations’ (61%), ‘science can change by proving that existing explanations are not accurate’ (17%) and ‘science is not stable, new knowledge and theories can change’ (19%). The other (3%) did not give response for this item.

Item 6: The scientific method ensures valid, clear, logical, and accurate results.

Seven pre-service science teachers (19%) believed that this statement was true and assert their own opinions that ‘when we do experiment correctly and carefully, follow theories; (11%),‘a scientific method can produce same results when we repeat it, then we can have a theory’ (6%) and ‘science can be in accurate mathematic equations’ (3%). Twenty-six pre-service science teachers (72%) thought scientific methods could not always give accurate results because of errors (56%), production of varied results which could make science change (8%), inappropriate underlying theories, hypotheses and conclusion (3%), subjectivity of interpreting the data (3%) and being accurate for everything (3%). The other three (8%) did not express their views about this.

Item 9: Some scientific discoveries are made by accident.

Thirty-three pre-service science teachers (92%) thought this statement was true. Sixteen of them gave examples of accidental scientific discoveries about the law of gravity by Newton and the discovery of Penicillin by Alexander Fleming. Ten of them did not give more explanation but repeat the give statement in their own words. Four of them asserted that the accidental discoveries needed more verification and three of them noted that scientists’ recognition and curiosity played a role in scientific discoveries. One pre-service science teacher did not agree by indicating that ‘scientific discoveries are from thinking processes rather than an accident’ (3%). The other two (6%) did not give response for this item.

In brief, the pre-service science teachers had appropriate views on the characteristics of science, scientific knowledge and methods. The viewed that science was understandable, changed with time, could not explain everything, could not always ensure accurate results and could be made by accident. High percentage of the appropriate ideas was shown in every aspect and some aspects were appropriately responded by more than 90% of them. This demonstrated their good understanding of the nature of science in this aspect.

Characteristics of Scientists

Item 7: The main motivation of scientists is to satisfy their curiosity.

The pre-service science teachers indicated three views of motivation of scientists; self, society and both self and society. Twenty-five of them (69%) thought that own curiosity motivated scientists to continue working. Responses of three of them (8%) could be inferred that scientists worked for the society, benefits of the majority and country development. While five (14%) believed that scientists worked for themselves as well as the society. The other three (8%) did not express their views about this.

Item 8: Scientists can use imagination and creativity to get results.

Thirty pre-service science teachers (83%) agreed with this statement. Twenty of them gave examples or repeated the given statement. Ten of them thought that imagination and creativity were only part of scientific activities, the examples of responses were ‘scientists use imagination and creativity for something, but something they do not’ (8%) and ‘imagination and creativity is part of science but the results must be proved that they are true’ (11%). However, five of them (14%)

thought that scientists must use facts from experiments to get the results. The other (3%) did not give response to the item.

Item 10: It’s part of a scientist’s job to ensure that no harm comes from discovery.

Thirteen pre-service science teachers (36%) agreed with this statement. Responses of six of them repeated the statement and three of them noted that if a discovery could cause more damage than benefit, scientists would not continue their work. Another three indicated that it depended on individual scientist; some scientists did not consider moral values and tried to discover anything they wanted. The other thought that scientists should present only knowledge that can produce benefits to people. Equally, thirteen of the pre-service science teachers believed that it was not part of scientists’ job to ensure no harm from their discovery. Five of them thought that it depended on the ones who used the discoveries (14%), or other people not scientists themselves (8%). Three of them (8%) indicated that some scientists discover things that cause damage such as nuclear weapons. One of them (3%) noted that it was good to present knowledge which could potentially cause damage because people would know and prepare for it. Also, one of them agreed that scientists presented their discoveries even they could cause damage.

Nine of them (25%) did not identify who would be responsible for potential harms from discoveries. Three of them (8%) expressed their opinions about morality of using discoveries such as ‘scientific knowledge should use only for benefits’ and ‘something should not be researched or experimented’. Five of them (14%) noted that any discoveries could both be benefit and damage. One of them expressed the idea that ‘scientists do not know what discoveries can cause damage, they have to do experiments first’. The other (3%) did not give response to the item.

Item 11: Scientists are logical, objective, unbiased and open-minded.

Twenty-seven pre-service science teachers (75%) agreed with this statement but did not extensively explain their ideas. Eight of them (22%) thought minority scientists held a strong belief of own ideas and bias and did not accept ideas of others'. The other (3%) did not give response to the item.

In brief, the majority of the pre-service science teachers' had appropriate views on the characteristics of scientists. They viewed that scientists were motivated by their own curiosity. They believed that imagination and creativity played part in scientific discoveries. They expressed that it was not a scientist' job to ensure that no harm comes from discovery, but morality played part in their work in that scientists should not do anything which could produce harms to the society. The also believed that the majority of scientists were logical, objective, unbiased and open-minded.

Interrelation of Science and Society

Item 12: Personal feelings and moral values have no bearing on scientists' decisions.

Nine pre-service science teachers (25%) expressed their ideas that feelings and values did not influence scientists' decisions. Five of these pre-service science teachers (14%) repeated the statement in their own words. Four of them (11%) explained that 'scientists must always consider truths' (6%), 'values cannot be verified, so they cannot be part of scientists' decisions' (3%) and 'scientists make decision from evidence, not values' (3%). Responses of twenty-four of them (67%) could be inferred that they believed that feelings and values influenced scientists' decisions. The examples of these responses were; 'scientists do not do anything against social values and morality' (8%), 'scientists must consider other people's feeling, and ideas' (8%), 'decisions are based on prior ideas' (6%) and 'scientists are human; each of them has different feelings and values that shape his decisions' (3%). Eight of them (22%) thought that feelings and values occasionally influenced scientists' decisions. Example of these response were; 'feelings and values play role in some decisions' (11%), 'it depends on individual scientist' (6%), 'some experiments need to kill animals, but scientists think it is not against morality, they think the killing is for discovery of knowledge' (3%). The other three (8%) did not explain their views.

Item 13: Society influences the direction of scientific discoveries.

Thirty-one pre-service science teachers (86%) agreed with this statement. Twelve of them indicated that scientific discoveries were produced according to demands from the society. Seven of them noted that direction of science must be accepted by the society, tradition and beliefs of people in the society. Six of them asserted that direction of science was supported by the society. Four of them expressed the ideas that direction of science depends on the characteristics of each society and two of them noted that the demand and change in the society make development in science. Two of them (6%) thought the society maybe influence the direction of scientific discoveries in which they responded that 'the change of society may produce new scientific discoveries' and 'some scientists do not need money support from society'. However, another two of them (6%) did not think that the society had any influence to science by asserting that 'science is truth and neutral which cannot determined by society' and 'the majority of scientific discoveries are opposite to societal view'. The other pre-service science teacher did not respond to the statement.

In brief, the majority of the pre-service science teachers thought personal feelings and moral values had an effect on scientists' decision. They expressed that to make decision, scientists always considered moral values and personal feelings. In their views, scientists tended to include scientists' personal feelings in their work and did not create the discoveries which were against the morality. Most of the pre-service science teachers also believed that the society influenced the direction of the scientific discoveries in that the discoveries must be accepted by the people in the society and required as the demand of the use in the society.

Overall, pre-service science teachers who responded to this questionnaire mostly had appropriate views of nine aspects of the nature of science. These aspects are (percentage in the parentheses are of the responses' with appropriate views):

- science cannot explain the supernatural (72%),
- science is understandable (97%),
- science can change over time (97%),
- scientific methods cannot always provide valid, clear and logical results (72%),
- scientific discoveries can be from accident (91%),
- scientist's curiosity mainly motivates them to do their work (69%),
- imagination and creativity can be used to get results (83%),
- scientists are logical, objective, unbiased and open-minded (75%) ,
- personal feelings and moral values have influences in scientists' decision making (66%),
- society influences the direction of scientific discoveries (86%).

Inappropriate views, held by more than 25% of the pre-service science teachers, were also found in some aspects in that science is views as a product or a body of knowledge, possible harms from scientific discoveries must be responsible by scientists who discovered them, personal feelings and moral values have no bearing on scientists' decision making. Additionally, the details of findings in this section were also found consistent with previous research studies.

Viewing science as a product or a set of ideas by more than half of the students is consistent with many previous studies (Bloom, 1989; Abell and Smith, 1994; Eick, 2000; Gess-Newsome, 2002; Gustafson and Rowell, 1995; Murcia and Schibeci, 1999; Rubba and Harkness, 1993; Sutherland and Dennick, 2002). About two fifths of the pre-service science teachers defined science as a process but in combination of a product. This is also consistent with the finding by Abell and Smith (1994) in that the responses mentioned processes of science were mostly found in combination of other aspects of science. The idea that science is a subject or topics to be learned was previously found by Gess-Newsome's (2002).

The idea that science is for new development are consistent with the findings of the study by Bloom (1989). Viewing science as benefit of mankind was previously found in studies by Bloom (1989) and Tairab (2001). This study found that some of the pre-service science teachers thought scientists did not take feelings and values in account to their decision making was familiar with a finding by Leach *et al.* (1997).

Abd-El-Khalick (2005) found that some preservice secondary science teachers thought that scientists could use creativity and imagination in their work. In addition, Murcia and Schibeci (1999) found that the majority of primary science teachers in their study expressed the conception of creativity playing some part, and somehow limited, in scientific endeavors. Both findings are consistent with the findings of this study. Some pre-service science teachers, in this study, noted that creativity and imagination could play no parts in scientific work. This idea is also consistent with a finding by Abd-El-Khalick and BouJaoude (1997) and Akerson, *et al*. (2000).

Most of the pre-service science teachers, in this study, had the appropriate view about science and society. They agreed that the society influenced the direction of science. The ideas that science is influenced by the society in that ‘science followed societal demands’ and ‘scientific discoveries must be approved by the society’ were previously found by Sadler *et al*. (2004). In the study, high school students in USA expressed their ideas that economy and other societal factors such as religion and beliefs had influences on science. Very few pre-service science teachers in this study noted societal factors play no roles in the direction of scientific discoveries. This idea is consistent with the finding from the majority of the samples in the study by Abd-El-Khalick (2005).

One part of the findings was found inconsistent with many research studies (Abd-El-Khalick, 2005; Eick, 2000; Murcia and Schibeci, 1999; Pomeroy, 1993). These studies found that most of preservice and inservice science teachers thought that science did not tend to be tentative. But all of the pre-service science teachers responding to this questionnaire excluded the one who did not give a response, thought that science can change with time.

Many research studies of pre-service science teachers' views of the nature of science found that they mostly had inappropriate views. This study found that the majority of the respondents had appropriate views on the nature of science. The possible learning experience which could promote the nature of science conceptions of Thai pre-service science teachers is learning about the history of science through Thai science textbooks in secondary level, written by IPST, such as the experiments related to photosynthesis by Van Helmont, development of the evolutionary theories by Lamark, and Darwin and genetic experiments by Mendel. In the Laboratory in Biology course, it presents a story of the discovery of enzymes. These scientific experiments and stories highlight some aspects of the nature of science, such as tentativeness of science, and characteristics of scientists. Stories of the discoveries of Penicillin by Alexander Fleming and gravity by Isaac Newton are also famous and widely taught in primary and secondary level.

Attitudes towards Biology

In this section, attitudes of thirty-six pre-service science teachers who participated in the regular course are presented and discussed. Their attitudes were measured by the Attitude toward Biology Inventory after learning in the first semester of 2004 academic year. This inventory, having 20 items, measured three attitude areas; biology (8 items), laboratory learning (6 items) and the Laboratory in Biology course (6 items). The result is shown in Table 4.10. It was found that, generally, the pre-service science teachers indicated positive attitudes (score range = 3.51 - 4.50) toward all three attitude aspects. For attitudes toward biology, biological knowledge was viewed as important and useful for solving everyday life and for country development. They believed that they could use biology in their real life and everyone benefits in having biological knowledge. In addition, biology subject is not very difficult for them. Only one statement had relatively low score, showing less positive attitudes; biological knowledge is as a serious cause of many world problems. This illustrated negative views of application of biological knowledge.

Table 4.10 Attitude towards biology (Phase I)

(n=36)

Items	Statements	Mean	SD
	Attitudes towards Biology		
1	Biology is useful for solving problems in everyday life.	4.19	0.58
2	Biological knowledge is important for a country's development.	4.36	0.64
3	Biology is difficult when it involves handling apparatus.*	3.00	1.1
5	Every citizen must have biological knowledge.	3.83	0.85
8	Biological knowledge is the cause of many of the world problems.*	2.53	1.06
14	People who understand biology are better off in our society.	3.78	0.83
15	I would like to have fewer biology lessons.*	3.31	0.92
17	I cannot use biology for my real life.*	3.72	0.94
	Average	**3.59**	
	Attitudes toward Laboratory Learning		
6	It is useless to do experiments in biology.*	4.53	0.56
7	I would rather agree with what other people say than do an experiment to find out the information for myself.*	3.86	0.80
10	Doing experiments is enjoyable.	4.33	0.68
12	Doing biology experiments helps me learn more than finding out information from instructors.	3.92	0.91
13	I think doing biology experiments is boring.*	4.14	0.53
18	I feel uncomfortable doing biological experiments by myself.*	2.89	1.12
	Average	**3.95**	
	Attitudes toward the Laboratory in Biology course		
4	Laboratory in Biology course is a difficult subject.*	3.08	1.02
9	There are too many facts to learn in the Laboratory in Biology course.*	3.17	0.88
11	I like learning in Laboratory in Biology course.	3.86	0.80
16	Laboratory in Biology course helps me understand biological concepts.	4.14	0.54
19	Learning in Laboratory in Biology course helps me have more confidence to use scientific methods.	4.06	0.58
20	Learning in Laboratory in Biology course helps me have more confidence to use scientific apparatus.	4.22	0.64
	Average	**3.76**	

Score 1 means disagree and score 5 means agree

*Negative statements, use inverted score: low score indicates agreement with the statement

Pre-service science teachers also had positive attitudes toward laboratory learning. They thought doing laboratory is useful and enjoyable. They valued in doing experiments to answer their questions rather than ask from other people. They also agreed that experiments would help them learn more than instructor's teaching. Even they experienced laboratory learning as enjoyable but in doing laboratory activities individually would possible make them uncomfortable. This was revealed by one of the items in this aspect which produced relatively low score. The Laboratory in Biology course was found to be favourable, and useful to help the pre-service science teachers understand biological concepts and promote the confidence to use scientific methods and scientific apparatus. This course was also not very difficult for them.

The thirty-six pre-service science teachers who gave responses to the Attitude toward Biology Inventory had positive attitudes toward biology, laboratory learning and the Laboratory in Biology course as the results shown in eighteen items. Results of two items from the inventory expressed pre-service science teachers' uncomfortable feelings in conducting an experiment individually and their negative views of using biological knowledge which could possibly be an important cause of many world problems. Considering SD values, both items had relatively high value comparing to other items (more than 1.0). This indicated that the ideas were divergent among the pre-service science teachers, not all, but some of them had relatively less positive attitudes toward these two statements.

Summary of Chapter IV

This chapter presented and discussed the results of phase I which is an exploratory phase aiming at finding out the pre-service science teachers' learning outcomes from the existing practice of the Laboratory in Biology Course. These learning outcomes covered biological concepts, understanding in science process skills, understandings in the nature of science and attitudes towards biology. The data were collected from 36 pre-service science teachers after they had participated in the Laboratory in Biology course in the regular practice in the first semester of 2004 academic year.

It was found that most of the pre-service science teachers had partial understanding of most of the biology concepts and misunderstandings were found in every concept. For understanding in science process skills, the results showed that they had better skills in interpreting data and drawing a conclusion than formulating hypotheses, identifying variables and designing an experiment. Most of the pre-service science teachers had appropriate views on the nature of science in most aspects. They all had positive attitudes towards biology, laboratory learning and the

Laboratory in Biology course. The findings of this phase were utilized in the development of the instructional set for the Laboratory in Biology course which is discussed in the next chapter.

CHAPTER V

DEVELOPMENT OF THE INSTRUCTIONAL SET

Introduction

This chapter detailed the development process of an instructional set for the Laboratory in Biology course for first-year pre-service science teachers. The instructional set was developed based on a learner-centred approach according the guidelines in Thailand National Education, Act, 1999, a review of related documents and research reports, and the finding of the exploratory phase. It aimed at providing learner-centred teaching and learning atmosphere and promoting first-year pre-service science teachers' understandings in biology concepts which all students were regularly required to achieve in the Laboratory in Biology, along with science process skills, understandings in the nature of science, and positive attitudes towards biology. Steps of the development process of the instructional set are shown in the followings

- Generating the guiding principles
- Analyzing the course's laboratory manual
- Setting out learning outcomes to be achieved
- Designing teaching, learning and assessment activities and instructional materials
- Reviewing the instructional set by experts
- Evaluating the instructional set by science educators and experience biology instructors who taught the Laboratory in Biology course
- Revising the instructional set before implementation
- Adjusting the instructional set during the implementation

The instructional set for the Laboratory in Biology course was developed by these eight steps. Details of each step are discussed in the following sections.

Generating the Guiding Principles

To develop the instructional set, guiding principles were generated from the guidelines for a centred-learner teaching and learning in Thailand National Education Act, 1999, a review of related documents and research reports, and the finding of the exploratory phase. These principles were taken into consideration to design the teaching and learning activities in the instructional set for the Laboratory in Biology course. There were four guiding principles for the instructional set as described below.

Understandings in Biological Concepts, Integrated Science Process Skills, the Nature of Science and Positive Attitudes towards Biology Are Important Learning Outcomes in Science

As mentioned in its Section 23, Thailand National Education Act, 1999 focuses on different learning outcomes. It highlights that learners must achieve to acquire scientific knowledge and skills for pursuing their careers. This can be referred that, in a biology subject, pre-service science teachers need to develop their knowledge in biology, the nature of science and science process skills. Positive attitudes towards the subject are signified in that the act regards learners as the being most important personnel in the learning process and instructors are responsible for providing teaching and learning activities in line with the learner's interests and enabling them to develop themselves at their own pace and to the best of their potential. The literature review of this study also showed that it is essential to promote these four learning outcomes, briefly discussed as following.

Possessing of correct biological concepts is undeniable one of the learning outcomes in biology and it could be said that most teachers pushed the majority of their attempts to help their students achieve this outcome. However, the literature review shows various misunderstanding in basic biology concepts held by students (e.g. Halsam & Treagust; 1987; Simpson & Marek, 1988; Eisen & Stavy, 1993;

Sander, 1993; Odom, 1995; Leach *et al.*, 1996a, 1996b; Kao & Su, 2004) and teachers themselves (e.g. Douvdevany *et al.*, 1997; Mak *et al.*, 1999; Yip, 1998).

Science process skills can enhance learners' development of understanding in science by testing their initial ideas via a scientific investigation, interpretation and judgment of evidence (Harlen, 1992). Previous research studies also showed that students were likely to have difficulties in science process skills which are related to intellectual and reasoning skills. Hence, the instructional set had a main concern in the promotion of integrated science process skills: formulating hypotheses, identifying variables, experimenting, interpreting data and drawing conclusions.

Understanding of the nature of science includes values and assumptions which explain 'what science is' and 'how science works'. It could enhance learners' scientific literacy including understanding of content, values in science and ability to make decisions about science issues (Driver *et al.*, 1996; McComas *et al.*, 1998). The nature of science was explicitly cooperated in Thai science standard for basic education in 2003 in which it could be said that it is quite new for both Thai teachers and learners. The literature review showed divergence in giving the meaning of the nature of science. However, it suggested a consensus in four aspects: definition of science, characteristics of scientific knowledge and methods, characteristics of scientists, and interrelation of science and society.

Having positive attitudes towards science is another desirable outcome in science learning. It was found that students who passively learned in the laboratory via a traditional approach had lower positive attitudes towards science (Okebukala, 1985; Gardner & Gauld, 1990; Shepardson & Pizzini, 1993; Russell & French 2001). From previous research studies, positive attitudes towards biology could be developed by engaging students in the joyful, meaningful and challenging activities such as open-ended inquiry, personal initiation, self-directed and problem-solving activities (Lazarowitz & Tamir, 1994; Zion *et al.*, 2004).

The results presented in Chapter 4 of this study showed that the 36 first-year pre-service science teachers' understanding in biology were found as partial understandings in most biology concepts. Their misunderstandings were also captured in every biology concept. Also, the majority of the pre-service science teachers could do better in interpreting results and drawing conclusions than other integrated science process skills. Hence, the teaching and learning activities in the instructional set for the Laboratory in Biology course must essentially be included the laboratory activities in which pre-service science teachers had opportunities to develop better understanding in biological concepts and integrated science process skills. Although, Chapter 4 showed that the pre-service science teachers had appropriate understandings in the nature of science and positive attitudes towards biology. The laboratory activities must also provide opportunities for the pre-service science teachers whom participated in the second phase of the study to promote the understanding in the nature of science and positive attitudes towards biology as these two learning outcomes were primarily required for every science subject.

Learner-Centred Teaching and Learning Has a Basis on Social Constructivism

The guidelines in Thailand National Education Act, 1999, had emphases corresponding to social constructivist perspectives as discussed in Chapter 2 of this study. For social constructivist, prior knowledge is important for learners in learning new knowledge. The teaching and learning in the instructional set included the activities to find out pre-service science teachers' prior knowledge of biology concepts, science process skills and the nature of science. The teaching and learning activities are based on the social interaction activities such as thinking in pairs, in groups, sharing of ideas, presentations and discussions. Group work is considerably cooperated in the learning process. The instructor is the creator of the active, challenging and collaborative learning environment and scaffolds learners' thinking skills.

Formative Assessment Is a Strategy to Enhance Pre-Service Science Teachers' Laboratory Learning

Formative assessment takes place during the teaching and learning activities and provides both teachers and learners information for decisions about the next steps in learning. Harlen (1998) suggested that formative assessment can effectively be used to assess learners in the laboratory learning. Formative assessment includes observing students including listening to how they describe their work and their reasoning, questioning using open questions, setting tasks of them to perform certain skills and asking students to communicate their thinking through drawings, concept mapping and writing. Instructor's feedback can help learners to improve their work. Rating scales and checklists are also tools for formative assessment.

The Understanding in the Nature of Science and Science Process Skills Are Best Taught By an Explicit Teaching Approach

Science process skills can be developed by practice and needed to be made explicit by the teacher. Tamir (1989) argued that learners could not automatically understand the concepts underlying the integrated science process skills when they engage in laboratory activities. The instructor is the key person who, by explicit teaching of the skills, helps learners to understand and use the skills in laboratory activities. Roth and Roychoudhury (1993) also found that most learners showed a lack of understanding of science process skills in early lessons, but their integrated science process skills developed after they had opportunities to participate in activities in which those skills were obviously taught.

The explicit teaching approach for learners' understanding of the nature of science was highly signified by the work by Lederman (1998; 1999) and Lederman and Abd-El-Khalick (1998). Teaching the nature of science through the explicit approach has also been suggested and successfully implemented by other science educators (Clough, 1998; Wellington, 1999; Colburn, 2004). In explicit teaching of the nature of science, the instructor provides opportunities for learners to explain their beliefs about science, reflect on and justify their ideas and not simply accept what the instructor say (Matthews, 1997). Colburn (2004) suggested that explicit teaching about the nature of science could also be enhanced by directly asking questions about the aspects of nature of science being focused and asking learners to reflect on their thinking about doing laboratory activities. Clough (1998) recommended that the nature of science could be discussed explicitly in post-lab discussions as well as through student reflection on their experiences in laboratory journals.

The instructional set for the Laboratory in Biology course was developed based on these four guiding principles. However, the instructional set needed to also help the pre-service science teachers to achieve the existing learning outcomes set up by the department. The instructional set then needed to follow the same content as the existing laboratory manual. The next step was to analyze the course laboratory manual and find out the points where the guiding principles could be applied to activities in the instructional set. This is discussed in the following section.

Analyzing the Laboratory Manual of the Laboratory in Biology Course

This step was to investigate the features of the course's laboratory manual to get information for designing the instructional set. This step signified that it should be different laboratory manuals for instructors and students. The instructor manual should provide lesson plans and clear learning objectives. The student manual should be revised. The reasons are discussed as the following.

It was found that Laboratory in Biology course Manual (2005) was served as both instructors' and students' manual at the same time. Considering the objectives presented in the laboratory manual, there were 50 objectives aiming at teaching for understandings in biological concepts. Most of the objectives were unclear as they began with 'to know' and 'to study', for example, to know types of microscopes, to know structure and function of ecosystem, to study microorganisms around us, and to study factors which affect rate of enzyme activity, etc. These objectives did not inform how an instructor would teach students to know, or to study. The instructional set was designed to include lesson plans for instructors with clear learning objectives. The Outline of sections depicted traditional laboratory teaching and learning. In each lesson, there were sections on content knowledge, a list of chemicals and apparatus, a list of the laboratory activities to be done, in chronological order. The biological concepts and information with most of the laboratory results were presented before the laboratory activities. A concern on a learner-centered based teaching and learning, the laboratory manual for first-year pre-service science teachers needed to be revised.

Setting out Learning Outcomes to be Achieved

The instructional set was aimed at promote four learning outcomes: understandings in biology concepts, science process skills, understanding in the nature of science, and positive attitudes towards biology. Table 5.1 presents all focused learning outcomes. Once, learning outcomes were set out, the subsequent step was to design teaching and learning activities, assessment strategies and choosing appropriate instructional materials which are discussed in the next section.

Designing Teaching and Learning Activities, Assessment Strategies and Instructional Materials

The teaching and learning activities had been adapted from many sources such as the existing activities in the laboratory manual, science education websites and the researcher's initiation. Various teaching and learning activities based on social constructivist perspectives were incorporated in the instructional sets, including practical laboratory activities, planning and critique of experimental designs, group presentations, exchange of ideas and discussions, reflections, and debating of ideas. The instructional materials were samples of organisms, wet-mount and permanent slides, word cards, readings, CD-Rom, and interactive flash animations.

Teaching and learning activities of each lesson began with finding student prior knowledge of what they were going to learn by allow them to present and share ideas to answer questions asked by the instructor or provided in a worksheet. Then laboratory activities would be done in groups. To work in groups, each student would be assigned to take responsibility as a manager, recorder or presenter. These roles would rotate weekly. To effectively accomplish laboratory activities, the group members must work together and help one another.

Table 5.1 Learning outcomes focused in the instructional set

Understanding in Biological Concepts
The same 12 biology topics taught in the Laboratory in Biology course: microscopes, cell structure & function, cell membrane & cell transport, enzymes, bioenergetics, cell division, reproduction, growth & development, plant tissues, animal tissues, ecology and biodiversity
Science Process Skills
Integrated science process skills: formulating hypothesis, defining operationally, identifying and controlling variables, experimenting and interpreting data and drawing conclusion
Understandings in the Nature of Science
1. Definition of Science - Science is a body of knowledge, such as principles, laws, and theories, which explain the world around us (matter, energy, and life). - Science is exploring the unknown and discovering new things about our world and universe and how they work. **2. Characteristics of Scientific knowledge and Methods** - Science cannot investigate the supernatural and can possibly explain it. - Science is understandable. - Scientific knowledge has always changed with time. - The scientific methods do not always ensure valid, clear, logical, and accurate results. - Some scientific discoveries are made by accident. **3. Characteristics of Scientists** - The main motivation of scientists is to satisfy their curiosity. - Scientists can use imagination and creativity to get results. - It is not part of a scientist's job to ensure that no harm comes from discovery. - Scientists are logical, objective, unbiased and open-minded. **4. Influence of Science and Society** - Personal feelings and moral values have bearing on scientists' decisions. - Society influences the direction of scientific discoveries.
Attitudes towards Biology:
Attitudes towards biology, laboratory learning and the Laboratory in Biology course.

For summative assessment, paper and pencil tests (midterm and final examinations) and review of quality of student work and practice during learning were employed. Some tools, including quizzes, a student thinking book, and strategies, including student self- and peer- assessment, observation of class participation, listening to student ideas, asking questions, observing their skills and giving feedback were utilized to formatively assess student learning during the learning.

Reviewing of the Original Instructional Set by Experts

Initially, the instructional set were comprised of lesson plans, lists of instructional materials, student worksheets, which were all written in English, The instructional set was reviewed by experts: four science educators and four biology instructors who were experienced in teaching in the Laboratory in Biology course. The instructional set biology content was validated. This determined by the correspondence of questions and answers and appropriateness of the teaching and learning activities and instructional materials. The experts' comments and suggestions on the original instructional set were used to improve the teaching and learning activities. Collaborative group work during the laboratory activities was recommended to have a more obvious emphasis. The instructional set was simultaneously improved and translated to Thai as it was targeted for use with Thai instructors and first-year Thai pre-service science teachers. The Thai version was then validated by two science educations and two biology instructors. The improved instructional set comprised of an instructor manual and a student activity book and a student thinking book. The next step was to evaluate the instructional set before the implementation.

Evaluating the Instructional Set

A meeting was held to evaluate the instructional set with the purpose to consider whether the instructional set was appropriate and suitable for use in the laboratory classroom. Two instructors experienced in teaching the Laboratory in Biology course, the course coordinator, two science educators and the researcher were participants at the meeting. The instructional set, as well as the underlying theories used to frame it, were presented and explained by the researcher. An overview of the instructional set was presented and then each lesson was discussed in turn.

Ideas and beliefs about teaching and learning were widely discussed. With their traditional view of teaching, the instructor and course coordinator did not seem to agree with many of the teaching and learning activities in the instructional set. Their beliefs about teaching and learning in the Laboratory in Biology course as well as their comments and suggestions for improving the instructional set are discussed as the followings.

Instructors' Opposition to the Underlying Ideas of the Instructional Set

From the discussion during the evaluation process of the development of the instructional set, the instructors and the course coordinator contributed their beliefs about teaching and student learning. Their beliefs seemed to be opposite to the guiding principles of the instructional set. These beliefs can be summarized in four main aspects as follows

1) The instructional set aimed at promoting 4 learning outcomes as discussed earlier, in this chapter. According to the instructors' idea, laboratory teaching, other than content knowledge, should focus on practical skills (such as using a light microscope, preparing wet mount slides, handling apparatus, etc). Integrated science process skills and the understanding in nature of science should not be promoted at the university level. They assumed that students had been taught these skills as well as thinking skills in schools.

2) The instructional set valued the development of pre-service science teachers' positive attitudes towards biology during learning. Teaching and learning activities were designed and adjusted to match pre-service science teachers' abilities with an expectation that they would be meaningful, challenging and enjoyable for them. The instructors considered learners should adapt themselves to match their teaching and concentrate on what they were being taught. Instructors did not need to change their teaching for learners.

3) The instructional set utilized an inductive approach as allowing pre-service science teachers to learn through the laboratory activities they had done. The instructors preferred a deductive approach. They believed that, at the beginning of the laboratory session, they needed to inform all learners what they were going to learn, what instruments would be used and the steps of any procedures. Then they checked if students got the correct results. The reason underlying their belief in this approach was that, according to their experience, most students were not likely to read the laboratory manual and prepare themselves before class.

4) According to the instructional set, marks toward final grades were to come from the examinations, class participation, performance and work during learning. The instructors expressed that they think it was not necessary to give marks for student performance during learning. They assumed that the student who concentrated on learning and had good performance in doing laboratory would get high marks in content-based examinations. They also did not think that performance assessment was fair because there was subjectivity in giving marks on performance among instructors.

It could be inferred that the instructors and course coordinator held a traditional beliefs about science teaching. They emphasized the promotion of biological understandings by presented laboratory results to confirm the content. So, the researcher presented and clarified the ideas of social constructivist perspectives and the features of desirable teaching and learning from the National Education Act, 1999 as discussed in the guiding principles for the instructional set. Each lesson plan and student worksheet was presented briefly and discussed the differences from regular activities discussed. To the instructors and the course coordinator, some activities in the instructional set were questionable and they did not think that they could use these activities in the classroom, as captured from their comments and suggestions on the instructional set which are shown in the next section.

Instructors' and course coordinator's comments and suggestions for improving the instructional set

According to their beliefs about teaching, the instructors' and the course coordinator's comments and suggestion can be summarized as follows.

1) The teaching and learning activities in the instructional set were interesting and worth trying. However, they expressed that to follow the instructional set would increase their work. They noted that discussion activities would take time and may be the whole lesson would not be finished in time. They also commented that the instructional set had many learning outcomes compared with the regular course learning outcomes which were understandings in biological concepts and practical skills.

2) The instructors and course coordinator disagreed with the activity in the lesson on reproduction which randomly assigned students to groups to do different laboratory activities. Then each group shared the results with the class. The instructors and the course coordinator did not think that this activity would help pre-service science teachers to understand the concepts. They thought that each learner was needed to participate in every laboratory activity either individually or in a group. Additional activities (such as presentation and word card activities) from the instructional set would take additional time. They preferred to allow students to complete the regular laboratory activities, if have enough time, the students were welcome to present the laboratory results for a review of content. For word card activities, they would be taken out because they seemed to be too easy for university students and time-wasting.

3) For assessing group members' performance in group work, rather than providing only levels of performance (4 = excellent, 3 = good, 2 = moderate, 1 = poor), the explanation of each performance level should be addressed. This would help to reduce the subjectivity of interpretation of the levels and help learners to carefully consider the performance of their group members.

4) The instructors did not want learners to bring their own interesting samples to the class in activities such as observing cells and the inner structure of plant leaves. They were not sure if they could teach and explain the correct characteristics of these organisms to the learners. In addition, the learners already had prepared samples to study.

5) Designing experiment activities were included in the instructional set to promote skill in experimenting. For example, in the lesson on enzymes, the pre-service science teachers were given statements about the properties of enzymes such as all enzymes could function best at pH = 7, enzymes could be inhibited. They were asked to design an experiment to test whether the statement was right. This kind of activity was considered to be too difficult for the learners because they needed to understand the scientific process. For the researcher, this was a good way to explicitly teach them the process. The instructors strongly disagreed. They noted that pre-service science teachers would not be able to complete the activities in the limited time. They suggested that the learners should be given the steps of the procedure (already addressed in the laboratory manual) and a prepared space to write down the questions, hypotheses, variables, results and conclusions of the experiments.

6) Originally, the laboratory lessons were sequence from lessons on microscopes, cell structure & function, cell membrane & cell transport, enzymes, bioenergetics, cell division, reproduction, growth & development, plant tissues, animal tissues, ecology and biodiversity. The sequence of the lessons was changed and biodiversity was brought in to the sixth lesson. The instructional set was needed to change the sequence of lessons following those of regular course. The instructors and course coordinator gave the reasons that the preparation of laboratory samples and instruments relied on the regular course. Having a different sequence of lessons lead to confusion and inconvenience in the lab preparation process.

7) The investigation activity which combined the lessons of ecology and biodiversity would not be possible. Because the week for biodiversity lesson was

changed from the twelfth week to the sixth week as discussed earlier. As a result, the midterm examination would cover the biodiversity lesson. The instructors and the course coordinator commented that if learners had not learned this lesson before midterm, they would be disadvantaged in the midterm examination. In addition, pre-service science teachers' initiation of investigation was also questionable that they would be able to achieve the activity. Due to a concern of time-taken and feeling of not covering all of the content, the instructors rather wanted pre-service science teachers to follow the activities in the laboratory manual.

8) The instructors suggested to slightly rearranging the activities in some lessons such as plant and animal tissues, growth and development according to their experiences.

9) The instructors suggested that formats of the lesson plans and student worksheets were suggested to be consistent in every unit.

From these comments and suggestions, it could be referred that the instructors' and course coordinator' beliefs about teaching shaped their comments and suggestion on the instructional set. Also, it was found that the instructors rejected two very important things which the research tried to emphasize in teaching towards a more learner-centred approach. First, the instructors did not feel comfortable to allow pre-service science teachers to bring samples they were interested in to study the classroom. For the researcher, this activity provided the opportunity for pre-service science teachers to learn from what they interested in and for the instructor and student teachers to construct their understanding together.

Second, the instructor felt that assigning each group to study different laboratory sample with help from the instructor, then share they had learned to the class was not appropriate. The instructors gave the reasons that the presentation activities would be time- taken and all of the learners must have done all activities by themselves. In the researcher's idea, this would reduce time and enhance deep understanding before sharing the results. This also allowed pre-service science teachers to communicate what they had learned and encourage the social constructivist perspectives of teaching and learning in the class.

With all these ideas from the evaluation process, the instructional set was improved. The revised instructional set is described in the following section.

Revising the Instructional Set before the Implementation

After the process of evaluation, the instructional set was revised. The teaching and learning activities were then improved and adjusted according to the instructors' and course coordinator's suggestions and researcher' deliberation. The revised instructional set was comprised of an instructor manual, a student activity book and a student thinking book. Details of each book are shown as the followings.

Instructor Manual

An instructor manual was for the instructor to use for teaching in the Laboratory in Biology course. From eleven lesson plans from the original instructional set, it became twelve lesson plans: microscopes, cell structure & function, cell membrane & d cell transport, enzymes, bioenergetics, biodiversity, cell division, reproduction, growth & development, plant tissues, animal tissues, and ecology. Each lesson lasted three hours. The last lesson, ecology, took two class periods for learners' initiation and conducting of group investigation.

In each lesson, a lesson plan and student worksheets with key answers were provided. A lesson plan consisted of:

1) learning objectives,
2) main ideas of the lesson,
3) details of teaching and learning activities,
4) assessment strategies both for formative and summative purposes,
5) a list of laboratory materials and instruments,
6) instructional media such as readings, word cards, pictures, etc., and

7) a concept map of summary of the main ideas, teaching and learning activities, related science process skills and the nature of science concepts.

The teaching and learning activities were based much on the regular activities as required by the instructors and the course coordinator. In the regular course, the instructor began every lesson with a lecture of related content and informed learners the steps of procedures of every activity to be done. Then the learners did all activities and the instructor checked whether they got the correct complete laboratory results. Teaching and learning in the instructional set tried to change how to present the lessons to pre-service science teachers. The activities in the instructional set began with asking pre-service science teachers to explain their prior knowledge and share ideas, and then discuss the steps of procedures and related science process skills. Pre-service science teachers were then conduct the laboratory activities and discuss the laboratory results.

Each lesson was not able to promote every integrated science process skills. In the activities which they did experiments such as the lessons on cell membrane and cell transport and enzymes were aimed promoting the integrated science process skills as they were asked to formulate hypothesis, identify variables and provide possible results, as their prior knowledge, do experiments, collecting and interpreting the results and draw a conclusion, then compared their prior knowledge with the conclusion to obviously see the difference of the concepts they had before and after the activities.

The instructional set was aimed at promoting the positive attitudes towards biology from participating in the meaningful, challenging and enjoyable laboratory activities with supportive helps of the instructor. The understandings of the nature of science were explicitly taught by asking them to reflect on some thoughts about science after laboratory activities and specific instructional materials such as pictures and readings. The understandings of the nature of science were integrated in each lesson. Definition of science was integrated in the lessons on cell membrane & cell transport, bioenergetics and biodiversity. Characteristics of scientific knowledge and methods were integrated in the lessons on microscopes, cell structure & function, enzymes, cell division, plant tissues. Characteristics of scientists were integrated in the lesson on ecology. Interrelation of science and society was integrated in the lessons on reproduction, growth & development, animal tissues.

A common feature of the lesson plans was the activities at the beginning and the end of classes. At the beginning of the class, the instructor asked the learners to do a quiz of what they had learned from the previous week and allowed them to question of what they did not understand. However, two lessons did not begin with a quiz; the first week and the week after midterm examination. The activity at the end of the class was a discussion of what the learners had learned using a concept map which summarized the content, activities, science process skills, and the related understanding in the nature of science. Then the learners were also asked to write in their student thinking book and assess their group members' performance. The teaching and learning activities of each lesson were described in Table 5.2. The sequence of the lesson was followed the sequence of the lesson in the regular course. The common activities at the beginning and the end of each lesson are not shown in Table 5.2.

Student Activity Book

The student activity book had twelve lessons following the instructor manual. It was an additional book for teaching and learning from the instructional set. The learners also needed a regular laboratory manual for the contents in biology. The student activity book began with a course syllabus, time table of the course and roles in group work explanation. The components of each lesson are: a concept map of summary of the lesson, a list of brief description of each activity, related science process skills, related documents, homework and assignment, worksheets following the teaching and learning activities from the instructional set and instructional materials: word cards, reading articles, and assessment forms, as required.

Table 5.2 Teaching and learning activities of each lesson in the revised instructional set

Lessons	Activities
1) Microscopes	• instructor introduced herself and learners introduced themselves with their expectations of learning in the course, assign the roles in group work and instructor explained a concept map of summary of topics taught in the course • learners *brainstormed* to answer questions on the understandings in the nature of science • learners *discussed* their knowledge about and experience in using a light microscope • learners and instructor *discussed* a history of microscopes • learners did laboratory activities: comparing the differences of a light microscope and a stereomicroscope, practice the skill at using a light microscope & stereomicroscopes, measuring the size of the samples, and preparing wet mount slides and completed worksheets,
2) Cell structure and function	• learners *discussed* their prior knowledge about cells • learners prepared wet mount slides of given samples and bring-their-own samples • learners observed the organisms by a light microscope • learners and instructor *discussed* the characteristics and similarities and differences between the cells of the organisms
3) Cell membrane and cell transport	• learners predicted the results of experiments about diffusion and conducted the experiments, collect the data and draw conclusions • learners *discussed* about cell membrane; structure and function then predict the experimental results and conduct the experiment about the appearance of dead and alive yeast cells in a dye • learners formulated a hypothesis, identified variables, conducted the experiment, collect data and draw a conclusion in an experiment of plant and animal cells in different concentrations • learners *discussed* to explain the term 'hypotonic', 'isotonic' and 'hypertonic' to the learners and asked the learner identify the tonicity of solutions used in the experiment • groups of the learners *discussed* applying questions about osmosis and share the answers to the whole class
4) Enzymes	• learners *discussed* the tentativeness of science from a given article about the discovery of enzymes • groups of learners *explained their ideas* about the related words about enzymes in word cards the whole class did a role playing about factors which affected enzyme activity; instructor played as a scientist who discovered enzymes and proposed some results from her experiments about factors affecting enzyme activities, the learners plays as groups of scientists trying to find out if the instructor' claims were right (the factors were enzyme and substrate concentration, temperature, pH and enzyme inhibitors)

Table 5.2 (Continued)

Units	Activities
5) Bioenergetics	• Instructor demonstrated two experiments about aerobic and anaerobic respiration, learners predicted and observed the results and drew conclusions • learners *brainstormed* to critique the design of experimental about anaerobic respiration and suggest to improve the design • learners analyzed pigments in leave solution by a paper chromatography technique and discussed the results with the whole class • learners prepared wet mount slide of leaves and identified from the structure if the plants were C_3, C_4 or CAM • learners *reflected on* and discussed about the nature of scientific knowledge and methods from the laboratory activities according to questions provided
6) Biodiversity	• learners *share ideas* to explain related terms in biodiversity and write down scientific names of organisms • learners conduct an activity to classify given plants and animals • learners observed the characteristics of the given organisms in every kingdom from the provided samples • instructor randomly showed 10 samples of organisms from every kingdom and learners to identified the name of organism, *discussed* main characteristics of the organisms in the same kingdom and phylum or division
7) Cell division	• groups of learners *reviewed their prior knowledge* about cell division • learners prepared wet mount slides of onion root cells and Chinese leek flower cells and assess the quality of the slide from a provided criteria • learners observed the cells in mitosis and meiosis to see each phase of division and then randomly assigned to set up a slide to show one phase in front of the class, the whole class *discussed* the characteristics of cells in each phases • instructor set up permanent slide of animal (white fish, *Ascaris* sp., frog and grasshopper) mitosis and meiosis and asked learners to *share ideas* to identify the phase and explain the characteristics and drew pictures in their worksheets • learners *discussed* their ideas about mitosis and meiosis according to questions provided in worksheets • learners *reflected on* and *discussed* the nature of scientific knowledge and methods from the laboratory activities according to questions provided

Table 5.2 (Continued)

Units	Activities
8) Reproduction	• groups of learners *brainstormed* to study plant and animal reproduction, each group studied different samples and prepared to *present what they had learned* to the whole class • groups of learners *presented what they had learned and allow the whole class to ask questions and discuss,* after presentation instructor helped in fulfilling their knowledge about reproduction • each learners *assess* the quality of presentation according to a given criteria • learners studied every organism by themselves if time left and complete worksheet • learners *reflected on and discussed* morality in science from the laboratory activities according to questions provided
9) Growth and development	• learners *discussed prior knowledge* and the link between the previous lesson and this lesson • groups of learners studied the component of seeds and seed development diagram and *presented what they had learned* to the whole class • learners *discussed* about seedless fruits from a given article • learners observed permanent slides of animal embryos • learners observed videos of embryonic development in sea urchin and frog and *discussed* to summarize what they had seen in the vedios • learners studied cloning from an interactive animation from a website and *share their ideas* about morality in science
10) Plant tissues	• learners observed pictures of cells and guess what organisms they were from, remembered their answers which would later used in the later activity • learners prepared wet mount slide of plant tissues, use *self- and peer-assessment* to determine the quality of the prepared slides • learners observed their prepared slides and permanent slides by light microscopes and *discussed* the structure & function of the tissues • learners were shown the pictures from the first activity again and asked to identify the type of organisms and tissues • instructor used the picture 'Aging President?' of Lederman & Abd-El-Khalick (1998) and link with their answers from the first activity in that existing knowledge, personal feelings and bias played a part in science and science can change over time
11) Animal tissues	• the whole class *discussed* an article of animal used in science and *reflected on* morality in science • learners *discussed their prior knowledge* about organelle, cell, tissue, organ, and organism and discussed the differences of plant and animal cells • learners observed animal tissues from permanent slides • learners *brainstorme*d to play a game by using word cards to assess their understanding of the lesson instructor showed pictures of animal tissues and asked learners to identify the type of tissues and important characteristic to review the lesson

Table 5.2 (Continued)

Units	Activities
12) Ecology	*Week 1* • the whole class briefly *discussed* about the concept of ecology • instructor explained about group investigation and tell about her own investigation as a scientist as a sample of a science investigation • learners were asked to identify how would they study the types and niches of organisms in a desert • learners *brainstormed* to identify problems about ecology in which they wanted to investigate and select the possible problems for later activities • learners were divided into group of 6 and assigned the roles in group work and randomly assigned the areas to investigate • the whole class came to areas of investigation, *identified problems to be investigated*, problems from the previous activity would help them in this activity (instructor suggested them to use the available instrument and techniques as in regular manual) each group *planned an investigation* and *presented* to the whole class, *improved the plan* and collect instrument used from instructors and started to conduct the investigation • learners might continue the investigation, write a report and prepare a poster for presentation and meet instructor during the week, out of the class period *Week 2* • each group *presented* their investigation activities • learners *assessed* the quality of the investigation and presentation and provided suggestion • the whole class *discussed* about science process skills used in their investigation, the nature of science and their feelings while doing the investigation • learners *discussed* what they had learned from the whole course and they were asked to complete a worksheet to write down about their experiences from the Laboratory in Biology course according to the instructional set

Student thinking book

A student thinking book is a formative self-assessment tool for pre-service science teachers to reflect on what they had done, learned, felt during learning. It also provided information for instructors to improve teaching. Each week, pre-service science teachers were asked to respond to nine questions in spaces provided. These questions are shown below.

1) What activities have you done in class this week?

2) What have you learned this week (Biological concepts, the nature of science concepts, science process skills and so on)?

3) What have you still not understood?

4) What do you want to know more about?

5) What activity did you like most? Why?

6) What activity did you dislike most? Why?

7) How do you feel during the learning (such as excited, happy, surprised, confused or bored)? Please explain.

8) If you could change anything you have done in the class this week, what would you change? How would you change it and why?

9) Do you have any other comments?

Group's member performance assessment tool was also included in the student thinking book. They were asked to assess each of their group members' responsibility, helping other members, performance following the roles of group work, expression of ideas in discussion and group activities, and listening to other group members' ideas. They were asked to give a mark to identify the level of performance (4 = excellent, 3 = good, 2 = moderate and 1= poor) in each item. The explanations of each performance level were also provided.

Adjusting the Instructional Set during the Implementation

The instructional set was adjusted during the weekly meetings of the instructor and the researcher in the semester of the implementation. The instructor and the researcher discussed to adjust teaching and learning activities to match pre-service science teachers' ability and learning styles. The adjustment concerned rearrangement of teaching and learning activities, time management and development of additional worksheets and quizzes. The adjustment was based on the implementing instructors' experience in teaching in the Laboratory in Biology course and the researcher deliberation.

Summary of Chapter V

An instructional set for the Laboratory in Biology for first-year pre-service science teachers was developed according to the guiding principles generated from a literature review of a learner-centred approach, social constructivist teaching and learning perspectives and findings of phase I of this research study. The original instructional set was reviewed experts; four science educators and four biology instructors who were experienced in teaching in the Laboratory in Biology course. It was improved and then evaluated by two science educators, the course coordinator and two experienced biology instructors. The instructional set consisted of an instructor manual, a student activity book and a student thinking book. The next chapter discusses the implementation of the instructional set.

CHAPTER VI

IMPLEMENTATION OF THE INSTRUCTIONAL SET

Introduction

This chapter presents and discusses the implementation of the instructional set for the Laboratory in Biology Course. This chapter begins with details of how the instructors taught and how the first-year pre-service science teachers learned during the implementation process. The first-year pre-service science teachers' learning outcomes, including their understanding in biology, the nature of science, science process skills and attitudes towards biology, during after learning through the instructional set are presented and discussed. Some comments and suggestions for improving the instructional set from the instructors and the pre-service science teachers are also discussed in the last section of this chapter.

The instructional set for the Laboratory in Biology Course was implemented in the second semester of the 2005 academic year (November 2005 to March 2006). The implementation lasted sixteen weeks including the examination weeks. Twenty-nine first-year pre-service science teachers and two instructors, Vipa and Darin (pseudonyms) participated. Vipa implemented the first two weeks of the set and Darin implemented the rest of the set. Normally, there is only one instructor teaching for the whole semester but, in this study, Vipa had other important work and could not continue the implementation after the second week of the semester. Darin then agreed to be part of the study. Both instructors participated in the evaluation process of the instructional set before the implementation and understood the underlying ideas of the instructional set. The next section presents how the instructors taught during the implementation.

The Instructors' Teaching and the Pre-Service Science Teachers' Learning

This section describes and discusses the teaching and learning that took place during the implementation of the instructional set for the Laboratory in Biology course. It begins with outlining the instructors' teaching including their beliefs about teaching which provide some insight into their actions in the classrooms and the ideas they shared during the weekly researcher-instructor meetings. The instructors' preparation, teaching and assessment strategies, adapted activities, reflections and changes are also outlined. The pre-service science teacher learning section describes and discusses how they learned and their learning outcomes.

1. The instructors' teaching

This section describes and discusses how the instructors taught while they were implementing the instructional set for the Laboratory in Biology in the second semester (November 2006 to March 2006) of the 2005 academic year. The section begins with detailing the instructors' beliefs which were strongly influenced instructors' overall teaching practice. Then it moves onto discuss their preparation before class and teaching strategies they employed in class. Formative assessment is then discussed as it benefited both instructors in gaining insight about the pre-service science teachers' learning and information for improving their teaching. Their adapted activities were described. Reflections on instructors' practice and change in their beliefs and teaching practice were then discussed.

1.1 Vipa's teaching

Information about Vipa's teaching was captured during the two weeks of her implementation of the instructional set during the weekly meetings and teaching in the classroom. Vipa tended to express her ideas extensively and enjoyed long talks. She seemed to give intensive attention to everything in detailed. She discussed, commented and reflected on her own teaching practice. Her teaching is discussed below.

1.1.1 Beliefs about teaching

During her implementation of the instructional set, Vipa expressed her beliefs about teaching which were captured in both weekly meetings. Her beliefs about teaching are discussed as the followings.

1) Teaching practice could be enhanced

Vipa, originally, would like to improve her teaching practice so she could provide more productive teaching and learning activities for every student in her class, for the Laboratory in Biology course and other courses. She expressed that she was interested in the educational ideas but she never had had a formal or academic chance to develop her teaching. She expressed the hope that participating in the study and implementing the instructional set would help her improve teaching. Before teaching, she tried to make sure she understood all the activities in the lesson plans and asked the researcher to clarify in detail how she might manage the teaching and learning activities. Vipa was concerned to follow the lesson plans as much as possible. She worried about forgetting the order and detail of activities in the lesson plans because the teaching approach in the instructional set was new to her. However, she said she would do her best in class.

2) Teaching concerned s Students for the examinations

Content knowledge dominated the midterm and final examinations. Vipa intended to help her students as much as possible to pass the examination. Her experience of the examination items led her teaching to promote the pre-service science teachers' understandings of biology concepts and information about the procedural steps in laboratory activities according what was asked in the examinations. Vipa helped the pre-service science teachers to prepare for the exams by presenting content information of and preparing quiz items on the microscope and biodiversity lessons. Details of these two strategies were as follows.

Vipa's first strategy was to provide all the content information in a PowerPoint presentation for the lesson "Microscopes". She needed a slide to show information about the components of a light microscope (including: the meaning of the numbers existing on a light microscope's lenses representing the modification of the lenses, numerical aperture, length of the mechanical tube and the thickness of the coverglass). She discussed each component extensively. This information was already in the manual which all the pre-service science teachers had. Vipa noted the reason for presenting and explaining the content was that "the exam asks about [it and so]..., pre-service science teachers must know". In the first weekly meeting, Vipa commented on the quiz questions that they should be similar to the questions asked in the examinations. Her reason for this was to benefit the pre-service science teachers in the examinations so they knew which parts of content would possibly be in the examination and what kinds of questions they were going to be asked.

3) All students learned by listening

Vipa strongly asserted before teaching that she must help the pre-service science teachers to understand the underlying biology concepts of the laboratory activities by giving them a lecture to summarize the concepts before doing the laboratory activities. Vipa implied many times it was necessary to 'explain' or ' talk' about what pre-service science teachers should know before she allowed them to begin doing laboratory actives. This implied that her belief that scientific knowledge could be transmitted to the learners. Before implementing the first lesson, she planned to use a PowerPoint presentation to remind her all activities she would do in class, provide the pre-service science teachers the content knowledge and detail each step of doing laboratory activities. She would tell pre-service science teachers what was on the PowerPoint presentation and they all would pay attention to the presentation as their centre of attention.

Vipa thought the science students teachers would concentrate on her lecture and take note. She decided not to give a handout of the presentation. Her reason was that she wanted the first-year pre-service science teachers learn to take note of what she said which would also benefit them in learning in other science courses. In addition, she considered taking notes would help students to stay on task while she was teaching, as she said before the implementation that:

> They [pre-service science teachers] will know that they need to take notes. If not they will *be free*. That means [taking notes] they need to have their own notebooks. Today, they will not fall asleep.

In Vipa's meaning of 'being free', was that students did not need to pay attention in class and could do anything they wanted at their seats. She also explained her idea about not giving the handout to students that:

> I won't give them the handout. They will be too comfortable (laugh). Another thing, they just come to listen. This is the first reason. The second, if I say that there will be a test… they all will pay attention… they will automatically take notes.

More evidence of her belief in the importance of telling was also captured. She explained how she would deal with the limited number of ocular and stage micrometers. There was only one set for the whole class. As she commented before the implementation that:

> It's not difficult at all. I will teach the theory to students. Everybody must get the same [result]... I may not be there once I set up the microscope. Every group will come to do the activity.... they just only have to know the principle of stage and ocular [micrometer]. They will count the number of scales... When each group finishes, they write [their results] on the whiteboard or keep them for a discussion later.

From her experiences, Vipa did not think that assigning the pre-service science teachers to read the content and steps for doing laboratory activities before class would help them to respond to her questions better. In addition, she was not confident whether the pre-service science teachers would read the lessons before class. Vipa believed that she needed to tell the pre-service science teachers what they were going to learn and do. She thought it wasted time to wait for their answers because, from her experiences, students responded very slowly when they were asked about content and laboratory procedures.

1.1.2 Instructor preparation before class

Vipa prepared the instructional materials and herself before teaching both of the weeks she implemented the instructional set. Her preparation is discussed next.

1) Gathering well-prepared materials

Vipa considered having good PowerPoint presentations, a high-detailed laboratory manual and ready-to-use laboratory samples were important as they would help in reducing learners’ confusion and time used in each activity. For the PowerPoint presentations, she wanted them to be short, easy to understand and included all the required information in order. The good laboratory manual, in her idea, should provide clear content and have pictures of all the organisms the pre-service science teachers would learn about. She thought laboratory samples must be all well-prepared, ready to be used and provide clear experimental results. The pre-service science teachers should be given good quality of laboratory apparatus. It was obvious that these well-prepared materials were mainly for the promotion of pre-service science teachers’ understandings in biology.

2) Rearranging the laboratory activities and time management

Using her teaching experience Vipa rearranged the order of the practical laboratory activities to what she thought would be easier for her to manage in the class within each class period and to solve the problem of limited of apparatus. She also considered the time given for each activity and decided how would be appropriate. She allocated time for the pre-service science teachers to listen to what she had to tell them. Then they would do several practical activities at the same time. For the limited apparatus, she planned to allow each group take turns to do activities with ready set up apparatus rather than allow them to do all the steps of an activity.

1.1.3 Teaching strategies

This section described teaching and assessment strategies Vipa used during the implementation of the instructional set. Her beliefs about teaching strongly affected her practice in the classroom. Details are discussed as the following.

1) Lecturing as the main teaching strategy

Vipa believed that all students learned by listening and used lecturing as her main teaching strategy. She wanted the pre-service science teachers to have access to the fundamental concepts they were going to learn before they did the laboratory activities. This was observed both weeks of her implementation of the instructional set. She began the lesson by explaining the content and also asked the pre-service science teachers many questions. The questions she used were mostly knowledge questions requiring short answers. When she did not get an immediate response, she kept asking the same question. After she got the answer, she explained more about the answers. If no pre-service science teachers answered, she answered her questions herself.

Most of the answers to Vipa's questions were in the regular laboratory manual. The pre-service science teachers could easily find them if only they read the manual as in the following excerpt from the dialogue during the first lesson on microscope and Vipa was using the PowerPoint Presentation at the same time:

Vipa: Let's look at the objective lens, in your book. (A picture of it is also shown on the screen) An objective lens has three numbers on it. Upper, middle and lower. These numbers identify many

	things which you need to know. The first number, the upper number. What does it tell?
Students:	Magnification
Vipa:	Magnification of ?
Students:	An objective lens.
Vipa:	The next number, the middle? What does it tell? ...NA value? ...What is NA value?
Students:	Numerical aperture.
Vipa:	What is it? (Some students answered softly at the same time and Vipa could not catch all of their words) ...A value of something. (Then she read the definition of NA value from the manual) Then the next number... 160... What is this value?
Students:	The length of mechanical tube
Vipa:	Or the body tube... the same. Each of the objective lens here has the same 160. When we adjust the focus we only use the fine adjustment knob then we can see the image. Because it's already adjusted. ...Next, the forth number, having in only high power objective lens, what is it? ...0.17.
Students:	The thickness of the coverglass.
Vipa:	Yes, this is very important. Because in the market, there are so many types of coverglass with different thickness. So we have to choose the coverglasses which are not thicker than 0.17 [millimetre]. If more than 0.17, what will happen?
Students:	Broken.
Vipa:	What is broken?
Students:	Coverglasses.
Vipa:	Coverglasses are not expensive, that's fine. But lens will be broken. Objective lens will be near this flat part which is called stage. This stage has condenser lens. These are objective lens. These parts are very close. If the stage is too high, the objective lens will be broken.

The question she asked about the meaning of NA value illustrated her repetition of a question when she did not get an immediate response from the pre-service science teachers. She explained more information about the numbers on an objective lens after she got short answers from them.

In the following excerpt, from the lesson on biodiversity, shows Vipa's questions and responses *(Question 1, 2, 3, 4 and 5)*. For question 1 the response was silence. She asked *Question 2* but did not really want a response; she suddenly continued talking. Then Vipa asked *Question 3, 4* and *5*, all knowledge questions requiring short expected answers, the type of questions she used mostly in her teaching.

Vipa:	The first topic we have to understand is the differences of biological diversity and organism diversity. Biological diversity, as you have read, what does it mean? *(Question 1)*
Students:	(Silence)
Vipa:	...Biological diversity, it's explained in three levels. These are genetic level... genetic diversity, organism level and ecosystem level. Three level together. But when talking about organism diversity, what is it? It's part of biological diversity. I say this, is it correct? *(Question 2)* ...Then biological diversity started from genetic diversity. Started from the molecular level. From molecule become what? Protoplasm... What are the components of protoplasm? Tell me the definition of protoplasm. The part which consists of what and what? *(Question 3)*
Students:	Liquid in the cell.
Vipa:	What is the English word for the liquid in the cell? *(Question 4)*
Students:	Cytoplasm.
Vipa	Cytoplasm. ...And? And what? *(Question 5)*
Students:	Nucleus.

Vipa: And nucleus. Very good.

2) Providing helpful and friendly guidance during laboratory activities

After the lecture, Vipa allowed the pre-service science teachers to do laboratory activities with her help. She answered their questions, observed them closely and gave them suggestions in doing activities. She also demonstrated how to use a light microscope and prepare a wet mount slide in groups. During the laboratory activity to practice how to use a light microscope, Vipa helped the pre-service science teachers to develop their thinking skill in problem solving. The pre-service science teachers asked for her help with the clarity of the microscopic images they had. Vipa asked them to consider what problems they should solve in order to make their images clearer. She pointed out the adjustment of light and the cleanliness of wet mount slides as possible solutions. She adjusted the focus of images and the light intensity and asked the pre-service science teachers to compare between their images and hers. She explained how she used this strategy to help the pre-service teachers learned during doing laboratory activities in the first weekly meeting that:

> …I guided them [pre-service science teachers] about light intensity. I adjusted a clear image for them and pointed out how to make clear images. …Having an overall clear image and having a clear focus of what we are observing are different. …if we want to observe a tissue so we need the clear image of the tissue, adjust [a microscope] to clearly see cell borders. …When pre-service science teachers got a clear image of cells then they also got a clear image of the tissue. All of them understood and they could then set up the microscopes for the clear images.

When the science students did not follow the steps in using a light microscope correctly, she guided them but allowed them to solve the problem by themselves. She also discussed with groups of the pre-service science teachers the appropriate way to use a light microscope and the function of each component of a light microscope. From her guidance, the pre-service science teachers could apply the way to adjust clear image in the subsequent laboratory activities. Vipa also allowed pre-service science teachers to take their time in practicing their skills. She did not blame them when they have done wrong in doing activities but provide friendly support. She described her idea about giving this kind of support in the second weekly meeting that:

> An instructor needs to be a good friend of students. …He/she must not look down on the students when they cannot correctly do laboratory activities at the beginning. That is fine. But they need to be able to get the activities done correctly. Most instructors don’t guide students the correct ways to do but blame them. The students then do not know what they have done wrong.

3) Paying individual attention facilitated student learning

Vipa paid attention to individual pre-service science teachers and considered giving different helps according to individual’s needs. Vipa showed her hospitality and helpfulness. She expressed about her delicate attention to individual pre-service science teacher during they were doing laboratory activities. She diagnosed one female pre-service science teacher’s special needs and provided her with encouragement and a closed-up help. She noted about one female pre-service science teacher who seemed to need an extra help in the first weekly meeting that:

> There was a girl. She seemed very stressful. She sat at the back of the class. She didn’t have confidence and was afraid that she couldn’t do the activities. ...I told her to take it easy and I would be her helper. ...In the first session, she had problems in decision making, she asked me often and worried about being wrong. ...I asked her what was she afraid of, I was there I was helping her. Then she could finish the activities.

1.1.4 Formative assessment

There were various formative assessment tools, including quizzes, a checklist of skills, student activity book and student thinking book, provided by the instructional set. Formative assessment benefited Vipa in gaining more insight about the pre-service science teachers as it captured pre-service science teachers' understandings, skills and feelings during learning. Formative assessment also reflected her teaching practice as the pre-service science teachers commented and gave suggestions.

Vipa benefited from the use of quizzes in assessing the pre-service science teachers' understandings in biology the pre-service science teachers learned previous lessons. Before beginning the new lessons, Vipa asked them to take a quiz. She allowed each pre-service science teachers to do the quiz for 5 -10 minutes. After they finished, she asked the questions in the quiz whole class to share their answers. This was time at which she had an opportunity to correct their misunderstanding and explained more about the content. Vipa ended up each question by providing them with best correct answers.

Vipa used a checklist of pre-service science teachers' skills at using a light microscope and preparing a wet mount slide. To complete the checklist, Vipa took closely observation to every pre-service science teachers. Vipa benefited from the checklist in that it informed her of the ability of the pre-service science teachers and she knew that she could help them achieve the skills by providing them care and guidance. With her guidance, after she knew their problems, she could facilitate the majority of the pre-service science teachers to achieve the skills., She expressed about what she had gained about pre-service science teachers' skills when using the checklist in the first weekly meeting that:

> As I saw, they had ability but they need intensive care and guidance. ...Many pre-service science teachers could do well but they didn't know how to do. At the first time, they set the microscope with unclear light, and a thick sample

> section. Then, the second time, [they did] very well and [had] excellent sample section. Because they did again after they did badly and then they could do well.

The responses in the pre-service science teachers' activity books were summarized by the researcher so that Vipa could capture their understanding and misunderstandings in biology. The pre-service science teachers could correctly answer to most of the questions in their activity books. Not many misunderstandings were also found. She corrected their misunderstandings by telling them the correct answers in the subsequent laboratory session, after they finished the quiz activity.

The pre-service science teachers' responses in their student thinking books informed Vipa about her teaching practice. Each pre-service science teacher gave some comments on Vipa's teaching. She was appreciated the information she gained from the student thinking books and planned improved her teaching. She realized that she should not have to take long time in lecturing and students liked to do laboratory activities. Her main intention to improve her teaching in the subsequent laboratory session was to speak less and allow them to say more. However, she did not have a chance to try in class because she could not continue the implementation.

1.1.5 Adapted activities

Vipa could not follow every activity in the instructional set when implementing the instructional set. Discussion to adapt the teaching and learning activities to mach pre-service science teachers' ability and class participation style was made in the weekly meetings. Vipa also readjusted several teaching and learning activities in according to her thoughts and consideration, in the way she thought it was most effective. These activities were probing the pre-service science teachers' prior knowledge about the nature of science, estimation of a sample size and drilling in skills at using light microscopes and preparing wet mount slides. Details are discussed as follows.

1) Probing the pre-service science teachers' prior knowledge about the nature of science

Vipa changed the discussion activity on pre-service science teachers' views on the nature of science to asking questions. In the plan, the pre-service science teachers would be asked to think in groups and write down their ideas about their understanding of the nature of science. Then each group would share their ideas to the whole class. Vipa did not allow them to think in a group but immediately asked the whole class. This might explained by two reasons. The first was that the class began late and she tried to finish the class in time. The second was that she did not reckon that giving more time to think could make the pre-service science teachers give better answers to her. So, she took over the discussion in groups before sharing ideas to the whole class.

The pre-service science teachers, without a prompt to answer questions about the nature of science, could not respond to her immediately. Vipa tended to tell them and explain her own ideas about the nature of science. The following is an excerpt of the conversation between her and the pre-service science teachers talking about the definition of science after none of the pre-service science teachers could clearly explained to her what science was. As in the following excerpt from the lesson on microscope, Vipa presented her ideas about the nature of science to the pre-service science teachers rather than allowed them explain what they thought about science. She also clarified her own ideas about experimental replication and bias.

Vipa: ...Science is knowledge from observation and systematically searching for knowledge and experiments which produces clear non-biased results. This is the meaning of science. Hence, we give the meaning... observation... observation before, right? Then searching to get knowledge. What next?

Students: (silence)

Vipa: Then experiment, right? Experiment to get results. How should the results be? If we conduct 10 replications and get the same results, 9 rep., 5 rep., or 10 rep. ...The results are the same? If results are the same for 5 times [out of 10], is it science? ... No. It must give the same results every time. O.K.? Until the results appear obviously [repeated]. With no bias. What does bias mean? Have you ever heard of it? What does it mean?

Students: No use of feelings.

Vipa: No use of feelings. Not because of feeling of liking. ...Two mice in an experiment. One mouse is cute so place it in air conditioned room; the other is fierce so place it outside. Can't do this because the results will be inaccurate. Or when we collect data, the experimental set nearby is observed and you note more information, but the rare set, lazy to walk, so no observation and records of data.... can't do this... O.K. you understand. Then the word "science" is passed.

2) Estimation of a Sample Size Activity

The laboratory manual mentioned a goal that all students should be able to measure a sample size. There was only one set of instruments used (stage and ocular micrometer) for each laboratory section. Referring to the laboratory manual, pre-service science teachers must measure a sample size under a light microscope using the stage and ocular micrometers. However, the manual did not clarify how students would achieve the purpose with the very limited set of instruments. Vipa created an activity of estimation of the sample size to help the pre-service science teachers practice a technique when the apparatus was limited. She asked the pre-service science teachers to draw lines in a small piece of paper; the distance between lines was one millimetre, mount the paper with water and observe the paper under a light microscope. The pre-service science teachers were then asked to record the width of the microscopic field in millimetres and observe a wet mount slide of haired-grass stem and estimate the width of the stem in millimetres. During the activity, she explained the procedure briefly. The pre-service science teachers did not clearly understand the procedure and many of them asked her while she was walking around and helping the class. She needed to call attention of the whole class and explain the procedure of the activity again. But the time ran out, none of the pre-service science teachers could finish the activity.

3) Practicing in skills at using a light microscope and preparing a wet mount slide

Vipa noticed that the pre-service science teachers did not have confidence and had not done well enough in using a light microscope and preparing wet mount slides in the lesson on Microscopes in the first laboratory session. She allocated some time of the lesson on biodiversity, in the second session, for them to have more chance to practice the skills. In the first weekly meeting, she discussed with the researcher that she would finish all of the activities in the lesson "Biodiversity" in a shorter time. Then, she would allow the pre-service science teachers to use light microscopes and prepare wet mount slides for half an hour before class done. At the end of the meeting, she noted that she would figure out how to manage the time used in the activities by herself again before teaching. In class, when the pre-service science teachers were allowed to observe various samples of organisms placing on tables around the class Vipa separated them into two groups. The first group observed the samples and the second group practiced using light microscopes and preparing wet mount slides with her help. But she could not manage the whole class while doing both activities at the same time.

1.1.6 Instructor's reflection on teaching practice

After each class and in the weekly meeting, Vipa expressed her reflection on her own teaching practice. She commented on her own practice and sought out possible solutions. She reflected on four main topics: her understandings of the nature of science, her unfitting standing position in the first laboratory session, pre-service science teachers’ responses to questions, and time management, discussed as following.

1) Vipa’s Understandings in the Nature of Science

Vipa expressed that she did not clearly understand about the nature of science. The information about the nature of science was provided in the first lesson plan but it seemed not clear enough to her. She asked the researcher to clarify the aspects of the nature of science but it could not make her clear as she expected. She summarized her own understandings of the nature of science and included it in the PowerPoint presentation. However, the understandings in the nature of science which she presented to the pre-service science teachers were appropriate. She reflected on her understanding about the nature of science in the first weekly meeting that:

> I don’t think I clearly understand in the nature of science. The nature of science, science process skills and science concepts, these three words. ...they need clearer definitions. So, in class, I can communicate to them [pre-service science teachers] what they are and how they relate. It might be a flow chart or something... I think if we are not clear, we can’t talk. ... I don’t really know about it [the nature of science].

This quote shows that Vipa thought she could not talked well about the nature of science to the pre-service science teachers because she did not clearly understand the nature of science and had no distinct definition for each of term related to science. Although she presented appropriate views on the nature of science, she would like to have more information of the nature of science which she considered it would help her do better in teaching. This quote also pointed out that Vipa, as a scientist and an experienced science instructor, did not have confidence in teaching about the nature of science.

2) Standing Position

Vipa commented on her standing position that it made her not be able to capture the pre-service science teachers' behaviours during the learning. In the first laboratory session, Vipa located herself in the middle left of the classroom where the computer was due to her need to manage the PowerPoint Presentation. She commented the disadvantage of standing there that it obstructed her observation of the pre-service science teacher's behaviours. She could not perceive how they reacted to her teaching. As she said in the first weekly meeting that:

> I should have stood at the front of the class ... the pre-service science teachers at the front of the class were pity. ... I could not see their eyes. There was no interaction between the instructor and the learners [who sat at the front of the class]. ...If I stand at the front, I can see them ...Their eyes will tell whether they understand or not. They might nod or tell me that they understand. ... Their faces will tell me.

She wanted to change where she stood from the middle left of the class to the in front of the class but she still wanted to use a PowerPoint presentation. Her solution was showed in the second laboratory session. She used the PowerPoint presentation only for inform pre-service science teachers' what activities they needed to be done. She used transparencies and the overhead projector when she gave lecture on biodiversity. She could stand in front of the class and see how the pre-service science teachers interacted to her teaching.

3) Pre-service science teachers' responses to questions

In class, Vipa asked the pre-service science teachers many questions which were mainly knowledge questions. She often asked the whole class rather than allow them to think in pairs or in groups before answering her questions. The pre-service science teachers gave slow responses or silences when they were asked. She noted that the pre-service science teachers could not answer her questions and waiting for their answers wasted time. As Vipa commented after the first laboratory session that:

> The problem is that I can't get their responses... I was stuck and couldn't continue. ...I asked them but they couldn't answer. I continued asking, asking and asking them... It was a waste of time.

The pre-service science teachers were assigned to read the laboratory manual before class. Vipa expected that the pre-service science teachers would gain some correct understandings before class which could make the questioning-answering activities went faster. So, in class, she started with asking the pre-service science teachers questions, but they had a delay to give their responses. Vipa thought that there was not enough time to continue asking questions and waiting for the answers. It can be said that Vipa appreciated activities which asking the pre-service science teachers to share ideas. But, for her, it seemed unpractical in class because the pre-service science teachers had insufficient understandings and could not communicate their thinking fast enough to answer the questions in the very limited time in class. In her thought, the instructor should have be the one who "tells" of what the pre-service science teachers do not know. Asking questions could induce a stressful feeling in learning. In the other hand, telling can make the class atmosphere more enjoyable. As she noted in the second weekly meeting that:

> I thought they should have known [the content] more than this. ... But I have to talk in short. I can't allow them much to answer. When they can't answer, I have to explain. I know that we want them to respond to us but they can't because they don't know. I tried to give them a hint but they didn't know... It wasted time. ...I guess I have to tell them. If not they will feel uncomfortable. ...This makes teaching and learning atmosphere stressful. I don't like to teach stressfully. Take it easy. If they know, they tell me. If not, I tell them...

4) Time Management

Vipa expressed that she could not run all of the activity in time. One of the causes of using more time than in the lesson plans was the delay of the pre-service science teachers' responding to her questions. The other cause was that she did not tell the pre-service science teachers how much time they should finish before she allowed them to do laboratory activities. In the second laboratory session, Vipa divided them into two groups and allowed each group to do two different laboratory; observing various organisms, and practice of using a light microscope. After they finished the activity, they switched to do the other. The pre-service science teachers took more time to finish each activity than she planned and she did not tell them how much time they should finished each activity and take turn to do the other. This resulted in reducing time used in the subsequent activity which was a discussion of important characteristics of organisms. Vipa commented after the first laboratory session that:

> The problem is time management. I couldn't manage time well. ...Maybe I did not well communicate to them. I had to say I gave them twenty minutes. If they couldn't finish, that was fine.... Then they could take turn to do the other activity.

Her comment above showed her own reflection on time management and how she thought to improve her teaching. She found out that she should tell the pre-service science teachers how much time they should take to control time used in the activity.

1.1.7 Instructor Change

Vipa developed her understanding in teaching from the instructional set that she slightly changed her beliefs towards a more learner-centred and social constructivist approach. She planned adapt teaching and learning activities used in the instructional set to teach third year science students in another course, Ecology, in which she taught in the same semester. However, this was only her expression which she would try to do. But it obviously demonstrated her changes in her beliefs about teaching. She noted that she adapted two activities from the instructional set; finding out students' prior knowledge and student presentation, discussed as follows.

Vipa planned to use questions to find out students' prior knowledge about the ecological structure, food chains and food webs in a mangrove ecosystem. She thought that her students would discuss and share various ideas according to their prior knowledge. She expressed that the activity would make her not to talk as much as the previous semesters. As she mentioned in the second weekly meeting that:

> ... Now, I don't have to teach a lot. I used to talk a lot... When I taught about the mangrove ecosystem, I fully described it. It didn't work. ...I will ask them [third-year science students] to discuss about the components of the mangrove ecosystem, identify organisms in the food webs and food chains. ...I will know individual student's idea about the mangrove ecosystem... A student may know only two organisms [in the mangrove ecosystem] because their parents have never taken him to a mangrove forest. This student may get ideas from another student.... and I will check if they are correct.

Evidently in the quote, she had the ideas that she would start to teach the lesson from the students were at, not where she think she should start. She implied that her students must have some ideas about what she was going to learn from somewhere and they would bring those ideas into the class. She also noted that knowledge would be socially constructed among students while they were sharing their ideas.

Vipa also planed to ask students to do a presentation in the coming class sessions in the Ecology course. She would assign each group of students to research on the information of different kinds of ecosystems and present what they learn to the whole class via group presentation. She would determine the content of the presentation as minimum requirement (such as niches, relationships of organisms and energy transfer in an ecosystem). She noted that her students would create and design their presentation to match her requirement and they might do better than she expected. Each group would present their work to the whole class and allow the class members to ask questions and discuss about what had presented. Explaining this activity, Vipa showed her ideas of allowing students to use their skills in designing and communicating ideas to the teaching and learning activity.

To sum up all about Vipa' teaching, she had an outstanding in giving guidance for student learning with a concern of individual differences during laboratory activates. Her beliefs about teaching and experiences strongly influenced her teaching practice. She used lecturing as the main teaching strategy to promote the first-year pre-service science teachers' understandings in biology concepts. She utilized the teaching and learning activities provided in the instructional set but by her own teaching style. She distorted most of the discussion activities and allowed little time for the learners to answer her questions. Her acquaintance, time constraint, summative assessment, content to cover and the number of laboratory activities to be done might be possible causes of her teaching based on a teacher-centred approach. After the two weeks of her implementation, she got some ideas about social constructivist teaching which she planned to use in another course with third-year science students in the same semester.

1.2 Darin's teaching

Information about Darin's teaching was accumulated from the third week until the semester ended. Comparing to Vipa, Darin talked very little. She did not often extensively express her beliefs, give comments and reflect on her teaching practice. She was likely to have short talks. As a result, there are few quotes presented in this section. Similar to the section on Vipa's teaching, this section begins with beliefs about teaching. Then it moves onto preparation before class, teaching strategies, formative assessment, adapted activities, instructor's reflection and change in teaching.

1.2.1 Beliefs about teaching

Darin's beliefs about teaching were revealed during the weekly meetings. She expressed her beliefs while she was sharing her ideas about teaching with the researcher. Her beliefs in teaching are discussed as the followings.

1) Students learned by doing and listening

Darin expressed her belief that students learned by doing laboratory activities before her implementation (the third week of the semester). She commented that doing every activity by themselves could facilitate students to highly achieve their learning because they could remember most of what they had done. She also argued that allowing each student to finish every laboratory activities was impractically possible in the classroom. She agreed that in some lessons, there were too many activities given in the laboratory manual to be done in three-hour laboratory session. The following conversation between her and the researcher occurred before Darin implemented the instructional set. The conversation illustrates Darin's belief that students learned by doing.

Researcher: How do you think students learn? ...How could they do to achieve the expected learning outcomes in the Laboratory in Biology course?

Darin: I think they must do every laboratory activities. They will surely achieve the learning outcomes. But mostly, due to not enough time, they couldn't do all. They needed to look at the results from other students.

Researcher: If they could do all...

Darin Right, if they could do all activities. But practically, they couldn't due to time constraint.

In the fifth weekly meeting, Darin also revealed her belief that students learned by listening while she look at the summary of the pre-service science teachers' responses in the lesson on cell membrane and cell transport" from their activity books. After she found out that most of the pre-service science teachers could not correctly answer about direction of water movement in osmosis experiments and identify the variables in the activity on cells in different concentration. She noted that she had already explained and given an example so they should have done correctly. She noted that "I told them but they did not get it" and "I told them but they might not pay attention to". This can be referred that if the pre-service science teachers listened to her, they could be able to correctly answer the questions in their activity books.

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2) Basic knowledge was needed to be told to students

Darin noted in several weekly meetings that the pre-service science teachers needed to understand the basic knowledge before doing some laboratory activities. The basic knowledge was important for them to understand the results of laboratory activities. To understand the basic knowledge, she explained it to the pre-service science teachers. She assumed that, for some lessons, some pre-service science teachers did not have or had very little prior knowledge about so that she needed to help them. This belief obviously impelled her to give brief lectures in the lessons on plant tissues and animal tissues according to the content knowledge written in the regular laboratory manual. She assumed that none of them learned about these lessons. Another situation showing the belief was in the lesson on cell structure and function where she showed her drawings of various cells investigated in the laboratory activities before the pre-service science teachers started doing the activities. She gave the reason of showing her drawings of the cells that according to her teaching experience, most students could not be able to draw the cells by themselves without seeing her drawings. They could not draw correct cell structure because they had not seen before. In addition, her drawing showed them the appearance of cells and they could recognize and understand what they saw under a light microscope.

3) Teaching concerned preparing students for examinations

Darin had the same belief as Vipa’s that she should help the students pass the examinations. She commented that observing cells, tissues and embryos from the permanent slides could make students confused and they might not achieve to observe what they needed to. She preferred to show them pictures in the projected slides than allow them to observe from permanent slides because the pictures in the projected slides were much alike the pictures in the examinations’ items. She were likely to show the projected slides to them and asked them to identify the names of cells or tissues from these project slides in the same way as asking in the examination questions. Darin also thought that her lecture with signifying the information possibly asked in the examination could make the pre-service science teachers achieve more in the examination. She also expressed a feeling of worry when she did not have time to recapitulate the content in the lessons.

4) Most students learned for good grades

Darin commented on a student learning behaviours according to her experience that most of them wanted to get good grades. She said before she implemented the instructional set that ninety-nine percent of students think marks were very important. They were likely to enrol in the subjects which give grade A easily because good grades could increase their opportunities to get a job, as shown in the following conversation.

Researcher: Do you think marks are important to students?

Darin: Oh, very much. These days, they learn for good grades. They do not enrol in difficult but useful subjects. Most of them felt sorry after they graduated. ...But while learning they chose only the subject which gives grade A easily. A hundred percent... ninety nine percent. I don’t want to say that was whole of them.

Researcher: ... Can you give a reason for this?

Darin: They want good grades.

Researcher: Why don’t they want to learn the useful subjects?

Darin: It is a value. If they get good grades, they could easier to pass tests [for applying a job], if no practical tests are required. Considering only grades and interview. Grades can tell, right?

The science student learning behaviours was discussed several times during the weekly meetings. The pre-service science teachers participated less actively in the teaching and learning activities after the midterm examination at which they made sure that no marks given for classroom participation. Also, Handing in activity books and thinking books were not part of their final grades. More pre-service science teachers did not hand in their books after the midterm examination. Darin commented that most students would not pay much attention to the tasks which they did not get marks. This implied that summative assessment strongly shaped student learning behaviours.

5) The instructional set was a supplement

When Darin began to implement the instructional in the Laboratory in Biology course, she indicated that teaching and learning activities must follow the regular laboratory manual and the pre-service science teachers must do activities in the same sequence as the regular course. She regarded the instructional set only as a supplement for the pre-service science teachers. She appreciated the social-interaction activities in the instructional set but the original laboratory activities must be done first. She got confused when the activities in the lesson plans did not follow the same sequence and use different samples which were not mentioned in the regular laboratory manual. In the lesson on cell membrane and cell transport, she firstly refused to follow the lesson plan. But the researcher asked her to try and she finally accepted. However, after teaching, she insisted her intention to follow the regular laboratory manual. In the lesson on bioenergetics, she also noted that she felt more confidence if the sequence of the activities were followed those in the regular laboratory manual.

1.2.2 Preparation before class

Darin prepared herself and instructional materials before class every week during her implementation of the instructional set. Her preparation concerned the correctness of teaching and learning materials and her careful study of the lessons plans, which can be summarized as follows.

1) Checking correctness of content and finding best answers for all questions in related teaching and learning materials

In the same year of the instructional set was developed, the regular laboratory manual was revised by the departments' members. Each lesson in the regular laboratory manual was written by instructors who have special expertise. She took time to check the correctness of the content in the regular laboratory manual as she thought it might include some errors. There were questions provided at the end of each lesson in the regular laboratory manual without answers. Some of these questions were newly created and she had never given the answers. Some questions used confusing wordings. She tried to rewrite these questions and provided the best answers for each question. The student activity book included all of the questions in the regular laboratory manual and other questions on science process skills and the nature of science with the answer keys provided in the instructor handbook. She also checked every question and answer. When she found that questions and answers were not correct, she tried to give the best answers for all questions. She consulted experts and textbooks to correct the content errors and answer the questions. For instance, to check if isotonic solution had same concentration in plant and animal cells, she asked an expert in botany. To find best answer to explained how euglenas move, she looked up her biology textbooks and clearly summarized the answers.

2) Carefully studying the lesson plans

Darin studied the lesson plans carefully and made herself clear about the content, science process skill, views on the nature of science before class. This could be seen in every weekly meeting. Sometimes she asked the researcher to clarify the definition of science process skills and aspects of the nature of science. She prepared phrases or sentences for explaining to pre-service science teachers in class. She also made a summary, step by step, of what she needed to do in class according to the lesson plans and little adjusted the wordings used to explain each activities to become easier to her to understand. She also suggested some the activities according to her teaching experience. For example, in the lesson on meiosis, she noted that it was difficult and took long time for students to find cells in all phases of meiotic division in the permanent slides of grasshopper and frog testes. So, she set up the light microscope and showed these cells rather than allowed them to do by themselves.

1.2.3 Teaching strategies

This section discusses the teaching strategies Darin utilized during the implementation of the instructional set. Her beliefs about teaching and experiences influenced her teaching practice. As she believed that student learned best by doing, Darin tended to give a very brief lecture of the content knowledge and laboratory procedures then allowed student to do all laboratory activities. She did not give much time for them to share extensive ideas. She did not feel confident and comfortable when she had to follow the lesson plans which were different from her regular practice. She was not sure whether the teaching and learning activities in the lesson plans would help the pre-service science teachers to do well in the examinations. The midterm examination results showed that the pre-service science teachers could do well. She seemed satisfied with the results. Then, she followed the majority of teaching and learning activities in the lesson plans. Darin's teaching strategies are discussed as follows.

1) Whole - class discussion as a main teaching strategy

For the first lesson of her implementation, Darin began with a lecture. For the second lesson, she agreed to try beginnings the laboratory activities with a whole class discussion. After this lesson she commented that the pre-service science teacher had been able to contribute their ideas so that the discussion flowed. She began all subsequent lessons with a whole class discussion. She used the questions provided in the lesson plans and the student activity book to lead the discussion. First several weeks of her implementation of the instructional set, Darin mostly asked knowledge questions and all of the answers for her questions were in the content knowledge provided in the regular laboratory manual. Once, she heard the key words in the pre-service science teachers' answers, she then explained the complete answers to them. She did not often give time to explain their answers. This is evidenced, as an example, in the following dialogue in from observation during the lesson on cell structure and function.

Darin:	…What is the next organelle we are going to study today?
Students:	Vacuole.
Darin:	Types of vacuole found in plants and animals are different, right?
Students:	Yes.
Darin:	What type of vacuole is found in plants?
Students:	Sap vacuole.
Darin:	What are vacuoles in animals?
Students:	Food vacuole.
Darin:	That's one. Two?
Students:	Contractile vacuole.
Darin:	What else? …Fat vacuole. What is the next organelle [which we going to study]?
Students:	Mitochondria.
Darin:	Is it found in every cell?
Students:	No.

Darin: What are the exceptional cells?

Students: Prokaryotic cells.

Darin: Generally, a mitochondrion can be found in most cells but not prokaryotic cells. What else?

Students: Red blood cells.

Darin: Yes. Red blood cells do not have mitochondria as well as nucleus. What is the function of mitochondria?

Students: Produce energy.

Darin: Yes, produce energy. They are a number of mitochondria in active cells. What are the next organelles?

Students: Cilia and flagella

Darin: What are the differences of cilia and flagella?

Students: Cilia are hair-like...

Darin: Cilia are short hair-like organelles and they are numerous. Flagella are long hair-like organelles and they are not many in a cell.

After the pre-service science teachers finished preparing wet mount slides, she used their wet mount slides as the centre of discussion in the lesson on cell structure and function, cell membrane and cell transport, cell division and plant tissues. There was a light microscope with a link to LCD provided in the laboratory classroom. Normally only the instructor uses it. Students are not allowed to use this microscope to prevent any damage possibly came from student inappropriate use of the microscope. Darin was confident that the pre-service teachers had good skill in using a light microscope so she allowed each group to set up their slides to use the microscope linked to the LCD and asked the whole class to share ideas about the observed cells or tissues. This was the first time that pre-service science teachers shared their products from learning with the whole class. This activity also helped Darin assess the pre-service science teachers' skill in using a light microscope while they were setting up the slides.

Darin also used whole class discussions for the pre-service science teachers to formulate hypotheses, identify variables and discuss the steps of laboratory procedures and results of the activities. The following dialogue is an example of using a whole class discussion on integrated science process skills before doing the experiment on how different temperatures effected rate of diffusion of potassium dichromate in water in the lesson on cell membrane and cell transport.

Darin: Do you think different temperatures make different results?

Students: Yes.

Darin: Make different results on what?

Students: Diffusion.

Darin: So, the next experiment is a test of a factor effecting diffusion. That is temperature. What is the independent variable of this experiment?

Students: ...

Darin: Do you know independent variables? What is the independent variable of this experiment?

Students: Temperature. (softly)

Darin: Louder.

Students: Temperature. (louder)

Darin: Temperature. What do you think is the dependent variables?

Students: Potassium dichromate will dissolve.

Darin: This experiment need to time. Time until it reaches an equilibrium point. You need to measure the time used. The dependent variable is time. Time used from the beginning until it reaches an equilibrium point. What are the controlled variables? ...We want to compare the temperature, what variables do we have to control? One is?

Students: Amount of water

Darin: Volume of water. Two?

Students: Amount of the solute.

Darin: Amount of the solute, which is potassium dichromate. In the

> previous experiment I saw some of you put spoonful of solute and some put very little. If you don't control the amount, you will not able to get the result, right? Two variables are controlled, volume of water must equal. It [regular laboratory manual] says 20 c.c., right? You don't put too much potassium dichromate. If you put too much, it's hard to recognize the result. I think only 1/10 spoon is o.k. or up to you. ...Now, we start doing this experiment.

In the subsequent weekly meeting, the researcher recommended her to ask more comprehensive, analysis and evaluation questions and gave more time for the pre-service science teachers to explain their answers. She improved her questioning technique in the later classes by asking more comprehensive questions during a whole class discussion and giving wait time. One example is evidenced in the lesson on growth and development. Darin assigned the pre-service science teachers who sat at the same laboratory table to form a team to answer her questions on frog development shown in projected slides. She asked the pre-service science teachers to observe a slide of a frog ovary and identify the differences comparing to a starfish ovary which they just had already discussed before.

Darin:	The next topic we learn is frog development. What is in this slide?
Students:	Ovary.
Darin:	Right or wrong? Some of you said ovary. The next question is for students at the first table. What is a difference between frog ovaries and starfish ovaries? Others have to think, too. There are some differences, I might ask you.
Students:	Nucleus.
Darin:	Not nucleus, but close.
Students:	Nucleolus.
Darin:	Yeah, nucleolus. What is the different?
Students:	Starfish has a big nucleolus.

Darin: I want better answer. Nucleolus is correct. In starfish, there are big nucleoli. How many?

Students: Only one.

Darin: How about in frog?

Students: Many.

Darin: Yeah, hundreds in some cells

2) Short lectures were given to provide basic knowledge

Darin also used short lectures as a teaching strategy at the beginning of some lessons in which she assumed that the pre-service science teachers would not have, or had very little, understanding in such as the lessons on bioenergetics, plant tissues and animal tissues to provide the pre-service science teachers' basic knowledge. Darin could give a lecture very well because she was very competent in biological content knowledge and had long experiences in giving lectures. She could explained clearly and give obvious examples with her fluent speech. Her lectures were very interesting. She also asked some questions during her lectures. She asked many questions at the beginning of her lectures but the number of questions decreased after a while and finally she only presented and explained the content. The questions Darin used was dominated to knowledge questions and required only short answers. However, she provided enough wait-time for the pre-service science teachers to answer her questions.

3) Providing assistance during laboratory activities

Darin provided assistance for the pre-service science teachers while they were doing laboratory activities. Darin usually helped them do the laboratory activities and explained the results individually and in groups. She always walked to each group and looked for pre-service science teachers who needed her help. The majority of laboratory activities of the lessons she taught were observations of cells, tissues and embryos under a light microscope. The pre-service science teachers needed her help when they could not find the cells or were not sure of what they were observing. She always set up the light microscopes for them and pointed out the cells or tissues which the pre-service science teachers needed to observe rather than guide them to do by themselves. When the pre-service science teachers could not get obvious experimental results, Darin explained the results for them. For example, in the lesson on enzymes, the whole class could not observe the bubbles produced by a reaction of an enzyme in potato solution: catalase and a hydrogen peroxide (H_2O_2) solution due to too-low concentration of H_2O_2 used in the laboratory. Darin presented and explained the results she got from the pervious semester. The pre-service science teachers were appreciated her assistance during learning.

1.2.4 Formative assessment

This section discusses Darin's use of and benefit from formative assessment strategies according to the instructional set. Formative assessment helped her in eliciting the pre-service science teachers' understandings and feelings during learning and also comments and suggestions on her teaching.

Darin did not value in acquiring the pre-service science teachers' responses in the activity books and thinking books at the beginning. She thought these responses were obtained for the results of the research study and had no bearing on her teaching. After the researcher presented the summary of these responses to her, she realized that pre-service science teachers' information reflect her teaching practice and could be useful to improve her teaching. She spontaneously became more interested in the information about the pre-service science teacher learning and carefully read the summary every week. Darin obtained the misunderstandings from the pre-service science teachers' activity books and thinking books. She corrected these misunderstanding by explaining the correct concepts after the quiz activity in the subsequent session.

In group presentation and whole class discussion activities, Darin listened to the pre-service science teachers' biology concepts then gave feedback and fulfilled the concepts. In the lesson on reproduction, Darin listened to the pre-service science teachers' group presentations of asexual and sexual reproduction in various organisms. While each group was presenting, she listened carefully and tried to capture some misunderstandings which they might included in their presentation. After each group finished their presentation, she gave comments, asked more questions, and correct the misunderstandings. The following excerpt shows how Darin commented on a group of the pre-service science teachers' presentation on pollen production.

> The presentation of this group is very good. But there is only one point…in your first transparency. Pollen production is not spermatogenesis. …All of the process is called pollen production. There is a term for it but it is not used anymore. Only this point is wrong. This group is very good.

The following excerpt is Darin's comment on the pre-service teachers presentation on the components of flowers. Darin corrected a misunderstanding that ovaries, pollen sacs and sepal were the most important parts of flowering plants for reproduction. Also, she introduced several term which had the same meanings as pollen.

> The content of this group had to be corrected a little. The answers were incorrect. I think there is only two parts [of a flower] which are the most important. These are? …Ovaries and pollen sacs. Only these two parts. …Because an ovary is the organelle which produces egg and a pollen sac produces pollens. …I will add that pollen, pollen grain and male gametophyte have the same meaning.

Darin also gave feedback and fulfilled the pre-service science teachers understanding in post-lab discussion. She allowed groups of science student teachers presented and discussed the laboratory results with the whole class. The following dialogue shows Darin's questions and feedback for the pre-service science teachers in a discussion of the result of an experiment on pH and enzyme activity in the lesson on enzyme.

Presenter: …At pH 7, it produced the highest level of bubbles so the enzyme effectively functioned in neutral pH.

Darin: What is the independent variable of this experiment?

Presenter: The independent variable is pH.

Darin: What is the dependent variable?

Presenter: The level of bubbles.

Darin: …Any other groups got a different result?

Students: Three.

Darin: What pH? Three? …there were no groups of students I taught [in the previous semesters] found the highest level of bubbles at pH 3. Any groups got a different result?

Students: Seven.

Darin: Seven. Most of you got seven, right? How many groups got three? …Two groups. O.K. most of you got seven. …As my experience of teaching many groups of students, the enzyme most effectively functioned at pH 9 or pH 7. At pH 3, there were very few bubbles.

Students: Because an experiment can easily produce errors, so we have to do the experiment many times.

Darin: We have to be very careful in doing experiment with the least number of errors. We have to do the experiments many times. We can check the result with other students in the same and the other laboratory sections …hundreds of times then we conclude the result.

Darin benefited in using quizzes to find out the science student understandings of biological knowledge they had learned from the previous lessons, same as Vipa did. Before the beginning of each lesson, she asked them to take a quiz of what they had learned in the last session. Then, she allowed the whole class to discuss to answer the quiz questions which were very similar to those asked in the examinations. Darin mostly generated the questions in the quizzes from the pictures in the projected slide because they were clear and easy to set up.

1.2.5 Adapted Activities

Darin adapted several activities to match the situations in the classroom. She followed the lesson plans as much as she could, especially after she gained more confidence on the instructional as the majority of the pre-service science teachers could do well on midterm examination. She expressed that they could do better than those who learned through the regular practice in the earlier years. The majority of her adapted activities were adjusting time used in order to finish the classes on time. She allowed more time for the pre-service science teacher to discuss, share and present their ideas and the laboratory results after the midterm examination. However, she noticed that the pre-service science teachers always took additional time in doing laboratory activities and sharing the results of the laboratory activities with the whole class. Darin, in response, gave less time for them in group discussion and sharing ideas to answer the pre-lab and post-lab questions in some lessons.

Another adapted activity Darin used was in the situation that none of the pre-service science teachers could prepare wet mount slides of plant leaves in the lesson on bioenergetics. Because the lab staff did not give them sharp razors, the pre-service science teachers could not make thin leaf sections for observing under a light microscope. Darin needed to show them the pictures in the laboratory manual. This situation reminded Darin the check if the pre-service science teachers were provided good quality of laboratory apparatus before the beginning of the class in the subsequent weeks.

1.2.6 Instructor's reflection on practice

Darin followed most of the activities in the lesson plans and researcher's suggestion as discussed in the weekly meetings, especially after the midterm examination. She indicated that she tried to follow as many as possible of the activities in the lesson plans which she was not used to with the pre-service science teachers for the sake of the study. She did not reflected on much of her own teaching but she used the information she obtained from the pre-service science teachers and the researcher to adapt the activities in the subsequent laboratory sessions.

There was only on activity which Darin could not always follow the lesson plan that is the last activity of every class session: summarizing the concepts, science process skills and the nature of science using the concept map provided. The intention of the instructional set for the summarizing of teaching and learning activities at the end of each laboratory session was to ask the pre-service science teachers to discuss and explain what they had done and learned. Darin reflected on the situation that the pre-service science teachers were very off-tasks as they were preparing themselves to go out of the class, talking aloud to each other and paid little attention to the classroom activity. This off-task behaviour made Darin ran this activity in a very short time and she thought that she needed to summarize the activities for them. The following excerpt is Darin's summary of teaching and learning according to the concept map in the lesson on plant tissues.

> Today we study plant tissues. There are meristematic tissues and permanent tissues. There are many tissues we study today. ...And what we have done. We prepared slides and observed. The observational skill is important. It enables us to acquire scientific knowledge. Existing knowledge, experiences and bias... the activities we have done today exactly shows that bias influences interpretation of results... It needs obvious evidence to change the biased ideas.

Darin was not used to summarize teaching and learning activities and it seemed that she partially understood the concept maps. Later, the researcher asked her to assign some pre-service science teachers to explain the concept map. Darin tried to do this in class and it was found that the pre-service science teachers could explain the concept map and give additional information which was not presented in the concept map. The following excerpt is a pre-service science teacher (S29)'s summary of teaching and learning according to the concept map in the lesson on reproduction.

> Activities we have done today are about reproduction. We studied both sexual and asexual reproduction. In asexual reproduction, the existing characteristics remains such as budding in hydras, fission in amoeba and paramecium, fragmentation in starfish and some algae and sporulation in mushrooms and ferns. …In sexual reproduction, in plants, flowers are the reproductive organ. The most important parts are stamens and pistils. …If these two parts were absent, plants could not reproduce. There are pollens in stamens and there are eggs in pistils. When pollens and eggs are together, it is called pollination. In animals, it [sexual reproduction] relates to oogenesis in ovaries. Fertilization produces zygotes. The knowledge about reproduction we learned today is from observation of slides and other materials. Then we present… this is related to the nature of science. …These activities make knowledge. …Do you think that the regeneration of a lizard's tail is reproduction? ...No. Because reproduction means increasing a number of organisms. If there are no more organisms, it is reproduction. This is an easy example of reproduction.

Darin commented the summative assessment by the department in the second weekly meeting. Her comments could be summarized that she quite disagreed with using only paper and pencil tests as the only strategy to assess student learning in the Laboratory in Biology course. She proposed the practical assessment of assessing students' skills at using microscopes to her colleagues but it was rejected because the majority of the instructors did not agree with her idea. Darin expressed that no marks given during the learning made most students pay little attention. She preferred to allocate 30% of the final grades to the marks during the learning. Many years ago, some marks were given to students during learning and she used quizzes of content and the laboratory procedure. She noted that after there were no marks given during learning, she ended up the activity. This could be confirmed that summative assessment influenced her practice.

1.2.7 Instructor change in beliefs and practice

It was found that instructor's beliefs could change after the teaching approach of the instructional set was proved its effectiveness by the pre-service science teachers' midterm examination result. Darin started implementing the instructional set with her doubts and worries in her mind whether she could follow the lesson plans which she was not used to. She was not sure if she could manage all of the activities in each three-hour period because there was already a large amount of content to cover as mentioned in the regular laboratory manual.

At the beginning of her implementation of the instructional set, Darin signified the regular laboratory activities as the most important material for teaching and learning in the Laboratory in Biology course. The pre-service science teachers had to finish all the regular laboratory activities before they did activities related to the nature of science and science process skills which included answering questions and discussion. For the first several weeks, she did not seem to be pleased with teaching following the lesson plans.

The midterm examination results showed that the pre-service science teachers could do better than the average comparing to pre-service science teachers who learned in the earlier years. Then Darin followed most activities in the instructional set from the week after midterm till the end of the semester. Darin provided opportunities for the pre-service science teachers to learn through social interaction. She gave wait time for the pre-service science teachers to explain their answers more than before. She allowed them to take time to think in groups and asked the whole class to check whether the laboratory results were correct.

Types of questions she used were changed from knowledge questions to comprehensive questions. Before the midterm examination, she mostly asked knowledge questions and gave them little time to think. Once, she heard the key words of the answers, she explained the complete answers. Darin with a use a lecture to provide basic knowledge and present the laboratory results at the first week of her implementation. Her teaching was changed since the second week in that she follows the lesson plans and suggestions from the researcher to allow the pre-service science teachers to discuss, reflect on and share ideas during learning. She also used every instructional materials provided in the instructional set such as word cards and articles to be read.

In addition, Darin started the implementation without appreciation of obtaining the information about the pre-service science teachers during the learning from the formative assessment tools provided by the instructional set. But she gave increasing concerns about pre-service science teachers' conception during learning in that she paid more attention to the weekly summary of their responses in the activity books and thinking books. She corrected the misunderstanding captured in their books at beginning of the subsequent lesson.

From the results on Darin' s teaching, it could be summarized that she teaching was based on a learner-centred approach as she employed the social constructivist teaching and learning perspectives. Darin provided opportunities for the pre-service science teachers to be active learners to discuss, reflect on and share their ideas on what they learned during learning. She allowed them to bring some samples to study in class according to their interests. Formative assessment helped her in acquiring student information which could be useful in adapting subsequent teaching and learning activities to match their abilities.

Like Vipa, Darin's beliefs about teaching obviously influenced in her teaching practice. Her superior aim of teaching was to promote understanding in biology concepts. Darin started the implementation with hesitation because the underlying ideas of the instructional set were mostly opposite to her beliefs. But some beliefs could change after the teaching approach of the instructional set was proved it effectiveness on the pre-service science teachers' marks in the midterm examination. Darin's teaching highlights the influence of summative assessment on both instructor teaching and students learning.

Comparing teaching of both instructors Vipa and Darin, they began the implement of the instructional set with a more teacher-centred approach which was impelled by their beliefs about teaching. They shared similar beliefs about teaching and students, for example, students learned by listening, instructor needed to tell the correct biology concepts so students would understand and instructors must help them to pass the examination. They were both well-prepared before class. They closely helped the pre-service science teachers while they were doing the laboratory activities, providing feedback and give suggestions. Their adapted activities were much based on the teaching strategy which they were accustomed to and used in the previous years by telling students of the content, laboratory results and how to do laboratory activities. During implementing the instructional set, both of them had learned about teaching from the instructional set and changed their ideas and teaching practice towards a more learner-centred approach.

2. Pre-service science teachers' learning

This section describes the pre-service science teachers learning during and after they participated in the Laboratory in Biology course in which the instructional set was implemented. This section covers two main topics; how the pre-service science teachers learned and learning outcomes, which are detailed as the followings.

2.1 How the pre-service science teachers learned

Data from observations, the responses in their student thinking books and interviews after learning highlighted how the pre-service science teachers learned. They had three learning strategies to develop their understandings and skills, which are learning by listening, learning by hands-on and minds-on activities and learning by social interaction. Details are presented and discussed as follows.

2.1.1 Learning by listening

Learning by listening was one important learning strategy the science student used when they participated in the Laboratory in Biology course in the semester in which instructional set was implemented. When the instructors gave lectures and showed them pictures and information in transparencies, all of them listened quietly and intentionally. They also took notes of what the instructor said in their handbooks or notebooks. Many pre-service science teachers commented in their student thinking books about Vipa’s and Darin’s teaching that they liked their teaching because it made them well-understood. Both instructors clearly explained the concepts, highlighted the important concepts they needed to know and gave good clear examples. For the strategy which could make them learn better, one of them suggested they should have had time to listen to the instructors to explain the concepts again.

The following quotes are examples of the pre-service science teachers expression related to their learning by listing in their thinking books.

> Today I learned happily because the instructor explained very clearly, had good examples. This makes me learn very well (S4).

> I want the instructor to explain more about classification of organisms (S22).

> I like that the instructor reviewed the content in the last lesson. This made me remember [the content] well and helped me in reviewing the lesson (S23).

> The instructor taught very well. She signified the content that we needed to remember (S15).

> [If I could change what I have done in the last laboratory session], I would carefully listen to what the instructor said and clearly identify the differences of cell appearance in different phases [of cell division] by myself (S18).

2.1.2 Learning by doing hands-on and minds-on activities

During doing laboratory activities, they developed practical skills via hands-on activities. The pre-service science teachers had opportunities to use light microscopes, prepare wet mount slides of various cells and do various experiments. They had learned how to use laboratory apparatus during the activities. Most of them could use the light microscopes more confidentially and prepare better wet mount slides in the later laboratory sessions. For example, a pre-service science teacher developed the skill at preparing slides by a squash technique in that she could prepare a very good slide of Chinese leek flower cells for observing the cells in meiotic phases and she could do better in the lesson on reproduction when she prepared the same sample.

The pre-service science teachers also conceptualized biological concepts from doing experiments. For example, in the lesson “Cell membrane and Cell transports”, one group of the pre-service science teachers was assigned to present and explain the result of the osmosis experiment which filled sucrose syrup in a tristle funnel sealed the broad end with a permeable membrane, turned it up-side-down and put in water. According to their experimental result, they could clearly explain that the rate of osmosis would decrease after a period of time because the concentration of the syrup and water became less different. Asking them, after class, where they got the idea, they noted that they directly got it from observing the experimental results and think by themselves.

The following quotes are examples of the pre-service science teachers expression related to their learning by doing hands-on and minds-on activities in their thinking books.

> I learned from real samples not from pictures in textbooks or by lectures (S2).

> I felt happy in learning as I did many activities by myself, not only listen to lectures (S4).

> It’s amusing to learn by doing activities by myself, not remember from textbooks (S12).
>
> I want to study all organisms in every slide by myself (S27).
>
> Discussing the results immediately after doing experiments made me understand very well (S13).
>
> Teaching and learning activities of this laboratory section is very good that students really do activities and see the results. I like very much… This makes me understand the problems occurred while doing activities and students in each group help each other to solve the problems (S14).

2.1.3 Learning by social interaction

Another important learning strategy that the pre-service science teachers were employed was learning by discussing and sharing ideas and knowledge in social interaction with their classmates, instructional materials and the instructors. This was highly evidenced in the teaching and learning activity in the lesson on reproduction. In the activity, each group of the pre-service science teachers was randomly assigned one of the nine topics to be learned in that period. Each group learned from the instructional materials provided such as permanent slides, organism’s samples and pictures, with helps of Darin’s. Then, they prepared a short presentation for the whole class. In the presentation, many groups could explain clearly about the content knowledge to their classmates. They also included some teaching strategies such as asking for shared ideas, using questions, and giving rewards when their classmates could correctly answers their questions which they used to assess their peer’s understanding of the topics they presented.

The following quotes are examples of the pre-service science teachers expression related to their learning by social interaction in their thinking books.

> I like that the instructor paid attention to us and wait for our answers for her questions. I felt active in learning (S1).
>
> I got bored when the instructor gave lecture because I had to sit still. I would like to learn through the activity that allows student to discuss in groups to answer the instructor's questions and give rewards (S17).
>
> I felt happy in learning because I worked with friends and shared ideas to explain the characteristics of the organisms we observed (S28).
>
> I was happy in learning as I worked with my friends and helped each other (S20).
>
> I think the instructor taught very well. All students had participation in the activities. She allowed us to consult and ask questions (S3).

To sum up, it was found three learning strategies; learning by listening, learning by hands-on and minds-on activities and learning by social interactions. The pre-service science teachers used these strategies to develop their biology concepts, science process skills, views on the nature of science and attitudes towards biology during they learned in the Laboratory in Biology course while the instructional set was implemented. In the next section, their learning outcomes during and after learning through the instructional set are presented and discussed.

2.2 Learning outcomes during learning through the instructional set

In the following section, the pre-service science teachers' learning outcomes; including biology concepts, science process skills, views on the nature of science and attitudes towards biology are presented and discussed. The learning outcomes during the learning were captured by documents including their activity books, quizzes, student thinking books and some pieces of work their produced during their learning.

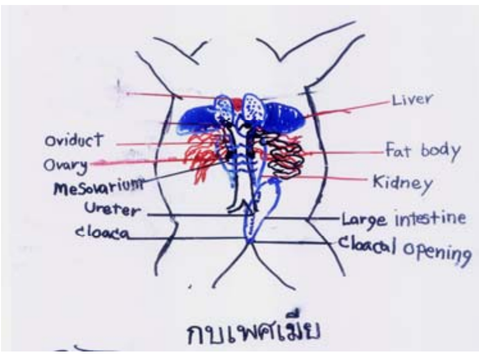
2.2.1 Biology concepts during learning

The majority of the pre-service science teachers' biology conceptions during the learning were captured in their activity books and thinking books that they were asked to hand in every week. In the first few weeks of the semester, almost all of them handed their books. But the subsequent weeks especially after the midterm examination, the number of their books was reduced by half of the total. This means that the findings were only from activity books and thinking books of the ones who handed these books in. In addition, the pre-service science teachers were likely to copy the answers in activity books of their peers. So, it could not say that the findings were biology conceptions of all but some of the participant pre-service science teachers.

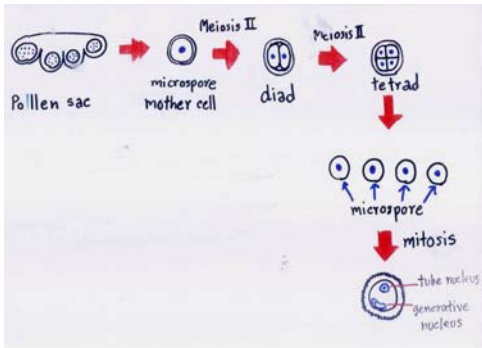
It was found that the pre-service science teacher had gained biology conceptions during the learning which was evidenced by their answers and drawings of cells and organisms in their activity books. The majority of the pre-service science teachers could correctly fill in most of the blanks and answer most of the questions provided. The answers of most questions were from the activities they had done and discussed in class. Some of them also wrote other facts and information they had learned from the activities in their books. In some lessons, they were asked to draw pictures such as cells, cell division and reproduction.

However, not all of the pre-service science teachers could perfectly complete the activity books. Some misunderstanding and mistakes were captured in every lesson. Their misunderstanding were found in terminology confusion such germ cells and sex cells, unique characteristics of different types of organisms' cells. Some pre-service science teachers also showed their misunderstanding in diffusion in gas phase, definition of paper chromatography and terms about growth and development; including grey crescent and neural tube. Some of them could not identify the differences between monocotyledons' and dicotyledons' leaves, and male & female frog reproductive systems. Mistakes in labelling of cell structure, identifying of the magnification of the drawing they drew from what they saw under light microscopes.

Working in group, the pre-service science teachers had opportunities to present their understandings in reproduction and ecology to the whole class. They could clearly communicate to the listeners although they showed several misunderstanding of the concepts. They also had the ability in art that they decorated their presenting materials wonderfully. In the lesson "Reproduction", each group chose transparencies to be the presenting materials. Figure 6.2 shows the examples of their transparencies. In the lesson "Ecology", they prepared posters to present the components and food webs in the areas which they had surveyed. Two of the presented posters are shown in Figure 6.3 and 6.4.



(a)

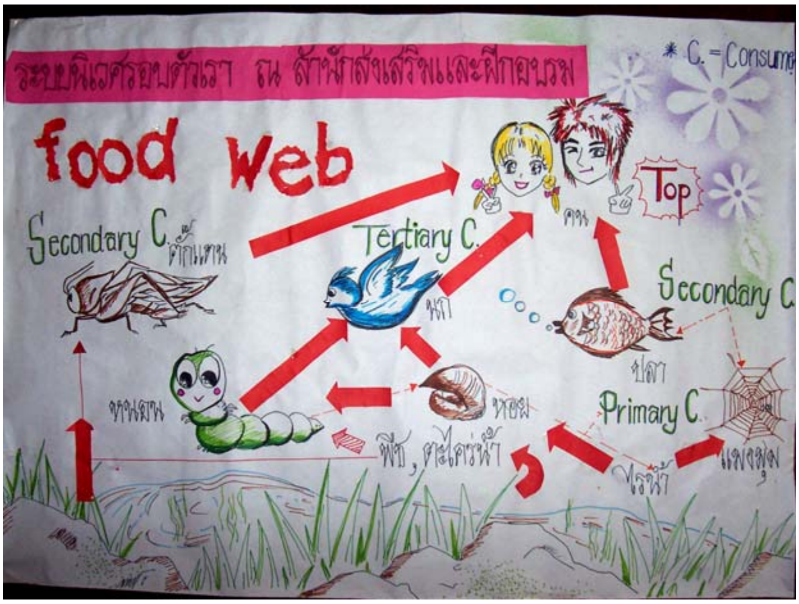


(b)

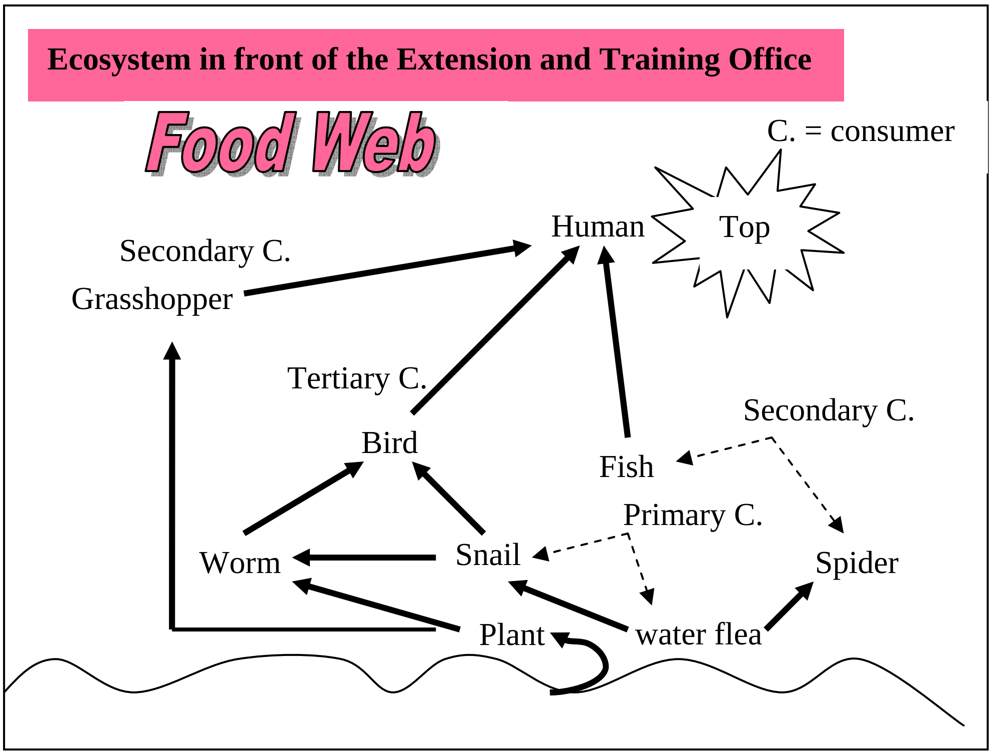
Figure 6.2 Pre-service science teachers' transparencies

Note: (a) Female frog reproductive system

(b) Genesis of microspores in *Lilium sp.*



(a)



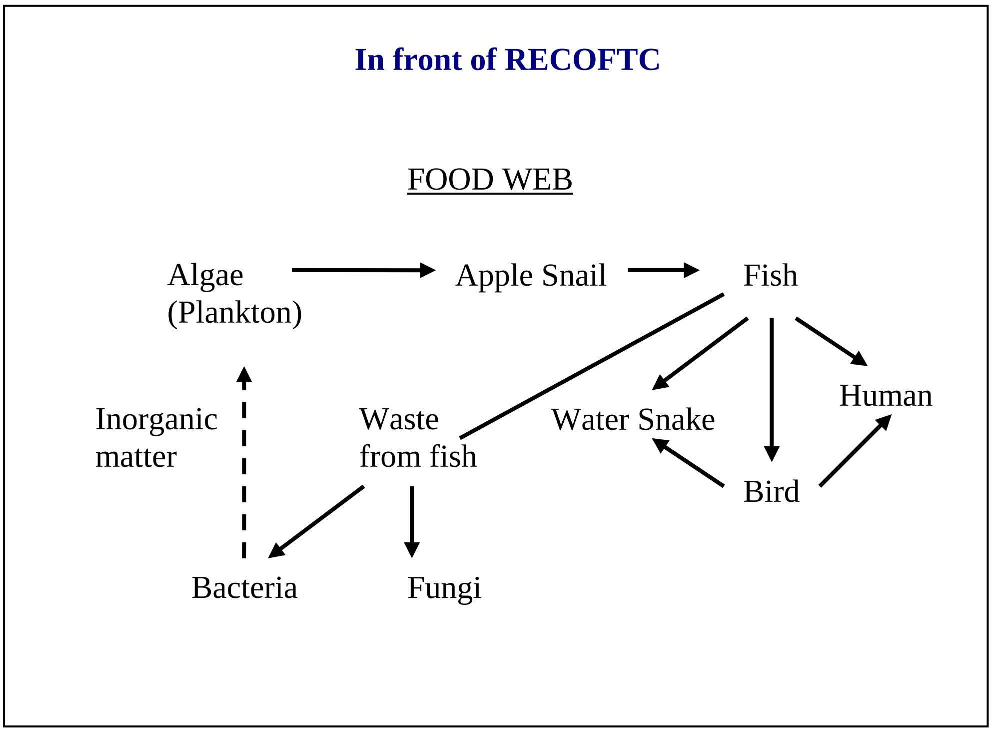
(b)

Figure 6.3 Pre-service science teachers' poster of food web (1)

Note: (a) Original poster

(b) Translated poster

(a)



(b)

Figure 6.4 Pre-service science teachers' poster of food web (2)

Note: (a) Original poster

(b) Translated poster

These transparencies (Figure 6.2) and posters (Figure 6.3 and 6.4) showed good drawings and decorating but part of them revealed some misunderstanding. For instance, the poster in Figure 6.3, identifying the niches in the ecosystem, showed some misunderstandings about consumers. The grasshopper must be a primary consumer but they noted it was a secondary consumer. Their confusion also showed by snail and water flea in which they indicated that both were primary consumer. As shown in the poster, the snail, if it eats water flea, should be a secondary consumer. In addition, most worms do not eat snails and spiders do not eat water fleas. The poster in Figure 6.4, attempted to show the cycle of energy transfer and included two decomposers and an organism's waste into the food web, but they could not identify the direction of energy transfer from fish to waste of fish.

2.2.2 Science process skills during learning

Science process skills focused during the learning through the instructional set were integrated science process skills; formulation hypothesis, identifying variables, experimenting, interpreting data and drawing conclusions. The pre-service science teachers had many chances to practice the skills, especially in the lessons on cell membrane and cell transport, enzymes, bioenergetics and ecology. The communication skill was very obvious in the lesson of reproduction and included in every lessons in which they were asked to share ideas and present their work to the whole class. Other lessons were related to the basic science process skills such as observation, classification and referring.

Their science process skills during the learning were captured by observations and evidenced in their activity books. In every activity related to experiments, there were discussions about formulating hypotheses, identifying and controlling variables. They were asked to provide possible experimental results, do the experiments, interpret data and draw conclusions and write down in their activity books. The discussions in the first few experimental activities were lead by the instructor because very few of them shared their ideas. Most of them kept quiet and listening. But, in the latter experimental activities, more of them shared ideas. In their activity books, most of them could correctly provided the sections which asked them to identify the hypotheses and variables, experimental results and conclusions for most experiments.

2.2.3 Understanding in the nature of science during learning

In lesson plans, the pre-service science teachers were provided many opportunities to share, discuss and reflect on their views on the nature of science in class through the activities. Due to the time constraint, the instructors could provide little time for the pre-service science teachers to share ideas in most of the nature of science activities. Their views on the nature of science were mostly captured from their student thinking books. They did not explain much of their ideas in their books. Most of them only wrote down the main ideas they learned about the nature of science. Most of their understandings in the nature of science in their activity book and thinking books were appropriate.

From observations, the most obvious view on the nature of science the pre-service science teachers expressed during learning was that science can change over time. Tentativeness of science was focused in the lesson on enzymes which asked them to read an article and identify this aspect of science from its content. Both instructors seemed to emphasize on this aspect more than the others. Vipa introduced this aspect since the first class. Darin also noted about it several times in the later classes such as in the lesson “Enzymes” and “Plant tissues”.

The pre-service science teachers obviously learned about the nature of science through the activities with instructional materials by discussion on given articles (lessons on enzymes and animal tissues) and pictures (lesson on plant tissues). Most of the pre-service science teachers wrote the main ideas about the nature of science as planned in the lesson plans. For several lessons which used questions to reflect on their ideas (such as lessons on cell division and bioenergetics), their views on the nature of science was not extensively explained in their thinking books.

An example of activities to promote the pre-service science teachers understandings in the nature of science was in the lesson on growth and development. Cloning was introduced as an application of the growth and development concepts. An interactive flash animation in a website was presented and the whole class discussed to answer some questions related to the content of the animation. Then the pre-service science teachers were asked to share ideas about interrelation of science and society. Darin gave an opportunity for the whole class to share ideas. The following dialogue illustrates this activity.

Darin:	How do you think about human cloning?
S3:	Immorally.
Darin:	If there are some people look alike.
S12:	When one of them commit a crime, on one knows who does.
Darin:	The criminal might not be arrested. This is a bad point. ...Do you think human clones should be made? Why?
Students:	(Mumbling)
Darin:	If you agree, raise your hands. ...None of you? ...None. If you disagree, raise your hands.
Students:	(Most of them raised their hands)
Darin:	Most of you. And the ones who did not raise your hands, what do you think? Whatever or ... no comments?
S17:	I think it’s good to clone animals but it’s bad to clone humans.
Darin:	Can you explain why you disagree with human cloning?
S17:	I agree with animal cloning. It provides benefits. For example, to clone a number of good-characteristic cows for agriculture. But human cloning might be bad. For example, in crimes as we have already discussed. Cloning is not all bad. It depends on what kind of organisms to be cloned.
Darin:	Very good. ...any of you have different opinions? ...Anyone? Or you all agree with your friend. ...Why do you think they generally accept human cloning? ...In what way?

Students:	Morality.
Darin:	Yeah, morality and ethics. ...If a scientist discover the scientific knowledge that potentially be harmful to the society, do you think he should present the knowledge to the public? And why? ...What do you think?
S21:	He shouldn't.
Students:	He should.
Darin:	But it [the scientific knowledge] might be harmful...
S17:	It will inform us that the experiment produces a harmful result so we will not do it. Just present the result...
S19:	What if someone use it in a bad way?
	(Students shared many ideas but not loudly)
Darin:	So, what do you think? He should or shouldn't?
S3, S12,S19:	He shouldn't because the scientific knowledge can be used in a bad way.
Darin:	But scientists should present the scientific knowledge they discover. ...They would present only facts but not recommend for applications.
S17:	Then the society will know only good things, not the bad things. I think we must know both good and bad things.

2.2.4 Attitudes towards biology during learning

The pre-service science teacher's attitudes were mostly captured by their responses in their student thinking books. Each week, many Statements towards teaching and learning activities through laboratory learning, the instructional set and the instructors' practice were written. Most of these messages expressed their positive feelings towards the Laboratory in Biology course and their enjoyment in learning. The examples of positive statements are shown in Table 6.1. Each statement was given by one pre-service science teacher.

Table 6.1 Positive statements related to positive attitudes towards biology

Lessons	Positive Statements
Microscopes	"I was happy to prepare a wet mount slide by myself and practice to use the microscope appropriately" (S4). "I learned happily. I'm excited to practice to use the microscope"(S11).
Biodiversity	"I enjoyed studying these beautiful organisms" (S15). "I was very excited to see many organisms... some organisms I only heard of their names but I saw them today" (S19). "I think the Laboratory in Biology course not very difficult as my friends told me. If we concentrate, we can do it. And I will pay attention to learning and do my best" (S28).
Cell Structure & function	"I felt very happy to work with my friends" (S22). "I was excited to see many cells I've never seen" (S11).
Cell membrane & Cell transports	"I was happy to do the experiments which helped me understand more than reading books"(S16). "I liked the instructor that she let us do experiments one by one, this made me understood, not confused and amused"(S 14).
Enzymes	"It's amusing to do many experiments. I was happy"(S11).
Bioenergetics	"I was amused and I understood what the instructor explained"(S19).
Cell division	"I'm happy, not bored because I prepared a slide by a squash technique" (S9).
Plant Tissues	"I was happy, not bored that we studied many interesting tissues" (S16).
Animal Tissues	"I was excited because I saw many cells that I've never seen and I like the matching game [animal tissues and functions], it challenged me a lot" (S27).
Reproduction	"I'm excited to study the real specimens" (S3). "I was impressed with all of the group presentations and they made learning not boring" (S5).
Growth & Development	"It was amusing while I was identifying the components of seeds... It's like I was playing a game" (S27). "I was happy with eating the fruit and watching the video clip at the same time" (S10).
Ecology	"I was very alert because we did the activities outside class" (S16). "I was happy, not bored, to get to the experimental site"(S9).

These positive statements showed their feeling of enjoyment, excitement, happiness and amusement when they participated in the Laboratory in Biology course. These statements were related to their satisfaction of various teaching and learning activities, experiencing the samples of organisms in which they found unseen and beautiful, working with peers and the instructor help.

The negative statements were also found, but from the minority of the pre-service science teachers. The lessons which the pre-service science teachers were likely to give negative statements were enzymes and animal tissues. For the lesson “Enzymes”, hydrogen peroxide used as the substrate in the enzyme experiment could not produce the clear results due to its low concentration. This made the pre-service science teachers could not observe the results. Also there were many experiments to finish and the last two experiments included a number of chemicals to add in the test tubes. As they noted that:

> I was confused because the experimental results were not very clear (S5).

> I was tired of adding chemicals (S10).

> It [Learning] was quite confusing because there were too many experiments. I could not make myself understand all in class (S11).

For the lesson “Animal Tissues”, the negative statements showed their confusion of the animal tissues and their appearance. As they noted:

> I was confused with the components of the tissues. I was confused that I can’t remember their appearance (S26).

> I was confused a little because I’ve never seen them before (S4).

In brief, most of the pre-service science teachers showed their positive feelings through laboratory learning, the instructors’ practice and the Laboratory in Biology course. Some negative feelings were found when they faced confusion of content and experimental procedures.

In summary, the results of pre-service science teachers’ learning outcomes during learning were mostly obtained by classroom observation and gathering information from the activity books and thinking books. It was found that the pre-service science teachers developed their understandings, science process skills and positive attitudes towards biology during doing laboratory activities which provided opportunities to share, discuss and reflect on their ideas about what they learned. The next section discusses the pre-service science teachers' learning outcomes after learning through the instructional set.

2.3 Learning outcomes after learning

2.3.1 Biology concepts after learning

This section presents and discusses the pre-service science teachers' understandings in biology after the learning. Their biology conceptions were assessed by the Biology Concept and Science Process Skill Questionnaire After the pre-service science teachers took the final examination of the semester in which the instructional set was implemented, all of them were asked to give responses to the questionnaire. But only fifteen of them were willing to complete the questionnaire. Table 6.2 presents their response of open-ended questions in percentage. The pre-service science teachers' biology concepts after learning are discussion as followings.

From Table 6.2, it was found that the majority of the pre-service science teachers had partial understanding in most concepts. Scientific understandings were found in three concepts; prokaryotes & eukaryotes, osmosis, application of osmosis and sexual reproduction. High percentage responses with specific misunderstanding were found in the concept of osmosis (47%), meiosis: genetic information in daughter cells (20%) sexual reproduction (20%) and ecosystem (20%). The pre-service science teachers were likely to give no responses for cell division in that they could not give more explanation of their responses and repeated what already given in the questions. Responses of these fifteen pre-service science teachers' to all questions in details are presented and discussed under the names of each biological topic as the followings.

Table 6.2 Pre-service science teachers' responses in open-ended question of each concepts (Phase II)

(n=15)

Concepts	Responses (%)				
	SU[1]	PU[2]	PS[3]	SM[4]	NA[5]
1. Cell structure & function	-	53	47	-	-
2. Prokaryotes & eukaryotes					
2.1 Prokaryotes	7	33	40	7	13
2.2 Eukaryotes	7	80	-	-	13
3. Osmosis	27	20	7	47	7
4. Application of Osmosis	7	87	-	7	-
5. Cell division					
5.1 Organisms having mitotic cell division	-	67	-	7	27
5.2 Organisms having meiotic cell division	-	80	-	-	20
5.3 Mitosis: genetic information in daughter cells	-	13	-	-	87
5.4 Meiosis: genetic information in daughter cells	-	80	-	20	-
6. Reproduction					
6.2 Sexual reproduction	-	100	-	-	-
6.2 Asexual reproduction	80	-	-	20	-
7. Photosynthesis: starch test	-	87	7	-	7
8. Ecosystem: meaning	-	73	-	20	7

[1] Scientific Understanding

[2] Partial Understanding

[3] Partial Understanding and Specific Misunderstanding

[4] Specific Misunderstanding

[5] No Answer

1) Cell structure & function

The pre-service science teachers were asked to identify the wrong labelling of cell structure (Figure 4.1) and provided explanation why the labels were incorrect. Their responses are shown in Table 6.3.

Most of the pre-service science teachers could correctly identify the correct labelling of cell wall, cell membrane, chloroplast and mitochondria. Every pre-service science teachers knew that the cytoplasm was correctly labelled so none of them chose this cell structure. Nucleus and nucleolus were chosen by seven of them (47%) and they supported their answer that these two cell structure had swapped labels. But these two cell structure were correctly labelled, so these pre-service science teachers showed misunderstanding of nucleus and nucleolus.

Table 6.3 Identifying the incorrect labelling of the cell in Figure 4.1 (Phase II)

(n = 15)

Cell Structure	**%Responses**
Cell wall	87*
Cell membrane	87*
Chloroplast	60*
Mitochondria	67*
Cytoplasm	0
Nucleus	47
Nucleolus	47

* correct answers

Considering their reasons for identifying the wrong labels of cell structure, none of pre-service science teachers could correctly identify the position of cell wall, cell membrane, chloroplast and mitochondria and also explain the characteristics and functions of these cell structures. Thus, no responses were categorized as scientific understanding (SU). The majority (53%) of pre-service science teachers had partial understanding (PU) in that they could identify only part of the response of the SU. Most responses in the PU category only explained the structure and function of cell wall and cell membrane. Forty-seven percent of pre-service science teachers had partial understanding with specific misunderstanding (PS). Most of them could identify the correct positions and correctly explain the structure and function of cell wall and cell membrane. Misunderstandings were found that they thought nucleus and nucleolus had swapped labels.

2) Prokaryotes & eukaryotes

Examples of organisms were given: bacteria, mushroom, blue green algae, starfish, hydra and fern. The pre-service science teachers were asked to categorize these organisms as prokaryotes or eukaryotes and identify the criteria of their categorization. Percent of pre-service science teachers' responses categorizing the given organisms as prokaryotes or eukaryotes is shown in Table 6.4.

Table 6.4 Categorizing organisms as prokaryotes or eukaryotes (Phase II)

(n=15)

Organisms	Prokaryotes	Eukaryotes
Bacteria	93*	0
Mushrooms	33	53*
Blue Green Algae	93*	0
Star Fish	0	93*
Hydras	7	93*
Ferns	0	87*

* correct answers

The majority of the pre-service science teachers (93%) could correctly categorize bacteria and blue green algae as prokaryotes. About half categorized mushrooms as a prokaryote but this is incorrect. A difficulty was found in categorizing mushrooms (33%), hydras (7%). Only one pre-service science teachers (7%) could provide the correct criteria of categorization that prokaryotes do not have nuclear membrane and membranous organelles and his response was only scientific understanding (SU). Thirty-three percent showed partial understanding (PU) in that they could either identify the absence of nuclear membrane or membranous organelles in prokaryotes. Forty percent of them showed partial understanding with specific misunderstanding (PS) in that they identified the wrong organisms and included incorrect characteristic of prokaryotes; only in unicellular, could not photosynthesize and did not have cell wall. Seven percent had specific misunderstanding (SM); they noted that prokaryotes had nuclear membrane. Another thirteen percent did not provide answers for the question (NA).

The pre-service science teachers could correctly categorized mushrooms, star fish, hydras and fern as eukaryotes for 53%, 93%, 93% and 87%, respectively. Consider their criteria to categorize an organism as a eukaryote. Seven percent of the pre-service science teachers had scientific understanding (SU) with the description of eukaryotes as having nuclear membrane and membranous organelles. Eighty percent had partial understanding (PU); all of them could only notify that eukaryotes must have nuclear membrane or nucleus. Another thirteen percent did not provide answers for the question (NA).

3) Osmosis

The pre-service science teachers were asked to identify the change of an osmosis experiment (Figure 4.2) and give a reason to support their answers. The results found that twenty-seven percent of them had scientific understanding (SU) by answering that the volume of the solution in Side 1 decreased (13%) and the concentration of solution in both sides was the same (13%). They gave the same reason that water moved through the semi-permeable membrane from the area which had lower concentration to higher concentration.

Twenty percent of the pre-service science teachers had partial understanding (PU) but showed very little understanding. Thirteen percent of them answered that the concentration of the solution in both side would be the same because osmosis occurred. Another seven percent of them noted the concentration of solution in Side 1 would increase and Side 2 would decrease because there was a difference of concentration in both side. Seven percent of them showed partial understanding and specific misunderstanding that the concentration of solution in both side would be nearly the same but gave the reason that diffusion occurred.

Forty-seven percent of them showed specific misunderstanding (SM). Twenty-seven percent of them noted that the volume of the solution in Side 1 would increase and Side 2 decrease because water moved through the semi-permeable membrane from the area that had higher concentration to lower concentration (Side 2 to Side 1). Thirteen percent of them noted there was no change because salt could not move through the semi-permeable membrane. Another seven percent noted that the process occurred in the given experiment was diffusion. One of them (7%) did not give any responses to the question (NA).

4) Application of osmosis

The pre-service science teachers were given the situation where a plant's root had been placed in 30% salt water for 30 minutes and a girl prepared a wet mount slide of the root and observed the root cell under a light microscope. They were asked to draw a picture of the root cell to illustrate the changes, if any, which would occur. They were also asked to explain why the appearance of the cell had changed or had not changed according to their drawings. Ninety-three percent of the pre-service science teachers drew shrivelled cells which was the correct answer. Considering their reasons, it was found that only one pre-service science teacher (7%) could provide scientific understanding (SU) in her reason. Eighty-seven percent of them could provide part of the expected reason such as water moved out of the cell and concentration of water in the cell was less than those of outside the cell. Thus, their responses were categorized as partial understanding (PU). One pre-service science teacher (7%) drew a normal-shape cell without the cell membrane and gave the reason that salt water destroyed the cell membrane, this made her response categorize as specific misunderstanding (SM).

5) Cell division

The pre-service science teachers were given Figure 4.3; Division A illustrates mitosis and Division B illustrates meiosis. They were asked to consider the picture and give examples of organisms, identify cells having mitotic and meiotic cell division and the amount of genetic information in the daughter cells after cell division. The pre-service science teachers' understandings in cell division were described as the followings.

5.1) Organisms having mitotic and meiotic cell division

The pre-service science teachers were asked to give examples of organisms having mitosis and meiosis. Some of them gave more than one example. Their responses are shown in Table 6.5

Table 6.5 Example organisms having mitotic and meiotic cell division (Phase II)

(n=15)

Organisms/ Types of Organisms	**% Responses**	
	Mitosis	Meiosis
All type of organisms	7*	-
Organisms having sexual reproduction	-	13*
Unicellular organisms	7	-
Human	17	27
Animals	53	40
Plants	40	7

*correct answer

Only 7% of them could identify correctly that all types of organisms had mitotic cell division. The first three organisms which they were identified that having mitotic cell division were animals (53%), plants (40%) and human (17%) However, excluded of the responses shown in Table 6.4, three of the pre-service science teachers (20%) did not identify organisms but they noted cell types which were somatic cells and onion root cells. Two of them (13%) did not give any example of organisms.

The question also asked them to give a reason for notifying these organisms as having mitotic division. Some of them gave one or more reasons for their responses. The majority of them noted that Division A was mitosis (53%). Other reasons were mitosis occurred in somatic cells (13%), the number of chromosomes were the same after cell divided (13%), it was for growth (7%) and it occurred in organisms (7%).

Analysis of their responses for this question, summarized in Table 6.2, none of their responses were in scientific understanding. Ten pre-service science teachers (67%) showed partial understanding (PU) by identifying part of the expected reason in their responses. Most of the responses in the PU category (53%) indicated that Division A was mitotic cell division with features of mitosis such as it was for growth and it occurred in somatic cells. One of them (7%) showed specific misunderstanding (SM) that mitosis occurred in the organisms which did not had sex cells. Four of pre-service science teachers (27%) provided the responses which were categorized as no answer (NA) in that they gave no reasons for the item.

Similarly to mitosis, the pre-service science teachers were asked to give example of organisms having meiotic cell division (responses are also shown in Table 6.4). Two of them (13%) could correctly identify that all sexually reproducing organisms had meiosis cell division. Other answers were animals (40%), human (27%) and plants (7%). Three of them (20%) responded that meiosis occurred in sex cells in which they did not respond to the question asking about types of organisms and their response also demonstrated the misunderstanding of meiosis. One of them (7%) answered germ cells which was correct but did not respond to the question. The other pre-service science teacher did not give a response to the question.

They were also asked to give a reason for why they notified the organisms as example of organisms having meiotic cell division. Some of them gave more than one reason. None of the reasons were equally to the expected answers so no scientific understanding (SU) found in this concept. The majority (80%) showed partial understanding (PU) in that they gave the two reasons; Division B was meiosis (53%) and meiosis was for producing sex cells (40%). Another 20% of them did not give any reasons so their responses were categorized as no answer (NA).

5.2) Cells having mitotic and meiosis cell division

Six cell types; a shoot apical meristemic cell, a root apical meristemic cell, an intestinal epithelial cell, a skin cell, an oocyte and a spermatocyte, were given. The pre-service science teachers were asked to identify cells in which mitosis and meiosis could occur. No reasons were required. The results are shown in Table 6.6.

From table 6.6, the majority gave correct answers. Eighty-seven percent of the pre-service science teachers identified that mitosis occurs in the shoot, root apical meristemic cells and intestinal epithelial cell. Seventy-three percent identified the skin cell as having mitotic cell division. The oocyte and the spermatocyte were both chosen to be the cells in which meiosis occurred by 87% of them. One of them (7%) did not give any responses (NA). Sixty-seven percent of them could correctly identify all six cell types. A few pre-service science teachers showed a difficulty to identify the intestinal epithelial cell and skin cell as somatic cells.

Table 6.6 Identifying cells having mitotic and meiosis cell division (Phase II)

(n=15)

Cell types	% Responses	
	Mitosis	Meiosis
A shoot apical meristemic cell	87*	0
A root apical meristemic cell	87*	0
An intestinal epithelial cell	87*	7
A skin cell	73*	13
An oocyte	0	87*
A spermatocyte	0	87*

* correct answers

5.3) Amount of genetic information in daughter cells

The pre-service science teachers were asked to identify the amount of genetic information in a daughter cell compared to the mother cell, if it would be less, the same or more, after mitotic cell division had finished. They all gave the same answer that the daughter cell would have the same amount of genetic information after mitosis. Two pre-service science teachers (13%) showed partial understanding (PU) in that they gave the reasons that chromosomes had been duplicated and shared by half in the daughter cells. The responses of the other thirteen (87%) were categorized as no answer (NA). The majority of these pre-service science teachers' reasons repeated the answer that the number of chromosomes/the amount of genetic materials remained the same (40%) and there would be the same amount of genetic information in a daughter cell comparing to the mother cell (27%). This showed that all of the pre-service science teachers could give the correct answers but most of them could not give an appropriate reason to support their ideas.

Similar to mitosis, the pre-service science teachers were asked to identify the amount of genetic information in a daughter cell compared to the mother cell, if it would be less, the same or more, after meiotic cell division had finished, and provide a reason to support their answers. Fourteen of them (93%) answered that the genetic information would be less after meiosis. One of them (7%) noted the genetic information would be more.

None of the pre-service science teachers could give the complete reason thus no scientific understanding (SU) was found in this item. Twelve of them (80%) showed partial understanding, they answered one or two of the following reasons; a daughter cell had n chromosomes would combine with another sex cell from the opposite sex; and chromosomes had been shared by half two times. Three pre-service science teachers (20%) had specific misunderstanding (SM). One of them noted the genetic information would be more because the daughter cells had 2n chromosomes and two of them thought synapsis was the cause of reducing in half of genetic information in the daughter cells.

6) Reproduction

The pre-service science teachers were asked to explain how the seeds were developed in the banana fruits, as to measure their conception of sexual reproduction. All of them (100%) showed partial understanding in that they noted one of these answers; seeds developed from an ovule in the ovary (73%), seed were from fertilization (20%) and seeds were from sexual reproduction (7%). To measure their conception of asexual reproduction, they were also asked to identify the possible origins of the small banana trees under a big matured one. The expected answer was the small trees were from asexual reproduction, specifically named budding. Twelve of them (80%) showed scientific understanding (SU) in that they could notify the expected answer. The other three (20%) showed specific misunderstanding (SM) by answering that the small banana trees were from seeds.

7) Photosynthesis and plant respiration

7.1) Plant's energy resource and light condition for photosynthesis

Thirteen of the pre-service science teachers (87%) chose the sun as the only plant's energy resource. The other 13% chose light and other given choices; soil, water and carbon dioxide. Four light conditions were given; in sunlight, in light from a bulb, in light all time and in the dark. The pre-service science teachers were asked to identify in which condition(s) plants could photosynthesize. Nine of them (60%) could identifying that plants could photosynthesize in sunlight, light from a bulb and in light all time. Six of them (40%) identify one or two of the first three given light condition. None of them chose in the dark.

7.2) Plant food

Different substances were given to the pre-service science teachers; soil, water, chlorophyll, carbon dioxide, oxygen, carbohydrate, fertilizer and light. The pre-service science teachers were asked to identify plant food from these given substances. Most of them identified more than one substance. Their responses are shown in Table 6.7. All of the given substances were chosen as plant food. Twenty percent chose carbohydrates but none could correctly identify only carbohydrates as plant food. Water, fertilizer and carbon dioxide were three most frequently chosen substances by the pre-service science teachers as plant food by 100%, 87% and 53%, respectively.

7.3) Plant Respiration

Asking the pre-service science teachers to identify the period of the day the plants respire, four choices were given, in day, at night, both in day and at night and plant did not respire. No reasons were required. Nine of them

(60%) could answer correctly that plants respired both in day and at night. Six of them (40%) noted only at night.

Table 6.7 Plant Food (Phase II)

(n=15)

Substances	% Responses
Soil	40
Water	100
Chlorophyll	7
CO_2	53
O_2	27
Carbohydrates	20*
Light	40
Fertilizer	87

* correct answer

7.4) Starch Test

The pre-service science teachers were asked to give reasons for the disappearance of starch in a plant's leaf after keeping the plant in a dark cupboard for 48 hours and reappearance of starch after placing the plant in the area exposed to light for another 48 hours. All of percent responses in each category are shown in Table 6.2. One pre-service science teachers (7%) did not respond to the question, thus their responses were in the no answer category (NA). None of them showed scientific understanding. One of them could give the adequate reason for this phenomenon but included a misunderstanding that plant food was proteins resulted in 7% of partial understanding and specific misunderstanding (PS). The majority of them (87%), showing partial understanding (PU), could only respond that plants could not photosynthesize without light.

8) Ecology

The pre-service science teachers were asked to decide whether a sealed bottle with water, soil, weeds, and snails from a pond placed exposing to the sunlight was an ecosystem and biological processes occurred. Eleven pre-service science teachers (73%) indicated that the given sealed bottle was an ecosystem, while the rest (3 pre-service science teachers, 20%) noted it was not. One of them (7%) did not give any reasons, categorized as no answer (NA). All of the reasons of the eleven pre-service science teachers who answered that the sealed bottle was an ecosystem had partial understanding (PU) and all of them explained about the structure of the ecosystem. Three of them also included the interrelationship of the components in the ecosystem. The pre-service science teachers who noted the seal bottle was not an ecosystem gave the reasons that it lacked energy flow and nutrient cycles (13%) and there were no decomposers and gaseous cycle (7%). These responses of these four pre-service science teachers were categorized as specific misunderstanding (SM).

The subsequent sub-question asked to the pre-service science teachers to determine whether the weeds and the snails could survive in the sealed bottle for one month. Four of them (27%) answered that the organisms could survive and all of them explained that there were nutrients, energy and gas cycle in the bottle. Eight of them (53%) answered that the organisms could not survive for a month in the bottle. They gave two reasons; there were not enough air or oxygen for the organisms and there was not enough food for the snails. Three of them (20%) were not sure whether there was sufficient oxygen and food for the organisms to survive in the bottle for one month.

The pre-service science teachers were asked to identify whether there were producers, consumers and decomposers in the given sealed bottles. These niches were expected to be all chosen to appear in the sealed bottle. All of them chose producers and consumers. Seven of them (47%) chose all of the three niches. In the other hand, eight of them (53%) did not include decomposers. Asking whether the weeds in the bottle could photosynthesize or not, all of the pre-service science teachers (100%) answered that the weeds could do so. They all gave the same reason that the weeds got light for photosynthesis. Two of them also added that there was carbon dioxide.

The pre-service science teachers were asked to determine if the weeds could respire in the sealed bottle. They were left a blank to provide their reasons to support their answers. One of them (7%) did not give any response to the question. Two of them (13%) answered that the weeds could not respire and all of them gave the same reason that there was no oxygen in the bottle. Twelve of them (78%) noted that the weeds could respire in the bottle with various reasons. The majority of the pre-service science teachers (33%) answered that the weeds could respire because photosynthesis could also occur. Misunderstanding was found in that seven percent noted that there was no carbon dioxide. Three pre-service science teachers (20%) did not give any reasons to support their answers.

2.3.2 Science process skills after learning

The pre-service science teachers' understandings in the integrated science process skills after learning through the instructional set were captured by the last two items in the Biology Concept and Science Process Skill Questionnaire. The results are shown as follows.

1) Designing an Experiment

The pre-service science teachers were given a situation that they were scientists who invented medicines to cure the bird-flu disease. They were asked to design an experiment to determine the effectiveness of three medicines with 1,200 farmed-chickens. Two of them did not give any responses to the item. None provided a wholly appropriate experiment for the given situation.

One of them (7%) formulated the hypothesis that the first medicine would have the best curing capacity for bird-flu. This hypothesis was considered appropriate to the experiment. Three of them (20%) identified correct independent and dependent variables while others did not mention these. Thirteen pre-service science teachers described their designs of experiments. Eight of them (53%) employed a three-group design; treating each medicine with each group of chickens. Five of them (33%) employed a four-group design; treating each medicine with each group and one control group. Two of these pre-service science teachers also included an experimental replication.

Three pre-service science teachers (20%) noted that their experiments were concerned with the duration in treating the chickens but they did not clearly identify how long the experiment would last. Ten pre-service science teachers (87%) noted that their experiments needed a control and identified the controlled variables. Six pre-service science teachers (40%) noted how they would collect data in that they would count the number of chickens which survived or died and observe the symptoms of the chickens. Another three of them (20%) only indicated that data would be collected, without more explanation.

Seven pre-service science teachers (47%) noted the word "conclusion" in their responses; only two (13%) identified the means they would draw a conclusion of their experiments by comparing of the efficiency of the medicines. They would use the greater number of surviving chickens to express the efficiency of the medicines. Five pre-service science teachers (33%) only indicated conclusion as the last part of their experiments. One pre-service science teacher prepared a table for data collection but it was not appropriate because they proposed the three - group experimental design which did not include a control group and experimental replication.

2) Specific science process skills

The pre-service science teachers were given a diagram of four graphs indicating the rate of activity of four enzymes at different pH levels (Figure 4.4). They were asked to identify a question, a hypothesis, variables, results and a conclusion of the experiment.

The first sub-item asked them to identify the question of the experiment. One of them did not respond to the sub-item. Seven of them (47%) identified a question of the experiment: "What is the optimum pH of each enzyme?"

(40 %), and “Does pH affect the rate of enzyme activity?” (7%). Another seven pre-service science teachers (47%) did not give the answers to this sub-item in a form of question. Their responses were more like the variables or conclusions, such as: “Enzymes could function differently depending on pH levels” and “pH levels affect enzyme activity”.

Sub-item 2 asked the pre-service science teachers to formulate an appropriate hypothesis of the experiment. The majority (12 pre-service science teachers, 80%) formulated a hypothesis like ‘Each enzyme has specific optimum pH’ (60%) and ‘pH affected the rate of enzyme activity’ (20%). Two pre-service science teachers (13%) indicated the results of the experiment as their hypotheses. The other pre-service science teacher (7%) did not give a response.

The pre-service science teachers were asked to identify the independent variables of the experiment in sub-item 3. Nine of them (60%) identified the names of the given enzymes and six of them (40%) identified the pH. None of them identified correctly that both enzymes and pH were the independent variables of this experiment. Nine pre-service science teachers (60%) correctly indicated that the rate of enzyme activity was the dependent variable in sub-item 4. Another four of them (27%) noted pH. One (7%) noted enzyme activity at different pH and the other (7%) noted the amount of enzymes.

Sub-item 5 asked the pre-service science teachers to identify the controlled variables of this experiment. Most of them identified more than one controlled variables in their responses. The three most frequently identified controlled variables were temperature (60%), the amount of enzymes (60%), and the amount of substrates (20%). Other controlled variables found in some pre-service science teachers’ responses were the concentration of enzymes (7%), concentration of substrates (7%) and experimental cite (7%). However, some pre-service science teachers identified wrongly that pH (20%), time (13%), as controlled variables of the experiment. However, totally, 67% of them could identify correct controlled variables without the wrong ones. Overall, none of the pre-service science teachers succeeded in identifying all three variables.

Sub-item 6 asked the pre-service science teachers to identify the results of the experiment. The majority of them (40%) just noted that there the results of the experiment on each enzyme were different. Three of them (20%) noted that each enzyme had different optimum pH and two of them (13%) noted that each enzyme had different optimum pH in ranges; in acid, or base. Four of them (27%) tried to identify the range of optimum pH of each enzyme but all of them could not correctly identify the correct pH range.

In sub-item 7, the pre-service science teachers were asked to draw a conclusion. Thirteen of them (87%) could conclude the results correctly that enzymes could work effectively at different pH. The other two of them (13%) concluded that two enzymes (papain & cholinesterase) yielded similar results (as seen from the shapes of the graphs) and the other two yielded different results (7%) and enzymes could best effectively function at pH = 7 (7%).

Table 6.8 Percent correct answers to specific questions for science process skills after learning

(n=15)

Science Process Skills	**% Correct Answers**
Posing questions	47
Formulating hypotheses	80
Identifying variables	0
Interpreting the results	73
Drawing a conclusion	87

From the table above, the majority of the pre-service science teachers could give correct answers for formulating hypotheses, interpreting results and drawing a conclusion. About half of them could provide appropriate questions for the experiment. None of them could correctly identify all three variables of the experiment. The next section presented their understanding in the nature of science.

2.3.3 Understandings in the nature of science after learning

This section presents and discusses the fifteen pre-service science teachers' understandings in the nature of science captured by Views on the Nature of Science Questionnaire after they learned through the instructional set. Two of them did not give any reasons to any of the items, thus the responses are from 13 students.

1) Definition of Science

Item 1: Science is a body of knowledge, such as principles, laws, and theories, which explain the world around us (matter, energy, and life).

The responses of this item in the questionnaire showed that seven of the pre-service science teachers (54%) thought science is both a process and a product. These pre-service science teachers agreed with the statement and referred to the science process skills, experiments and thinking process for construction of scientific knowledge. The other pre-service science teachers (46%) agreed with the statement and explained that science is knowledge which explains everything around us.

Item 2: Science is exploring the unknown and discovering new things about our world and universe and how they work.

In this item, all of the pre-service science teachers responded with several appropriate views about science. The majority of the pre-service science teachers (77%) agreed with the statement and science was for 'seeking of new knowledge'. One of them (8%) noted that science is related to 'development'. Two of them (15%) noted that science was related to process or the activity for constructing of knowledge.

To sum up, about half of the thirteen pre-service science teachers had appropriate views on definition of science and thought science was both process and product. Most of them also believed that science is for seeking of new knowledge, discoveries and improving existing knowledge.

2) Characteristics of scientific knowledge and methods

Item 3: Science can investigate the supernatural and can possibly explain it.

Only one pre-service science teachers (8%) agreed with this statement and extended that scientific experiment could do so. Others (92%) expressed the views which indicated the limitation of science that ‘Many things are still not provable such as ghosts and spirits.’ They thought science could not provide enough obvious results about the supernatural.

Item 4: Science is understandable.

All of the pre-service science teachers (100%) agreed with this statement. Nine of them (69%) explained that science was from human understanding logical explanation and provable experiments. The other four (31%) who also agreed with this statement considered the effects of positive attitudes toward science and intention; the one with a positive attitude and paid enough intention for science would make the person understand it.

Item 5: Scientific knowledge has always changed with time.

All of the pre-service science teachers (100%) agreed with the statement. Eleven of them gave more explanation that ‘science can change when better acceptable evidence or explanation is found. One of them gave the reason that everything is uncertain, including science. The other noted that science can change because scientists always discover new things.

Item 6: The scientific method ensures valid, clear, logical, and accurate results.

Five pre-service science teachers (38%) believed that this statement was true and assert their own opinions that ‘scientific method was systematic, logical and always accurate’ (23%), had been accepted to used among scientists (8%) and had done repeatedly until getting the results (8%). The other eight of them (62%) did not agree with the statement and explained that via the scientific method, some errors can occur due to the experimenters and scientists’ bias.

Item 9: Some scientific discoveries are made by accident.

All of the pre-service science teachers (100%) indicated their agreement with the statement. Seven of them (54%) gave examples of accidental scientific discoveries, including the law of gravity by Newton, and eureka. The others (46%) believed that discoveries from accidents were by-product or beyond scientists’ expected results which they had recognized.

In brief, all of the pre-service science teachers had appropriate views on the characteristics of scientific knowledge and methods. The viewed that science was understandable, changed with time could be made by accident and could not explain the supernatural. The majority thought science could not always ensure accurate results. High percentage of the appropriate ideas was shown in most aspects and 3 of the 5 items about this aspect were appropriately responded by all of them. This demonstrated their good understanding of the nature of science in this area.

3) Characteristics of scientists

Item 7: The main motivation of scientists is to satisfy their curiosity.

All of the pre-service science teachers (100%) agreed with the statement. Ten of them (77%) extended their ideas that curiosity makes scientists search for the answers by doing science. One of them (8%) noted that she read scientists' bibliography and found out that all of scientists were curious people who questioned about things around them and turned themselves into scientific work. One of them (8%) inserted that another motivation was to make things better. The other (8%) expressed that some scientists also motivated by money and the wish for to help other people.

Item 8: Scientists can use imagination and creativity to get results.

Ten pre-service science teachers (77%) agreed with this statement. The majority (62%) noted that imagination and creativity were only part of scientific activities. One of these pre-service science teachers also added the examples of concepts which needed imagination; cells and atoms. Another noted that imagination and creativity could widen scientists' ideas in formulating hypotheses. The rest of them (23%) disagreed with the statement and explained that using imagination and creativity might produce errors (15%) and science must be from experiments (8%).

Item 10: It's part of a scientist's job to ensure that no harm comes from discovery.

Eight pre-service science teachers (62%) disagreed with this statement. Four of them (31%) thought scientists discovered both useful and harmful things. Two of them (15%) noted that sometimes scientists did not know what they would get for results. Another two (15%) thought it depended on the ones who used the discoveries in that they might use in the harmful ways. Other five pre-service science teachers agreed with the statement in that they thought scientists must concern public safety (31%) and harmful discoveries would not be allowed to do because it was not acceptable by the society.

Item 11: Scientists are logical, objective, unbiased and open-minded.

All of the pre-service science teachers (100%) agreed with this statement. Six of them (46%) noted that good scientists have such characteristics. Four of them (31%) inserted that the characteristics facilitated scientists to work better. One of them (8%) commented that it depended on individual scientist; a minority of scientists did not have such characteristics due to their own bias. The other two (15%) did not explained their ideas for the item.

In brief, the majority of the pre-service science teachers' had appropriate views on the characteristics of scientists. They viewed that scientists were motivated by their own curiosity. They believed that imagination and creativity played part in scientific discoveries. They thought scientists could not ensure that no harms would come from their discoveries. They also believed that the majority of scientists were logical, objective, unbiased and open-minded.

4) Interrelation of science and society

Item 12: Personal feelings and moral values have no bearing on scientists' decisions.

All of the pre-service science teachers (100%) disagreed with the statement. They gave the reason that personal feelings and moral values had very much influence on scientists' decisions. For them, scientists must have morality and ethics when they do their work.

Item 13: Society influences the direction of scientific discoveries.

All of the pre-service science teachers (100%) agreed with this statement. Six of them (46%) thought scientific discoveries followed society demands. Four of them (31%) thought that scientific discoveries must be accepted by the society. Two of them (15%) noted science was supported by the society in that Thai government desires to promote Thailand to be a knowledge-base society. The other (8%) did not give a reason to support her answer.

In brief, all of the pre-service science teachers thought personal feelings and moral values had a huge effect on scientists' decisions. They expressed that scientists must have morality and ethics to do their work. In addition, all of the pre-service science teachers believed that the society influenced the direction of the scientific discoveries in that the majority thought discoveries must be accepted by the society and required as the demand of the use in the society. Overall, the thirteen pre-service science teachers who responded to this questionnaire had appropriate understandings in all aspects of the nature of science, summarized as Table 6.9.

2.3.4 Attitudes towards biology after learning

The pre-service science teachers were asked to give their responses to the Attitudes towards Biology Inventory after they learned through the instructional set for the Laboratory in Biology course. Fifteen pre-service science teachers gave responses to the inventory. The result is shown in Table 6.10.

Table 6.9 Appropriate understandings in the nature of science after learning

(n=13)

The Nature of Science Statements	**Appropriate Understandings (%)**
Definition of Science	
- Science is a process and knowledge.	54
- Science is exploring the unknown and discovering new things.	77
Characteristics of Scientific Knowledge and Methods	
- Science cannot explain the supernatural.	92
- Science is understandable.	100
- Science can change over time.	100
- Scientific methods cannot always provide valid, clear and logical results.	62
- Scientific discoveries can be from accident.	100
Characteristics of Scientists	
- Scientist's curiosity mainly motivates them to do their work.	100
- Imagination and creativity can be used to get results.	77
- Scientists are logical, objective, unbiased and open-minded.	100
- It is not a scientists' job to ensure that no harms come from discovery.	62
Influences of Science and Society	
- Personal feelings and moral values have influences in scientists' decision making.	100
- Society influences the direction of scientific discoveries.	100

According to Table 6.10, the pre-service science teachers had positive attitudes towards biology, laboratory learning and the Laboratory in Biology course in that the average score were in a range of 3.51-4.50. One item points out their high positive attitudes towards biology (score > 4.51) in that they thought the biological knowledge is very important for country development. Some items showed relatively low scores (2.51<score< 3.50) which the pre-service science teachers had moderate attitudes towards the statements. They indicated that they thought biology was difficult when it involved handling apparatus, biological knowledge was the cause of many of the world problems, Laboratory in Biology course was a difficult subject, they would like to have fewer biology lessons and there were too many facts to learn in the Laboratory in Biology course.

Table 6.10 Attitudes towards biology after learning

(n=13)

Items	Statements	Mean	SD
	Attitudes towards Biology		
1	Biology is useful for solving problems in everyday life.	4.36	0.63
2	Biological knowledge is important for a country's development.	4.57	0.65
3	Biology is difficult when it involves handling apparatus.*	3.07	1.14
5	Every citizen must have biological knowledge.	4.07	0.73
8	Biological knowledge is the cause of many of the world problems.*	2.64	1.21
14	People who understand biology are better off in our society.	3.57	0.94
15	I would like to have fewer biology lessons.*	3.14	0.87
17	I cannot use biology for my real life.*	3.64	0.92
	Average	**3.63**	
	Attitudes toward Laboratory Learning		
6	It is useless to do experiments in biology.*	4.36	1.15
7	I would rather agree with what other people say than do an experiment to find out the information for myself.*	3.57	0.85
10	Doing experiments is enjoyable.	4.50	0.52
12	Doing biology experiments helps me learn more than finding out information from instructors.	3.93	0.73
13	I think doing biology experiments is boring.*	3.71	1.14
18	I feel uncomfortable doing biological experiments by myself.*	3.57	1.22
	Average	**3.94**	
	Attitudes toward the Laboratory in Biology course		
4	Laboratory in Biology course is a difficult subject.*	3.50	0.76
9	There are too many facts to learn in the Laboratory in Biology course.*	3.21	0.80
11	I like learning in Laboratory in Biology course.	3.79	0.70
16	Laboratory in Biology course helps me understand biological concepts.	4.07	0.62
19	Learning in Laboratory in Biology course helps me have more confidence to use scientific methods.	4.07	0.73
20	Learning in Laboratory in Biology course helps me have more confidence to use scientific apparatus.	4.50	0.65
	Average	**3.86**	

Score 1 means disagree and score 5 means agree

*Negative statements, use inverted score: low score indicates agreement with the statement

2.4 Pre-service science teachers' final grades

This section presents and discusses the final grades of the first-year pre-service science teachers who participated in the Laboratory in Biology course in which the instructional set was implemented in 2005 academic year. Two grading strategies are presented and compared; that of the Department of Zoology, which is the administrator of the Laboratory in Biology course, and that of the instructional set. According to the Department of Zoology, student's final grades come from the department's midterm and final examination (50% and 50%). In the instructional set, the final grade came from student marks during learning and the examination. The marks the pre-service science teachers were assigned to from quizzes (10%), class participation (10%), handing in their worksheets and student thinking books (10%), and a report and presentation (10%). The midterm and final examination were counted 25% and 25%, respectively. These midterm and final examination marks were the same as those of the Zoology Department but divided by two. Grades in the instructional set were based on criterion-based referencing. Grades in the Zoology Department were norm referenced. Table 6.11 shows the pre-service science teachers' final grades by these two strategies.

Considering individual grades, ten pre-service science teachers got the equal grades, eleven of them got the lower grades in the instructional set and five got higher grades. The grade differences could be attributed to work during the learning. The pre-service science teachers who came to every class session, handed in their worksheets and thinking books, reviewed the lessons for the quizzes got the lower grades from the department. In contrast, the pre-service science teachers who were often absent and did not hand in their worksheet and thinking books but who did well on the examination got the higher grades from the Department.

Table 6.11 Pre-service science teachers' final grades via two grading strategies

(n=29)

Grades	No. of Pre-service science teachers	
	Department of Zoology	The Instructional Set
A	1	0
B^+	1	1
B	1	4
C^+	4	4
C	4	3
D^+	4	2
D	3	6
F	8	6
W*	3	3
Total	29	29

*W = Withdraw

Comments and suggestions to the instructional set

Both instructors gave comments and suggestions on the instructional set during weekly meetings. The pre-service science teachers were given a worksheet “Summary of Experience in the Laboratory to in Biology course 424112” in their activities books. Their comments and suggestions can be summarized as follow.

Instructors’ comments and suggestions

Vipa, implemented the first two lessons. She commented on the instructional set that she really liked the teaching and learning in second lesson, Biodiversity. It introduced the method of classifying organisms to provide ideas of classification for the pre-service science teachers. It also obligated the pre-service science teachers to prepare themselves and study the content in the laboratory manual, before class. She also commented that some activities (such as discussion, and allowing the pre-service science teachers to think in groups) needed to taken out or reduced in time used. The reason was that she preferred to give more time for the pre-service science teachers to do laboratory activities.

Darin, who spent much more time in the implementation than Vipa, commented that the teaching and learning activities of the instructional set had an advantage in that they allowed the pre-service science teachers to participate more in class. They could share ideas in answering her questions and in presentations in front of the class. From Darin’s experience, students had very little participation and had much less attention in class and she had to spend long time and efforts to help them understand the content knowledge. She considered the instructional set had helped her reduce the time needed for the lecture at the beginning of the class and provided her an opportunity to listen to pre-service science teachers’ ideas that she had not considered before. She also suggested that the activities in each lesson needed to be shorten to finish in the three-hour period.

Pre-service science teachers' comments and suggestions

Thirteen students turned in the worksheet on a summary of their experiences in the Laboratory in Biology course. There were six questions in the worksheet. The first three questions asked about gains in biology concepts, science process skills and understanding of the nature of science from learning through the instructional set. The fourth question asked students to identify the activities they liked most. The fifth question asked them to evaluate the total experience of the course and indicate how much they enjoyed it. The last question asked them to give suggestions for teaching and learning in the course.

Most of the students gave short answers to the questions. To gain more information, interviews of the pre-service science teachers were conducted with eight of them. The interviewed pre-service science teachers were randomly selected according to their levels of achievement. The pre-service science teachers who were interviewed were; 1 grade A, 1 grade B, 1 grade C+, 1 grade C, 1 grade D+, 1 grade D, and 2 grade F students. Only one pre-service science teacher got a B+ but they dropped out of the university before the interview. Student comments and suggestions are summarized below.

The majority of the pre-service science teachers indicated that they gained a good deal of understanding of biology concepts, science process skills and understanding of the nature of science from the learning through the instructional set. They explained that they had opportunities to do laboratory activities and learning from concrete examples by themselves in which they could construct their understanding of the biology concepts. They also learned that scientific knowledge was developed by a systematic scientific process. They reported that during learning they developed their science skills including formulating hypothesis, identifying variables and observation.

The pre-service science teachers noted that they had learned about the nature of science but most of them could not explain the word "the nature of science". Few of them demonstrated correct meaning of the nature of science. Some of them expressed that they did not know what the nature of science was all about. This was inconsistent with other evidence of their learning outcomes. They could give appropriate ideas of the nature of science statement in the Views on the Nature of Science Questionnaire. This shows that teaching of the nature of science in the instructional set was not clear enough. Another possible source might start in the first laboratory session which Vipa expressed her thought that she was unclear in understanding of the word “the nature of science” (discussed in section of her reflection on teaching). Vipa did not talk about what the nature of science was but she presented some aspects in details. In addition, in the subsequent sessions, some aspects of the nature of science were taught separately.

The activity which the majority of the pre-service science teachers liked most was preparing wet mount slides and observing them under a light microscope. The reason they gave was that the activity helped them see various organisms and cells which they had never seen before. The other activities they liked were frog sectioning and ecology activities. The former activity gave them new experience observing frog’s visceral organs. The latter activity was comprised of various laboratory activities; surveying, collecting water samples, experimenting and observing organisms in fresh water. The majority were highly pleased with their total experience of learning through the instructional set. They supported the opinion they had had great opportunity to do laboratory activities by themselves with supportive help from instructors.

Some of them gave suggestions to improve the instructional set. Their suggestions related to teaching and learning activities, assessment, instructional materials and the instructors. They suggested that there should be more experiments, presentations and out of class activities included in the teaching and learning activities. There should be some marks given during the learning to motivate them to give more attention and participation in class. The instructional materials should include a brief summary of content in each lesson and a picture book of all the projected slides. The suggestions for the instructors were to be stricter. There should be more than one instructor in class to give a thorough care for all students during the laboratory activities.

Summary of Chapter VI

This chapter has presented and discussed the implementation of the instructional set for the Laboratory in Biology course in the second semester of 2005 academic year. Two instructor participated in the study, Vipa and Darin. Vipa implemented the first two lessons of the set and Darin continued until the end of the semester. Instructors' beliefs about teaching strongly influenced their teaching practice. They shared the beliefs that they needed to tell the pre-service science teachers the content knowledge before they did laboratory activities as this was most effective way to promote learners' understanding in biology and help them pass the examinations.

They began implementing the instructional set with a teaching practice based on a more teacher-centred approach. During the implementation, they changed their beliefs and practice towards a more learner-centred approach. Vipa used lectures as her main teaching strategy but she had an outstanding in her helpful and friendly guidance for individual learner. Vipa implemented the first two weeks of the semester and acquired some ideas to improve her teaching based on social constructivism for the Laboratory in Biology course and Ecology course. Darin changed her teaching by giving a short lecture before allowing the pre-service science teachers do laboratory activities to whole-class discussion since the second week of her implementation. Darin gave opportunities for the pre-service science teachers to share, discuss and reflect on their ideas during learning.

Formative assessment helped the instructors participated in this study shift their teaching towards a more teacher-centred approach. Both instructors observed the pre-service science teachers performance during learning, gave feedback and provided guidance and assistance. The pre-service science teachers had opportunities to reflect on their learning in their activity books and thinking books. The obtained information of the pre-service science teachers understandings, skills and attitudes towards learning were used to adapt the teaching and learning activities. However, after the midterm examination, they did not write much in their books as they thought their work during learning did not count as part of their final grades.

Summative assessment seemed to have a strong influence on both teaching and learning behaviours. Both instructors were like to the prepared the pre-service science teachers with content knowledge and ignored other activities which were not related to the examinations. The pre-service science teachers were less active and handed in less work after they found out that class participation and handing in activity books and thinking books were not count as final grades. It was also found that the instructors needed time to understand learner-centred teaching and learning. They also need to see the evidence which could prove the effectiveness of the new teaching approach. After Darin found that the pre-service science teacher could do well in the midterm examination, she tended to follow most of the teaching and learning in the instructional. This was because she perceived that the instructional set did not make the pre-service science teachers achieved lower than the regular practice.

This chapter reports three learning approaches the pre-service science teachers used during learning: learning by listening, learning by hands-on and minds-on activities and learning by social interaction. They developed understanding in biology, the nature of science, science process skills and attitudes towards biology during learning through the instructional set. After the finished the course, the learning outcomes were assessed by two questionnaires and an inventory. It was found that they had partial understanding in most concepts. They had very good understanding in every aspects of the nature of science. They could do better in science process skills in interpreting results, drawing conclusion, posing questions, formulating hypothesis than identifying variables and experimenting. Their attitudes towards biology were found positive.

Their final grades given by the Zoology Department and the instructional set were compared and it was found that it had a difference in their final grades from these to source. Most of the pre-service science teachers who always participated in class and handed in their activity and thinking books had higher grade from the instructional set. The final grades given by the Department were higher for some of who did well on the examinations.

The last section of this chapter ended up with the instructors' and first-year pre-service science teachers' comments and suggestions on the instructional set. The instructors thought the instructional set had interesting and useful teaching and learning activities but there seemed not enough time to cover all of the activities in three hours of each laboratory session. The pre-service science teachers were pleased by the various laboratory activities they had done by themselves with supportive helps of the instructors.

CHAPTER VII

CONCLUSION, DISCUSSION AND RECOMMENDATIONS

Introduction

This chapter presents the conclusion and discusses the results of this research study then sets out some recommendations. The first section presents the conclusion from each phase of the research study to answer the research questions. Findings are discussed according to the guiding principles utilized in the development of the instructional set to illustrate the implementation of the principles in the classroom and point out some facilitating and obstructing factors. In the last section of this chapter, recommendations for further research studies and tertiary teaching are detailed.

Conclusion

The urgent requirement for the Thailand education reform was stipulated in the National Education Act in 1999 in response to an economic crisis. The Thai government suggested a learner-centred approach as being at the heart of a more effective teaching approach. Research done in Thailand and documents, by OEC (1999), ONEC (1999a), Polsaram and Thephasdin Na Ayudhaya (2000) and Areekul (2005) showed a mismatch between educational policies and normal practice in classrooms at the tertiary level as well as low-quality of graduates. This research study was initially designed to promote learner-centred teaching and learning at the tertiary level according to the Thailand National Education Act (1999). It was hoped the study would benefit the teaching and learning experience of pre-service science teachers who would be the future personnel to implement the act. The Laboratory in Biology Course was targeted as it was a course required for every first-year pre-service science teacher.

The research study had two phases: an exploratory phase and a development and implementation of an instructional set phase. These two phases were conducted in response to the three research questions of the study:

1) What were pre-service science teachers' understandings in biological concepts, science process skills, the nature of science and attitudes towards biology after the existing teaching and learning of the Laboratory in Biology Course?

2) How did instructors teach and pre-service science teachers learn during the implementation of the instructional set developed in accordance with the National Education Act, 1999?

3) What were pre-service science teachers' understandings in biological concepts, science process skills, the nature of science and attitudes towards biology after the implementation of the instructional set?

Phase I: Exploratory Phase

The first phase of the research study, in response to the first research question, was aimed at exploring the learning outcomes of the pre-service science teachers who learned through the regular Laboratory in Biology Course which was based on a more teacher-centred approach. Three instruments: the Biology Concept and Science Process Skill Questionnaire, the Views of the Nature of Science Questionnaire and the Attitudes towards Biology Inventory were developed and utilized to assess learning outcomes at the end of the first semester (in October) of the 2004 academic year.

The findings of the first phase of this study revealed that a majority of the 36 pre-service science teachers who learned through the regular course did not understand many of the biological concepts taught after learning in the Laboratory in Biology Course. They had only partial understandings in most concepts including: cell structure and function, prokaryotes and eukaryotes, cell division, sexual reproduction photosynthesis and ecosystem. Some of them showed scientific understandings in cell structure and function, prokaryotes and eukaryotes, osmosis, asexual reproduction and photosynthesis. However, no scientific understandings were found in cell division, sexual reproduction and ecosystem.

In their responses, the pre-service science teachers gave short reasons for their answers. Most of their responses were categorized as partial understanding. In addition, some of their reasons for some concepts (especially cell division) indicated a memorization of concepts and fragmented understanding in that the pre-service science teachers noted correctly the concepts but their responses did not respond to the questions. Most misunderstandings found in this study, especially in photosynthesis, were similar to those identified in other studies around the world (e.g. Bell, 1985; Barker and Carr, 1989; Eisen and Stavy, 1993; Sander, 1993; Amir and Tamir, 1994; Leach *et al.*, 1996a; Kao and Su, 2004; Kijkuakul and Yutakom, 2004).

Asking the pre-service science teachers to design an experiment for testing effectiveness of three medicines to cure bird-flu, most of them went straight to the experimental procedure. The majority did not formulate hypotheses and identify variables for their experiment. About 70% of their experimental designs lacked a control group and none of them indicated experimental replications. Most of them could not explain how they would collect and interpret the experimental results. This is consistent with a study by Germann and Aram (1998). Providing specific questions asking them to identify possible an experimental question, a hypotheses, variables, results and a conclusion for given experimental results presented in a graph form. About 50% could pose an experimental question. About 70% of them could formulate an appropriate hypothesis and about 80% could interpret the results and draw a conclusion. In contrast, only 3% could successfully identify the variables in the experiment. This is similar to the finding of a study by Beaumont-Walter and Soyio (2001) in that they found Jamaican students had better skills in interpreting data and drawing conclusions than formulating hypotheses, identifying and control variables and experimenting.

The findings on the pre-service science teachers' understandings in the nature of science were inconsistent with research studies conducted elsewhere. Most studies had reported many students and teachers have inappropriate views on aspects of the nature of science (e.g. Pomeroy, 1993; Abd-El-Khalick and BouJaoude, 1997; Murcia and Schibeci, 1999; Akerson, *et al*., 2000; Eick, 2000; Abd-El-Khalick, 2005). In this study, the questionnaire indicated that Thai pre-service science teachers possessed mostly appropriate views. A high percentage of their responses showed that they had good understandings about characteristics of scientific knowledge and methods. The majority of the pre-service science teachers demonstrated appropriate views of the characteristics scientists. However, their appropriate views in this aspect had a lower percentage compared with the previous aspect because some responses concerned differences among individual scientists and indicated that a minority of scientists might not always have good work habits.

The majority of the pre-service science teachers believed there was a strong interrelationship between science and society. They considered scientists' personal feelings and moral values played a part in scientists' decision making and societal values, traditions, beliefs, and demands strongly influenced the direction of scientific discoveries. About 60% of the pre-service science teachers showed inappropriate views of the definition of science in that they viewed science as a product. This finding is consistent with the findings of many previous research studies (e.g. Bloom, 1989; Abell and Smith, 1994; Gustafson and Rowell, 1995; Murcia and Schibeci, 1999; Eick, 2000; Gess-Newsome, 2002).

The Attitudes towards Biology Inventory asked the pre-service science teachers to rate their attitudes in three attitude areas: attitudes towards biology, laboratory learning and the Laboratory in Biology Course. The results of this study revealed that, overall, the pre-service science teachers showed positive attitudes after learning though the regular practice of the Laboratory in Biology Course. Some items of the inventory showed relatively low scores with high standard deviation. The data indicated that the pre-service science teachers held divergent views with respect to being difficult when biology involved handling apparatus, biological knowledge as the cause of many world problems, feeling uncomfortable to do biological experiments individually, the Laboratory in Biology as a difficult subject and too many facts to learn in the Laboratory in Biology Course.

To sum up, it was found that most of the pre-service science teachers responded to the questionnaires and inventory in the first phase of this study had partial understanding of most of the biology concepts and misunderstandings were found in every concept. They had better skills in interpreting data and drawing a conclusion than formulating hypotheses, identifying variables and designing an experiment. Most of them had appropriate views on the nature of science and they all had positive attitudes towards biology.

Phase II: Development and Implementation of the Instruction Set

The findings of the exploratory phase, educational guideline in the National Education Act, 1999 and information synthesized in the literature review about laboratory teaching, learning and assessment were utilized in generating of the guiding principles for the instructional set in the second phase. There were four guiding principles as the followings.

1) Understandings in biology concepts, integrated science process skills, the nature of science and positive attitudes towards biology are important learning outcomes in science

2) Learner-centred teaching and learning have a basis on social constructivism

3) Formative assessment is a strategy to enhance pre-service science teachers' laboratory learning

4) The understanding of nature of science and science process skills are best taught by an explicit teaching approach

The instructional set was aimed at helping pre-service science teachers' to achieve the biological concepts originally notified in the regular laboratory manual, published by the Zoology Department. The set also aimed to promote pre-service science teachers' understanding of the nature of science, better science process skills and positive attitudes towards biology through a learner-centred approach. The teaching and learning activities for 13 lessons were designed and instructional material were gathered and created. The instructional set was comprised of an instructor manual, a student activity book and a student thinking book.

The teaching and learning activities emphasized pre-service science teachers' expression of prior ideas, sharing and reflection of ideas. Formative assessment tools were included for pre-service science teachers to reflect on their own learning and for instructors to elicit learners' understandings, skills and attitudes during learning which was used to adapt the subsequent activities. The instructional set was reviewed by eight experts, improved and evaluated by two science educators and three science instructors who experienced in teaching of the Laboratory in Biology Course. The set was also improved before and during the implementation.

Vipa and Darin, experienced instructors in teaching of the Laboratory in Biology Course, implemented in instructional set in the second semester of the 2005 academic year with 29 first-year pre-service science teachers. Vipa implemented the first two lessons and Darin continued until the semester ended. Typically, there is only one instructor teaching for the whole semester. But in this study, Vipa had other important work to be responsible for and could not continue the implementation. Darin, then turned up to the study. During the implementation, some activities in the set was revised and rearranged to match the pre-service science teachers' abilities and classroom situations.

The researcher was a participant observer, acted as a teacher assistant and participated in every class and the examination sessions. Classroom observations with videotape recording were employed during every laboratory session. After each session finished, several pre-service science teachers were randomly interviewed about their feelings in learning and suggestions for the set. Every week, the researcher checked student activity books, thinking books and responses of quizzes and made a summary for the instructors. The summary was brought to each weekly meeting. Unstructured interviewed were employed during the weekly meeting to capture the instructors' perspectives after teaching. The weekly meetings were also the place for the instructors and the researcher to discuss the summary of student work and adjust lesson plans for the subsequent sessions.

It was found that instructors' beliefs had a very strong impact on their implementation. Teachers' beliefs in teacher-centred teaching resulted in their adapting the teaching practice based on a teacher - centred approach in the first few weeks of implementation when they hesitated to follow the lesson plans in instructional set. For example, Vipa used lecturing as the main teaching strategy; she explained concepts and procedure before allowing the pre-service science teachers to do laboratory activities and gave helpful and friendly guidance to individuals during practical activities.

Darin, who implemented the instructional set for longer, changed to use whole class discussion as the main teaching strategy and also provided assistance during laboratory activities. Darin benefited from the weekly meetings with the researcher who gave support for the new instruction approaches by providing recommendations such as how to do group work, how to allow students to share ideas in whole class discussions, questioning techniques and wait time. Formative assessment tools also enabled the instructors, particularly Darin, to obtained feedback from the pre-service science teachers via the students' activity books and thinking books. The students' written reflections included information on their understandings as well as their performance during learning. With these supports and feedback, both instructors gradually changed their beliefs and practice towards a more learner-centred approach.

The findings of this study suggest that instructors need time to change their beliefs and teaching practices. To follow a new teaching approach, instructors need to be assured that the new teaching approach will not lower learner achievement relative to their regular approach. In this study, Darin gained more confidence in the instructional set after the midterm examination which showed a benefit for the pre-service science teachers' content knowledge. She subsequently followed most of the teaching and learning activities in the instructional set and changed her teaching towards a more learner-centred approach. She dedicated more time to preparation in the later lessons and looked at the summaries of student work until the semester ended. Darin often used whole class discussion and asked more comprehension questions in the subsequent laboratory sessions. She also gave more time to the pre-service science teachers to explain their answers.

This study found that pre-service science teachers had three learning strategies: learning by listening, learning by doing hands-on and minds-on activities and learning by social interaction. While the instructors were giving lectures, they tended to listen quietly, took notes in their books and usually slowly gave responses to the instructors' questions. They tended to assign each group member to do different laboratory activities and put together the results which were used in post-lab discussion with the whole class. They could communicate well in the presentation activities and post-lab discussion. They were less active in class after midterm examination, after they were sure that all of marks counted as their final grades were only from content knowledge.

The pre-service science teachers' responses in their activity book showed that most of them could correctly answered most of the questions asked about biology concepts. Some misunderstanding were captured by several questions in each lesson such as terminology confusion between germ cells and sex cells, diffusion in gas phase, definition of paper chromatography, and meanings of terms in the lesson of growth and development. These misunderstandings were corrected by the instructor explanation in the subsequent sessions.

The pre-service science teachers' responses for the biological concept part, assessed by the Biology Concept and Science Process Skill Questionnaire, after learning showed that a majority had partial understanding (PS) in most concepts: cell structure and function, eukaryotes, cell division, sexual reproduction, photosynthesis and ecosystem. A majority of their responses for prokaryotes and osmosis were fallen in to the partial understanding with specific misunderstanding (PS), and specific misunderstanding (SM), respectively. Some of them could give scientific understanding (SU) for prokaryotes and eukaryotes and osmosis. Eighty percent of them showed scientific understanding in asexual reproduction. No answers (NA) were mostly found in mitosis. No specific misunderstandings (SM) were found in concepts of eukaryotes and sexual reproduction.

The pre-service science teachers' responses for the science process skill part, revealed their capability of science process skills after learning. The results showed that after learning through the instructional set, the majority of the pre-service science teachers who gave responses to the questionnaire could correctly gave correct answers to specific questions of posing experimental questions (47%), formulating hypotheses (80%), interpreting results (73%), and drawing a conclusion (87%). Dependent and controlled variables were correctly identified by 60% and 67% of them, respectively. There were two independent variables but each pre-service science teacher could only identify one of them. As a result, none of them could successfully identified variables of the experiment.

In designing an experiment for testing effectiveness of three medicines to cure bird-flu, seven percent of the pre-service science teachers started with formulation an appropriate hypothesis. Twenty percent of them could correctly identify independent and dependent variables of their experiments. Eighty-seven percent of them notified controlled variables. All of them described their experimental designs. Thirty-three percent of them employed a four-group design: 3 treatment groups and 1 control group. Thirteen percent of these pre-service science teachers also indicated experimental replication. However, the majority (53%) proposed a three-group design, without a control group. Forty percent and thirteen percent of all respondents explained how they would collect the experimental results and drawing a conclusion, respectively.

After the implementation of the instructional set, most of the pre-service science teachers had very good understandings in the nature of science but they were unfamiliar with the term 'the nature of science'. The pre-service science teachers were asked to explain what they had learned about the nature of science. Very few of them could notify what it was about. Most of them could not give any ideas about it. In contrast, the results showed high percentages of appropriate understandings in the nature of science when asking them to express their opinions towards specific statements about science.

It was found that the majority of the pre-service science teachers who gave responses to the Nature of Science Questionnaire showed very good understandings in every aspect of in the nature of science. For definition of science, 54% of them thought science was both a product and a process. They all believed that the science process was for construction and development of new knowledge. Their responses indicated very good understanding in the characteristics of scientific knowledge and methods. More than 90% up to 100% noted science was understandable, tentative, had limitations and could be made by accident. More divergent ideas were shown towards the accuracy of the scientific methods. Sixty-two percent of them recognized that errors and biases might lead to the invalid results. All of them believed that all scientists were logical, objective, unbiased and open-minded and mainly motivated by their own curiosity. Seventy-seven percent of them thought imagination and creativity could be used to get results and 62% believed that it was not a scientists' job to ensure that no harms from discoveries. All of them expressed that there was a very strong interrelationship between science and society. They highlighted a huge effect of scientists' personal feeling and moral values on their decision making. Also, the direction of scientific discoveries was based on social beliefs and demands of use.

The pre-service science teachers were asked to give responses to the Attitudes towards Biology Inventory after learning through the instructional set. The results showed that they, in average, had positive attitudes towards all three attitude areas: attitudes towards biology, attitudes towards laboratory learning and attitudes towards the Laboratory in Biology Course. Several items of the inventory showed relatively low scores with high standard deviation. The scores of these items were less than 3.51 which indicated moderate attitudes. These low-score items showed that some of the pre-service science teachers thought: the Laboratory in Biology Course was a difficult subject; there were too many facts to learn in the course; they would like to have fewer biology lessons; biology was difficult when it involved handling apparatus; and biological knowledge was the cause of many of the world problems.

Discussion

Four guiding principles were generated from the literature review and results of the exploratory phase. These were utilized in the development of the instructional set. This section links the findings of this research study in terms of the guiding principles to consider how these principles played out in the classroom as well as what supported and obstructed the implementation process.

Understandings in biology concepts, integrated science process skills, the nature of science and positive attitudes towards biology are important learning outcomes in science

The study found that the characteristics of regular teaching in the Laboratory in Biology Course are consistent with the work by Abraham *et al.* (1997), Woolnough (1998) and Sundburg *et al.* (2000). It was found that laboratory activities were used mainly to promote scientific understandings. The midterm and final tests were dominated by questions asking about facts and concepts in biology. All of the marks in students' final grades in the Laboratory in Biology Course were based on biological content knowledge. This study resembles that of Millar (1989) who found that instructors' teaching relied on transferring the content knowledge provided in the regular laboratory manual rather than allowing the pre-service science teachers learn from and discuss the results which emerged from the laboratory work they had done. The nature of science, science process skills and attitudes towards biology were less emphasized.

It was found that students who did not have adequate understanding of the relevant concepts could not accomplish the laboratory activities (Toh, 1991; Berry *et al*., 1999). In this study the instructors provided an overview of key ideas such as cell structure and function, enzymes, bioenergetics and ecology at the beginning of classes. This then helped ensure the pre-service science teachers had adequate understandings and facilitated them to achieve the laboratory activities.

It is important that students have time to develop and practice technical skills (Hudson, 1994). In this study the instructors provided many opportunities for the pre-service science teachers to practice the skill of using a light microscope and preparing wet mount slides which were the main skills they needed to accomplish the activities in the Laboratory in Biology Course. The pre-service science teachers could develop and perform these two skills well because they received guidance and assistance from the instructors.

There is however a need to balance technical activity with thinking. Arce and Betancourt (1997) argued that students should not spend so much time on laboratory activities that they do not have time to think about and discuss the results. Instructors need to ensure there is time for reflection. One way to do this is to thoroughly check laboratory apparatus before class. The sufficiency and quality of samples and laboratory apparatus appear to impact on student learning outcomes. For instance, when the provided razors were not sharp enough to section plant leaves, none of the pre-service science teachers could prepare a slide to see the inner structure of the leaf. So they could not learn from observing the samples. Checking the quality of laboratory apparatus before class could also help reduce the time spent on laboratory activities to provide more time for discussion and sharing ideas about the results.

The summative assessment shaped both instructors' and the pre-service science teachers' teaching and learning approaches. Both instructors dedicated most time to teaching and learning for the promotion of understanding in biology concepts which would help the pre-service science teachers pass the exanimation. All of the pre-service science teachers focused on content knowledge and paid little attention to teaching and learning activities, especially after the midterm test. This was evidenced by the pre-service science teachers' being less active in class and a decline in the numbers of handing in activity books and thinking books.

Learner-centred teaching and learning have a basis on social constructivism

Teachers' beliefs had been found to be important and interrelated to teaching practice (Cronin-Jones, 1991; Appleton and Asoko, 1996; Bryan, 2003; Veal, 2004). This was also found to be the case in this research study. For Both instructors in this study, scientific knowledge was structured and could be transmitted to students. Similar teachers' views were previously found by Gallagher (1991) and Lemberger *et al*. (1999). This could be inferred that both instructors held traditional view of teaching (Powell, 1994; De Jong *et al.*, 1999; Lemberger *et al.*, 1999; Tsai, 2002). This is the reason why they tended to explain the content knowledge and laboratory procedures to the pre-service science teachers at the beginning of their implementation of the instructional set.

Teachers' beliefs are stable and resistant to change (Kegan, 1992). In the very first weeks of the implementation, with the opposite position of beliefs to those of the instructional set, the instructors hesitated to follow most of the social constructivist based activities. Pair and group discussion among the pre-service science teachers were not apparent in Vipa's teaching as she thought this kind of activity took more time and did not provide better answers for her questions. She distorted this activity and changed it to whole class discussion. Darin sought for correct keywords in the pre-service science teachers' answers and explained the complete answers. This illustrates that genuine social interactions between student-student and student-instructor to socially construct knowledge was rarely happened in the classroom.

Content loading has been found to be an obstacle to productive teaching and learning activities (Geddis *et al.*, 1993). This study also found a similar result. Darin, with the responsibility to cover all of the content uppermost in her mind, was worried that she could not present all the content and finish all of the activities. The volume of prescribed content left insufficient time for pre-service science teachers to social interact with their classmates and the instructors.

The weekly meetings allowed the researcher to discuss teaching and learning activities with the instructors in details and encourage them to take a risk in teaching. Problems happened in class were discussed and the instructors were provided time to reflect on classroom practice. Darin tried her best in class to run the activities based on a balance of her own beliefs and the instructional set. She gained more confidence in the social constructivist teaching approach after she was satisfied with the pre-service science teachers' marks in the midterm examination. She followed most of the activities in the instructional set until the end of the semester. This supported that professional development required continuous and ongoing learning from teaching experience and students' needs and abilities (Eraut, 1995). This study also found that instructors may also need distinct verification of the effectiveness of the new teaching approach.

Formative assessment is a strategy to enhance pre-service science teachers' laboratory learning

Formative assessment is "the process used by both teachers and students to recognized and respond to student learning in order to enhance that learning, during the learning" (Bell and Cowie, 2001). The instructional set provided various tools and strategies of formative assessment: quizzes; a checklist of student skills of using a light microscope and preparing a wet mount slide; and listening to student ideas with providing feedback. In addition, student thinking books and self- and peer-assessment tools were for the pre-service science teachers to report their own learning. This form of assessment was regarded as a new assessment strategy which both instructors had never used in classrooms. They firstly thought it was not necessary, took much time to be accomplished and impractical for their own teaching practice. However, both of them adopted formative assessment for the sake of doing a research study.

The instructors began to appreciate the benefits of formative assessment during the implementation. The checklist of the pre-service science teachers' skills provided information and Vipa came to realize that they needed individual guidance. After she gave them suggestions, most of them improved their practical skills. Darin usually provided feedback after the pre-service science teachers' presentations and discussions. The summary of responses in student activity books and thinking books also benefited both instructors in correcting misunderstanding and improved their teaching practice according to pre-service science teacher comments and suggestions.

Student thinking books were expected to be the material for each pre-service science teacher to report their own learning and express their feelings during the learning. However, they did not often elaborate what they had learned. This might reflect that there were too many concepts to be learned in one laboratory session so that they could not explain every concept. The pre-service science teachers did not seem to be able to effectively use self- and peer- assessment because this kind of assessment was not part of their final grades. They always gave themselves and their peers high marks when they assessed the quality of work during learning and participation in group work without critically consideration of the given criteria.

This study found that formative assessment provides benefits for both instructors and the pre-service science teachers. Instructors can shift their teaching towards a learner-centred approach when they have a better understanding of what their students do and do not know. They can access this information by observation of learner performance and through the process of providing feedback and assistance during learning. Learners have opportunities to reflect on what they have learned and how they feel during learning when they are involved in formative assessment activities such as writing in a thinking book. This involvement has the potential to facilitate life-long learning. To gain these benefits however students need to appreciate the value of formative assessment.

The understanding of nature of science and science process skills are best taught by an explicit teaching approach

Instructors' understanding of the nature of science and science process skills strongly affected their teaching practice. Although they were scientists; both instructors could not fully describe the nature of science and science process skills. Their science process skills seemed to blur with their idea of scientific investigations without clear definition. Their understandings of the nature of science and science process skills seemed fragmented. Being unfamiliar with these two areas in the form of content knowledge meant their teaching practice in class had less emphasis and allocated little time to discussion about the nature of science and science process skills. The instructors' unclear definition of the nature of science seemed to transfer to the pre-service science teachers. Some pre-service science teachers did not recognize the term 'the nature of science' but they showed very good understanding towards each nature of science statement in the Views on the Nature of Science Questionnaire.

A high percentage of responses to the specific questions on the science process skills might have been provoked by the activities in the instructional set which required the pre-service science teachers to formulate hypotheses, identify variables, specify the results and draw a conclusion for every experiment they did. In contrast, they did not have a chance to design their own experiments during the semester due to the limited time large numbers of activities to be done. Very few of them gave an appropriate experimental design. This result supports the findings of the studies by Roth and Roychoudhury (1993) and Tamir (1989). They found science process skills can be developed by practice where they are made explicit by the teacher.

Overall, the findings of this study are similar to those of research done elsewhere to improve science teaching and learning however they provide evidence from a different context, that of pre-service science teachers in Thailand. The results on Thai pre-service science teachers' understandings of the nature of science are inconsistent with the findings elsewhere. This study found that Thai pre-service science teachers had very good understandings in the nature of science after learning through the instructional set. The findings also indicate that an instructional set based on social constructivism that incorporates formative assessment can be effective in assisting instructors to adopt a more learner-centred teaching approach. However, instructors need to be assured that a new teaching approach will not lower achievement relative to their regular approach. In addition, the study indicates that pre-service science teachers benefit from opportunities to share, reflect on and construct ideas. The next section presents some recommendations from this study.

Recommendations

This research study was done in a unique course with a specific group of learners: the Laboratory in Biology Course with 2 instructors and 29 pre-service science teachers. Hence, any recommendations may not be generalizable to other laboratory in science courses. However, there are some important recommendations arising from the study.

Recommendation for Future Research

Further but similar research studies in fundamental laboratory courses would allow for a fuller understanding of what it takes to support university lecturers to use a more learner-centred teaching approach. This research study suggests the need for a longer-term study as instructors need time to change their beliefs and practice. Both of the instructors who participated in this study gained some insight into a learner-centred approach during the one semester in which the instructional set was implemented. The findings of the research would be expanded if instructors had more time to participate and understand the instructional set and its implications.

If similar research studies were done, they should use a collaborative action research. This research study faced opposition due to instructors' beliefs contradicting with the underlying theory of the instructional set. This somewhat obstructed the implementation process so that the implementation of the instructional set was not fully accomplished. Further research should allow instructors to participate in the development process of the instructional set. They could be invited to conceptualize the guiding principles and learning theories, set out the objectives and learning outcomes as well as design teaching and learning activities and assessment strategies. This may reduce their hesitation to try new activities in classrooms.

Recommendation for Tertiary Teaching and Learning

Part of discussion of this study has highlighted the role and importance of summative assessment. This study recommends that content to be learned, the teaching and learning activities and assessment used need to correspond. It provides evidence that formative assessment is practical and useful in a tertiary course. Both instructors in this study benefited from formative assessment tools and strategies such as quizzes, a checklist of student skills and listening to student ideas with providing feedback. So, in addition to using summative assessment to evaluate student learning outcomes, formative assessment can be useful during learning to prompt learners to reflect on their own learning and to provide instructors with information to improve their teaching practice. In this study the pre-service science teachers did not use the formative assessment tools to their full effect. When teaching and learning activities incorporate student thinking books and self- and peer- assessment, it is necessary to help students appreciate the value of writing in thinking books and critically using self- and peer-assessment.

Recommendations for Professional Development

As found in this study, science instructors who have no educational background in science education teach science the way they have learned, that is through a traditional approach with a main concern on the promotion of scientific concepts. The National Education Act, 1999, provides guidelines for learning reform for not only basic education but also higher education. This research suggests that it is necessary to provide professional development in teaching and learning to all science instructors. Tertiary science instructors should have opportunities to participate in seminars and workshops for tertiary science educators. These workshops could begin by facilitating instructors to increase social interaction and to incorporate formative assessment in teaching and learning activities. These would help them conceptualize the ideas of social constructivist teaching and formative assessment as the study found that these can help instructors change their teaching towards a learner-centred approach.

REFFERENCES

Abd-El-Khalick, F. 2005. “Developing deeper understandings of nature of science: the impact of a philosophy of science course on preservice science teachers’ views and instructional planning.” **International Journal of Science Education** 27 (1): 15-42.

Abd-El-Khalick, F. and S. BouJaoude. 1997. “An exploratory study of a knowledge base for science teaching.” **Journal of Research in Science Teaching** 34 (7): 673-699.

Abd-El-Khalick, F. and N. G. Lederman. 2000. “Improving science teachers’ conceptions of nature of science: a critical review of the literature.” **International Journal of Science Education** 22 (7): 665-701.

Abraham M.R., M.S. Cracolice, G. A. Palmer, A.H. Aldhamash, J.G. Kihega, J.G., Palma Gal and V. Varghese. 1997. “The nature and state of general chemistry laboratory courses offered by colleges and universities in the United States.” **Journal of Chemical Education** 74 (5): 591-594.

Abell, S. and D. Smith. 1994. “What is science? Preservice elementary teachers’ conceptions of the nature of science.” **International Journal of Science Education** 16:473-487.

Adeniyi, E. O. 1985. “Misconceptions of selected ecological concepts held by some Nigerian students.” **Journal of Biological Education** 19 (4): 311-316.

Aguirre, J. M., S. M. Haggerty and C. J. Linder. 1990. “Student-teachers’ conceptions of science, teaching and learning: A case study in preservice science education.” **International Journal of Science Education** 12 (4): 381-390.

Aikenhead, G., R.W. Fleming and A.G. Ryan. 1987. "High-school graduates beliefs about science-technology-society: Methods and issues in monitoring student views." **Science Education** 71 (2). 145-161.

Airasian, P. W. and M. E. Walsh. 1997. "Constructivist cautions." **Phi Delta Kappan** 78 (6): 444-449.

Akerson, V.L., F. Abd-El-Khalick and N.G. Lederman. 2000. "Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science." **Journal of Research in Science Teaching** 37 (4): 295-317.

Amir, R. and P. Tamir. 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): 94-100.

American Association for the Advancement of Science. 1989. **Science for all Americans** (Online). www.project 2061.org/tools/sfaaol/sffaatoc.htm, February, 28, 2005.

______. 1993. **Benchmarks for Science Literacy** (Online). www.project2061.org/tools/benchol/bolintro.htm, February, 28, 2005.

Anderson, C. W., T. H. Sheldon and J. DuBay. 1990. "The effect of instruction on college nonmajors' conceptions of respiration and photosynthesis." **Journal of Research in Science Teaching** 27 (8): 761-776.

Appleton, K. and H. Asoko. 1996. "A case study of a teacher's progress toward using a constructivist view of learning to inform teaching in elementary science." **Science Education** 80 (2): 165-180.

Arasian, P. W. and M. E. Walsh. 1997. “Constructivist cautions.” **Phi Delta Kappan** 78: 444-449.

Arce, J. and R. Betancourt. 1997. “Student-designed experiments in scientific lab instruction.” **Journal of College Science Teaching** 27 (2): 114-118.

Areekul, S. 2005. **Higher Education for Country Development** (Online). www.onec.go.th/publication/4009001/index.htm, March, 17, 2005.

Aronson, J. 1994. “**A Pragmatic View of Thematic Analysis”** (Online). www.nova.edu/ssss/QR/BackIssues/QR2-1/aronson.html, May, 8, 2005.

Arzi, H. J. 1998. Enhancing science education through laboratory environments: more than walls, benches and widgets. In B. J. Frazer and K. G. Tobin (eds.). **International Handbook of Science Education** Great Britain: Kluwer Academic Publishers.

Atkinson, E. P. 1990. “Learning scientific knowledge in the student laboratory.” In E. Hegarty-Hazel (ed.). **The Student Laboratory and the Science Curriculum**. London: Routledge.

Barker, M. 1985. **Teaching and Learning about Photosynthesis**. Working Paper, No. 220-229. Hamilton, NZ: The University of Waikato.

Barker, M. and M. Carr. 1989. “Teaching and learning about photosynthesis. part 1: an assessment in terms of students’ prior knowledge.” **International Journal of Science Education** 11 (1): 49-56.

Barufaldi, J. P., L. Bethel and W. G. Lamb. 1977. “The effect of a science method course on the philosophical view of science among elementary education majors.” **Journal of Research in Science Teaching** 14 (4): 289-294.

Barman, C.R., N.S. Barman, M.L. Cox, K. Newhouse and M.J. Goldston. 2000. "Students' ideas about animals: Results from a national study." **Science & Children** 38 (1): 42-47.

Beaumont-Walters, Y. and K. Soyibo. 2001. "An analysis of high school students' performance on five integrated science process skills." **Research in Science & Technological Education** 19 (2): 133-145.

Behrens, J. T., and M. L. Smith. 1996. "Data and data analysis." In D. C. Berliner and R. C. Calfee (eds.). **Handbook of Educational Psychology**. New York: Macmillan.

Bell, B. 1985. "Students' ideas about plant nutrition: What are they?." **Journal of Biological Education** 19 (3): 213-218.

Bell, B. 1993. **Children's Science, Constructivism and Learning in Science**. Victoria: Deakin University Press.

Bell, J. 1993. **Doing Your Research Project**. Philadelphia: Open University Press.

Billingsley, B. S. 2004. Special education teacher retention and attrition: A critical analysis of the research literature. **The Journal of Special Education** 38 (1): 39-55.

Bell, B. and B. Cowie. 2001. "The characteristics of formative assessment in science education." **Science Education** 85: 536-553.

Beaumont-Walters, Y. and K. Soyibo. 2001. "An analysis of high school students' performance on five integrated science process skills." **Research in Science & Technological Education** 19 (2): 133-145.

Bentley, M., C. Ebert and E. S. Ebert II. 2000. **The Natural Investigation: A Constructivist Approach to Teaching Elementary and Middle School Science.** California: Wardsworth.

Berry, A., P. Mulhall, R.F. Gunstone and J.J. Loughran. 1999. "Helping students learn from laboratory work." **Australian Science Teachers' Journal** 45 (1): 27-31.

Berry, A. and J. Loughran. 2001**. Curriculum Change in Science Teaching: The Need to Listen to Teachers** (Online). www.ied.edu.hk/apfslt/v2_issue1/ berry/index.htm, January, 26, 2004.

Bloom, J. W. 1989. "Preservice elementary teachers' conceptions of science: science, theories and evolution." **International Journal of Science Education** 11 (4): 401-415.

Bodner, G. M. 1986. "Constructivism: A theory of knowledge." **Journal of Chemical Education** 63 (10):873-878.

Bouma, G. D. 2000. **The Research Process**. 4th ed. Melbourn: Oxford University Press.

Brooks, M. G. and J. G. Brooks. 1999. The courage to be constructivist. **Educational Leadership** 57 (3): 18-24.

Bryan, L. A. 2003. "Nestedness of beliefs: examining a prospective elementary teachers' beliefs system about science teaching and learning." **Journal of Research in Science Teaching** 40: 835-868.

Bryman, A. 1988. **Quantity and Quality in Social Research**. London: Routledge.

Bryman, A. 2001. **Social Research Methods**. NY: Oxford University Press.

Carlsson, B. 2002. “Ecological understanding 1: ways of experience photosynthesis.” **International Journal of Science Education** 24 (7): 681-699.

Chaplin, S. B., J. M. Manske and J. L. Cruise. 1998. Introducing freshmen to investigative research – a course for biology majors at Minnesota’s University of St. Thomas. **Journal of College Science Teaching** 27 (5): 347-350.

Champanario, J. M. 2002. The parallelism between scientists’ and students’ resistance to new scientific ideas. **International Journal of Science Education** 24 (10): 1095-1110.

Clackson, S. G. and D. K. Wright. 1992. An appraisal of practical work in science education. **School Science Review** 74: 39-42.

Clough, M.P. 1998. “Integrating the nature of science with student teaching: rationales and strategies.” In W. F. McComas (ed.). **The Nature of Science in Science Education: Rationales and Strategies**. Netherlands: Kluwer Academic Publishers.

Coble, C.R. and T.R. Koballa. 1996. Science Education. In J. Siluka, T.J. Buttery and E. Guyton. (eds). **Handbook of Research on Teacher Education.** 2nd ed. New York: Simon & Schuster Macmillan.

Cohen, L. and L. Manion. 1994. **Research Methods in Education.** 4th ed. London: Routledge.

Cohen, L., L. Manion and K. Morrison. 2000. **Research Method in Education**. 5th ed. London: Routledge.

Colburn, A. 2004. “Focusing labs on the nature of science.” **The Science Teacher** 71 (9): 32- 35.

Cosgrove, M. and R. Osborne. 1985. “Lesson frameworks for changing children’s ideas.” In R. Osborne and P. Freyberg (eds.). **Learning in Science: The Implications of Children’s Science**. Auckland, N.Z.: Heinemann.

Creswell, J. W. 1998. **Qualitative Inquiry and Research Design: Choosing Among Five Traditions.** Thousand Oaks: Sage Publication.

Cronin-Jones, L. L. 1991. “Science teaching beliefs and their influence on curriculum implementation: two case studies.” **Journal of Research in Science Teaching** 28: 235-250.

Crowther, D. T. 1997. “The constructivist zone.” **Electronic Journal of Science Education** 2 (2): 1-11.

Darling, R. 2001. “Don’t settle for imitation laboratory assignments.” **Journal of College Science Teaching** 31 (2): 102-105.

Department of Zoology. 2005. **The Laboratory in Biology Manual**. Bangkok: Office of Training and Extension, Kasetsart University.

Derry, S. J. 1996. “Cognitive schema theory in the constructivist debate.” **Educational Psychologist** 31 (3/4): 163-174.

Detel, W. 2001. “Social constructivism.” In U. A Pettit (ed.) **International Encyclopedia of the Social & Behavioral Science** 14264-14267. Elsevier Science.

Doran, R. L., J. Boorman, F. Chan and N. Hejaily. 1993. "Alternative assessment of high school laboratory skills." **Journal of Research in Science Teaching** 30 (9): 1121-1131.

Doran, R. L., B. J. Freser and G. F. Giddings. 1995. "Science laboratory skills among grade 9 students in Western Australia." **International Journal of Science Education** 17 (1): 27-44.

Douvdevany, O., A. Dreyfus and E. Jungwirth. 1997. "Diagnosing instruments for functional relationships within the 'living cell'." **International Journal of Science Education** 19 (5): 513-606.

Dreyfus, A. and E. Jungwirth. 1988. "The cell concept of 10th graders: curricular expectations and reality." **International Journal of Science Education** 10 (2): 221-229.

______. 1989. "The pupil and the living cell: a taxonomy of dysfunctional ideas about an abstract idea." **Journal of Biological Education** 23 (1): 49-55.

Driver, R. 1983. **The Pupil as Scientist?**. England: Open University Press.

Driver, R., E. Guesne and A. Tiberghien. 1985. **Children's Ideas in Science**. United Kingdom: Tamworth.

Driver, R., A. Squires, P. Rushworth and V. Wood-Robinson. 1994. **Making Sense of Secondary Science.** London: Routledge.

Driver, R., H. Asoko, J. Leach, E. Mortimer and P. Scott. 1994. "Constructing scientific knowledge in the classroom." **Educational Researcher** 23 (7): 5-12.

Driver, R., J. Leach, R. Millar and P. Scott. 1996. **Young People's Images of Science**. Buckingham: Open University Press.

Driver, R. and V. Oldham. 1986. "A constructivist approach to curriculum development in science." **Studies in Science Education** 13: 105-122.

Duit, R. and D. F. Treagust. 1998. "Learning in science - from behaviourism towards social constructivism and beyond." In B. J. Fraser and K. G. Tobin (eds.). **International Handbook of Science Education** (pp. 3-25). London: Kluwer Academic Publishers.

Ebenezer, J. V. and U. Zoller. 1993. "Grade 10 students' perceptions of and attitudes toward science teaching and school science." **Journal of Research in Science Teaching** 30 (2): 175-186.

Eick, C.J. 2000. "Inquiry, nature of science, and evolution: the need for a more complex pedagogical content knowledge in science teaching". **Electronic Journal of Science Education** 4 (3): 1-14.

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 student teachers use scientific conceptions to discuss a complex environment issue." **Journal of Biological Education** 37 (3): 126-132.

Eraut, M. 1995. "Developing professional knowledge within a client-centered orientation." In T. R. Guskey and M. Huberman (eds.). **Professional Development in Education**. New York: Teacher College Press.

Erickson, F. 1986. "Qualitative methods in research on teaching." In M.C. Wittrock (ed.). **A Handbook of Research on Teaching**. New York: Macmillan.

Etheredge, S. and A. N. Rudnitsky. 2003. **Introducing Students to Scientific Inquiry: How Do We Know What We Know?.** Boston: Allyn and Bacon.

Finley, F. N. 1983. "Science processes." **Journal of Research in Science Teaching** 20 (1): 47-54.

Francis, L. J. and J. E. Greer. 1999. "Attitude toward science among secondary school pupils in northern Ireland: relationship with sex, age, and religion." **Research in Science & Technological Education** 17 (1):67-74.

Freebody, P. 2003. **Qualitative Research in Education: Interaction and Practice**. London: California: Sage.

Fontana, A. and J. H. Frey. 1994. "Interviewing: the art of science." In N.K. Denzin and Y.S. Lincoln (eds). **Handbook of Qualitative Research**. California: Sage.

Friedler, Y. and Tamir, P. 1990. "Life in science laboratory classrooms at secondary level." In E. Hegarty-Hazel (ed.). **The Student Laboratory and the Science Curriculum**. London: Routledge.

Flores, F., M. E. Tovar and L. Gallegos. 2003. "Representation of the cell and its processes in high school students: an integrated view." **International Journal of Science Education** 25 (2): 269-286.

Foote, L.C. and K. A. FitzPatrick. 2004. "Introduction to biological investigations." **Journal of College Science Teaching** 34 (3): 35-40.

Gallagher, J. J. 1991. "Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science." **Science Education** 75: 121-133.

Gardiner, P. G. and P. Farrangher. 1999. “The quantity and quality of biology laboratory work in British Columbia high schools.” **School Science and Mathematics** 99 (4): 197-204.

Gardner, P. and C. Gauld. 1990. “Labwork and students’ attitudes.” In E. Hegarty-Hazel (ed.). **The Student Laboratory and the Science Curriculum**. London: Routledge.

Geddis, A. N., B. Onslow, C. Beynon and J. Oesch. 1993. “Transformation content knowledge: learning to teaching isotopes.” **Science Education** 77: 575-591.

Germann, P. J., R. Aram and G. Burke. 1996. “Identifying patterns and relationships among the responses for seventh-grade students to the science process skill of designing experiment.” **Journal of Research in Science Teaching** 33 (1): 79-99.

Germann, P. J. and R. J. Aram. 1998. “Student performances on the science processes of recording data, analyzing data, drawing conclusions and providing evidence.” **Journal of Research in Science Teaching** 33 (7): 773-798.

Germann, P. J., R. J. Aram and G. Burke. 1998. “Identifying patterns and relationships among the responses of seventh-grade students to the science process skill of designing experiments.” **Journal of Research in Science Teaching** 33(1): 79-99.

Gess-Newsome, J. 2002. “The use and impact of explicit instruction about the nature of science and science inquiry in an elementary science methods course.” **Science & Education** 11, 55-67.

Giddings, G.J., A.Hofstein and V.N. Lunetta. 1991. "Assessment and evaluation in the science laboratory." In B. E. Woolnough (ed.). **Practical Science** (pp. 167-178). Milton Keynes: Open University Press.

Glasson, G. E. and W. L. McKenzie. 1997. "Investigative learning in undergraduate freshman biology laboratories." **Journal of College Science Teaching** 27 (3): 189-193.

Goetz, J. P. and M. D. LeCompte. 1984. **Ethnography and Qualitative Design in Educational Research.** New York: Academic Press.

Goodwin, J. 2003. "Students' perspectives on debate: exercises in content area classes." **Communication Education** 52 (2): 157-163

Gott, R. and J. Mashiter. 1991 "Practical work in science – a task - based approach?" In B. E. Woolnough (ed.). **Practical Science** (pp 53-66). Milton Keynes: Open University Press.

Grant, B. W. and I. Vatnick. 1998. "A multi-week inquiry for an undergraduate introductory biology laboratory." **Journal of College Science Teaching** 28 (2): 109-112.

Griffiths, L. K. and B. A. C. Grant. 1985. "High school students' understanding of food webs: identification of a learning hierarchy and related misconceptions." **Journal of Research in Science Teaching** 22 (5): 421-436.

Guba, E.G. 1990. **The Paradigm Dialog**. California: Sage.

Guba, E.G. and Y.S. Lincoln. 1989. **Fourth Generation Evaluation**. California: Sage Publications.

Guba, E.G. and Y.S. Lincoln. 1998. “Competing paradigms in qualitative research.” In N.K. Densin and Y.S. Lincoln (eds.). **The Landscape of Qualitative Research: Theories and Issues.** California: Sage.

Gunstone, R. F. 1993. “Constructivist learning and the teaching of science.” In B. Hand and V. Prain (eds.). **Teaching and Learning in Science: The Constructivist Classroom.** Australia: Harcourt Brace & Company.

Gustafson, B. J. and P. M. Rowell. 1995. “Elementary preservice teachers: constructing conceptions about learning science, teaching science and the nature of science.” **International Journal of Science Education** 17 (5): 589-606.

Haidar, A. H. 1997. “Prospective chemistry teachers’ conception of the conservation of matter and related concepts.” **Journal of Research in Science Teaching** 34 (2): 181-197.

Haigh, M. 1998. **Investigative Practical Work in Year 12 Biology Programmes**. Ph.D.Thesis: The University of Waikato.

Haigh, M. and D. Hubbard. 1997. “I really know I have learned something: Investigative work in science education.” In B. Bell and R. Baker (eds.). **Developing the Science Curriculum in Aotearoa New Zealand**. Auckland: Addison Wesley Longman.

Halsam, F. and D. F. 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.

Harker, A. R. 1999. “Fully application of the scientific method in an undergraduate teaching laboratory.” **Journal of College Science Teaching** 29 (2): 97-100.

Harlen, W. 1992. **The Teaching of Science**. London: David Fulton Publishers Ltd.

______. 1999. "Purposes and procedures for assessing science process skills." **Assessment in Education** 6 (1): 129-144.

Hazel, E. and M. Prosser. 1994. "First-year university students' understanding of photosynthesis: their strategies & learning context." **The American Biology Teacher** 56 (5): 274-279.

Hegarty-Hazel, E. 1990. "Life in science laboratory classrooms at tertiary level." In E. Hegarty-Hazel (ed.). **The Student Laboratory and the Science Curriculum**. London: Routledge.

Henderson, L. H. and C. A. Buising. 2001. "Research-based molecular biology laboratory." **Journal of College Science Teaching** 30 (5): 322-327.

Henson, K. T. 2003. "Foundations for learner-centered education: a knowledge base." **Education** 124(1): 5–16.

Hirtle J. 1996. "Social constructivism." **English Journal** 85 (1): 91-92.

Hitchcock, G. and D. Hughes. 1995. **Research and the Teacher**. 2nd ed. London: Routledge.

Hodson, D. 1985. "Philosophy of science, science, and science education." **Studies in Science Education** 12: 25-57.

______. 1996. "Laboratory work as a scientific method : three decades of confusion and distortion." **Journal of Curriculum Studies** 28 (2): 115-135.

Hodson, D. 1998. “Is this really what scientists do? Seeking a more authentic science in and beyond the school laboratory.” In J. Wellington (ed.). **Practical Work in School Science: Which Way Now?.** London and New York: Routledge.

Hudson, T. 1994. “Developing pupils’ skills.” In R. Levinson (ed.). **Teaching Science.** London: Routledge.

Husén, T. 1997. “Research paradigm in education.” In J. P. Keeves (ed.). **Educational Research, Methodology, and Measurement: An international Handbook.** (2nd ed). Oxford: Elsevier Science Ltd.

Institute for Promoting Teaching Science and Technology. (2002). **National Science Content Standards.** Bangkok: Karusapa Press.

Jaramillo, J. A. 1996. “Vygotsky’s sociocultural theory and contributions to the development of constructivist curricula.” **Education** 117 (1): 133-140.

Jenkins, E. 1998. “The schooling of laboratory science.” In J. Wellington (ed.). **Practical Work in School Science: Which Way Now?.** London and New York: Routledge.

Jesky-Smith, R. 2002. “Me, teach science?.” **Science and Children** 39 (6): 26-30.

Jinks, J. 1997. **The Science Processes** (online). www.coe.ilstu.edu/scienceed/jinks/processes.htm, February, 28, 2005.

John-Steiner, V. and H. Mahn. 1996. “Sociocultrual approach to learning and development: a Vygotskian framework.” **Educational Psychologist** 31 (3/4): 191-206.

Johnson, B. and L. Christensen. 2000. **Edcuational Research: Quantitative and Qualitative Approaches.** Boston: Allyn & Bacon.

Jones, A. 2005. "Qualitative research in science education." In **Workshop on Qualitative Research in Science Education,** 14-18 March 2005. Bangkok: Kasetsart University.

Kao, L. and M. Su. 2004. **A Study of Students' Concepts on Respiration.** Paper presented at annual meeting of the National Association for Research in Science Teaching, Vancouver.

Kegan, D. M. 1992. "Implications of research on teacher belief." **Educational Psychologist** 27: 65-90.

Kelly, A.E. and R.A. Lesh. 2000. **Handbook of Research Design in Mathematics and Science Education.** New Jersey: L. Erlbaum.

Kijkuakul, S and N. Yutakom. 2004. "A study of level 4 students' photosynthesis conceptions." **Kasertsart Journal (Social Sciences)** 25 (2): 139-149.

Kindfield, A. C. H. 1994. "Assessing understanding of biological process: elucidating students' models of meiosis." **The American Biology Teacher** 56 (6): 367-371.

King, B. B. 1991. "Beginning teachers' knowledge of and attitudes toward history and philosophy of science." **Science Education** 75 (1): 135-141.

Kiraly, D. 2000. **A Social Constructivist Approach to Translator Education: Empowerment from Theory to Practice**. Manchester: St. Jerome Publishing.

Knabb, M. T. 1997. “Creating a research environment in an introductory cell physiology course.” **Journal of College Science Teaching** 27 (3): 205-209.

Kracker, J. and H. R. Pollio. 2003. “The experience of libraries across time thematic analysis of undergraduate recollections of library experiences.” **Journal of the American Society for Information Science and Technology** 54 (12): 1104-1116.

Lawlor, F. X. 1999. “SAPA: science - a process approach.” **Enhanced Science Helper K-8** (online). www.coe.ufl.edu/esh/Projects/sapa.htm, March, 4, 2005.

Lazarowitz, R. and P. Tamir. 1994. “Research on using laboratory instruction in science.” In D. Gabel (ed.). **Handbook of Research on Science Teaching and Learning.** New York: Macmillan Publishing Company.

Leach, J. 1998. “Teaching about the world of science in the laboratory.” In J. Wellington (ed.). **Practical Work in School Science: Which Way Now?.** London and New York: Routledge.

Leach, J., R. Driver, P. Scott and C. Wood-Robinson. 1996a. “Children’s ideas about ecology 2: ideas found in children aged 5-16 about interdependency of organisms.” **International Journal of Science Education** 18 (2): 129-141.

______. 1996b. “Children’s ideas about ecology 3: ideas found in children aged 5-16 about the cycling of matter.” **International Journal of Science Education** 18 (1): 19-34.

Leach, J., R. Driver, R. Millar and P. Scott. 1997. “A study of progression in learning about ‘the nature of science’: issues of conceptualisation and methodology.” **International Journal of Science Education** 19 (2): 147-166.

Leach, J. and P. Scott. 2002. “Designing and evaluating science teaching sequences: an approach drawing upon the concept of learning demand and a social constructivist perspective on learning.” **Studies in Science Education** 38: 115-142.

Lederman, N. G. 1992. “Students’ and teachers’ conceptions of the nature of science**:** a review of the research.” **Journal of Research in Science Teaching** 29 (4): 331-359.

______. 1998. “The state of science education: subject matter without context.” **Electronic Journal of Science Education** 3 (2): 1-12.

______. 1999. “Teachers’ understanding of the nature of science and classroom practice: factors that facilitate or impede the relationship.” **Journal of Research in Science Teaching** 36 (8): 916-929.

Lederman, N. G., W. F. McComas and M. R. Matthews. 1998. “Editorial”. **Science and Education** 7 (6): 507-509.

Lederman, N. G., P. Wade and R.L. Bell. 1998. “Assessing understanding of the nature of science: a historical perspective.” In W.F. McComas (ed). **The Nature of Science in Science Education**. Netherlands: Kluwer Academic Publishers.

Lemberger, J., P. W. Hewson and H. Park. 1999. “Relationships between prospective secondary teachers’ classroom practice and their conceptions of biology and of teaching science.” **Science Education** 83: 347-371.

Lewis, J., J. Leach and C. Wood-Robinson. 2000. “Chromosomes: The missing link-young people’s understanding of mitosis, meiosis, and fertilization.” **Journal of Biological Education** 34 (4): 189-199.

Lincoln, Y. S. and E. G. Guba. 1985. **Naturalistic Inquiry**. California: Sage.

Lorsbach., A. and K. Tobin. 1992. **"Constructivism as a Reference for Science Teaching." Research Matters to the Science Teacher**. Monograph No. 5, 7 pp.

Loucks-Horsley, S. and C. Matsumoto. 1999. "Research on professional development for teacher of mathematics and science: The state of the scene." **School Science and Mathematics** 99 (5): 258-271.

Lundford, E. 2002. "Inquiry in the community college biology lab." **Journal of College Science Teaching** 32 (4): 232-235.

Lunetta, V. N. 1998. "The school science laboratory: historical perspectives and context for contemporary teaching." In B. J. Fraser and K. B. Tobin (eds). **International Handbook of Science Education** (pp. 249-262). Great Britain: Kluwer Academic Publishers.

Mak, S. Y., D. Y. Yip and C. M. Chung. 1999. "Alternative conceptions in biology-related topics of integrated science teachers and implication for teacher education." **Journal of Science Education and Technology** 8 (2): 161-170.

Mann, M. and D. F. Treagust. 1998. "A pencil and paper instrument to diagnose students' conceptions of breathing, gas exchange and respiration." **Australian Science Teachers Journal** 44 (2): 55-59.

Marbach-Ad, G. and R. Stavy. 2000. "Student's cellular and molecular explanation of genetic phenomena." **Journal of Biological Education** 34 (4): 200-205.

Marek, E. 1986. "They misunderstand but they'll pass." **The Science Teacher** 53 (9): 32-35.

Matthews, M. 1997. “James T. Robinson’s account of philosophy of science and science teaching: Some lessons for today from the 1960s.” **Science Education** 81 (3): 295-316.

Matthews, W. J. 2003. “Constructivism in the classroom: Epistemology, history, and empirical evidence.” **Teacher Education Quarterly** Summer: 51-64.

McComas, W.F., M. Clough and H. Almazroa. 1998. “The role and character of the nature of science in science education.” In W.F. McComas (ed.). **The Nature of Science in Science Education**. Kluwer Academic Publishers: Netherlands.

McIntosh, W. J. 2000. “Beyond 2000. The changing face of undergraduate science education.” **Journal of College Science Teaching** 29 (6): 379-380.

Meichtry, Y.J. 1992. “Influencing student understanding of the nature of science: data from a case of curriculum development.” **Journal of Research in Science Teaching** 29 (4), 389-407.

Merriam, S. B. 1998. **Qualitative Research and Case Study Applications in Education**. San Francisco: Jossey-Bass Pulishers.

Millar, R. 1989. “Bending the evidence: The relationship between theory and experiment in science education.” In R. Millar (ed.). **Doing Science: Images of Science in Science Education**. London: The Falmer Press.

______. 1991. “A means to an end: the role of processes in science education.” In B. Woolnough (ed.). **Practical Science**. Buckingham: Open University Press.

Millar, R. and R. Driver. 1987. “Beyond processes.” **Studies in Science Education** 14: 33-62.

Moore, R. W. and R. L. H. Foy. 1997. “The scientific attitude inventory: A revision (SAI II).” **Journal of Research in Science Teaching** 34 (4): 327-336.

Mouly, G. J. 1978. **Educational Research : the Art and Science of Investigation**. Boston : Allyn and Bacon

Munson, B. H. 1994. “Ecological misconceptions.” **Journal of Environmental Education** 25 (4): 30-34.

Murphy, M. K. 2000. “Javametrics 101: Introducing nonscience majors to the chemistry laboratory.” **Journal of College Science Teaching** 30 (2): 106-108.

Murcia, K. and R. Schibeci. 1999. “Primary student teachers’ conceptions of the nature of science.” **International Journal of Science Education** 21 (11): 1123-1140.

National Economic and Social Development Board (NESDB). 2002. **The Ninth National Economic and Social Development Plan**. Bangkok: Suksapan Panitch.

National Science Teachers Association (NSTA). 1998. **NSTA Standards for Science Teacher Preparation** (online). www.nvgc.vt.edu/nsta-ncate/november98.htm., April 25, 2003.

______. 2005. **Laboratory Science** (online). www.nsta.org/positionstatement &psid= ,16, March 9, 2005.

Nazario, G. M., P. A. Burrowes and J. Rodriguez. 2002. “Persisting misconceptioins.” **Journal of College Science Teaching** 31 (5): 292-296.

Nola, R. 1997. “Constructivism in science and science education: A philosophical critique.” **Science and Education** 6: 55-83.

Nott, M. and J. Wellington. 1996. "When the black box springs open: practical work in schools and the nature of science." **International Journal of Science Education** 18 (7): 807-818.

Nott, M. 1997. "Keeping scientists in their place." **School Science Reviews** 78 (285): 49-61.

Odom, A. L. 1995. "Secondary and college biology students' misconceptions about diffusion and osmosis." **The American Biology Teacher** 57 (7): 409-413.

Odom, A. L. and L. H. Barrow. 1995. "Development and application of a two-tier diagnostic test measuring college biology students' understanding of diffusion and osmosis after a course of instruction." **Journal of Research in Science Teaching** 32 (1): 45-61.

Odom, A. L. and P. V. Kelly. 2001. "Integrating concept mapping and the learning cycle to teach diffusion and osmosis concepts to high school biology students." **Science Education** 85: 615-635.

Office of Education Council. 1999. **Higher Educational Reform in Accordance with the National Education Act, 1999** (online). www.onec.go.th/publication/4309026/dereformudom.pdf, March 17, 2005.

______. 2005. **Strategies and Roadmap for Higher Education Reform in Thailand** (online). www.onec.go.th/publication/47042/ full47042.pdf, March 17, 2005.

Office of the Council of State. 2005. **The 1997 Constitution of the Kingdom of Thailand** (online). www.krisdika.go.th/searchShowFile.jsp?path=%2Fexport %2Fnew_htdocs%2Fdata%2Flaw%2Flaw1%2F%25c306%2F%25c306-10-2540-a0001.pdf, March 17, 2005.

Office of the National Education Commission. 1999a. **Learning Reform: A Must for a Nation** (online). www.edthai.com/reform/dec03a.htm, March 17, 2005.

______. 1999b. **Policies of Teacher Education and Teacher Development** (online). www.thaiteacher.org/develop/teacher_dev/index.html, March 17, 2005.

______. 1999c. **Thailand's Educational Reform: The National Education Act 1999 Hope for a Better Reform** (online). edthai.com/reform/nov28a.htm, March 17, 2005.

______. 2001. **Report of Research and Development of Science Education Reform in Thailand**. Bangkok: Office of the National Education Commission.

O'Loughlin, M. 1992. "Rethinking science education: beyond Piagetian constructivism toward a sociocultural model of teaching and learning." **Journal of Research in Science Teaching** 29 (8): 791-820.

Olson, J. K. 1990. "Teacher's conceptions of their subject and laboratory work in science." In E. Hegarty-Hazel (ed.). **The Student Laboratory and the Science Curriculum**. London: Routledge.

Oppenheim, A. N. 1966. **Questionnaire Design and Attitude Measurement**. New York: Basic Books, Inc.

Osborne, J. F. 1996. "Beyond constructivism." **Science Education** 80 (1): 53-82.

Özay, E. and H. Öztas. 2003. "Secondary students' interpretations of photosynthesis an plant nutrition." **Journal of Biological Education** 37 (2): 68-70.

Öztap, H., E. Özay and F. Öztap. 2003. "Teaching cell division to secondary school students: an investigation of difficulties experienced by Turkish teachers." **Journal of Biological Education** 38 (1): 13-15.

Palincsar, A. S. 1998. "Social constructivist perspectives on teaching and learning." **Annual Review of Psychology** 49: 345-375.

Patton, M. Q. 1990. **Qualitative Evaluation and Research Methods**. Beverly Hills: Sage.

Perkins, D. 1999. "The many faces of constructivism." **Educational Leadership** 57 (3): 6-11.

Petersen, C. E. 2000. "An experimental project approach to biology." **Journal of College Science Teaching** 30 (3): 162-165.

Plourde, L. A. and O. Alawiye. 2003. "Constructivism and elementary preservice science teacher preparation: Knowledge to application." **College Student Journal** 37 (3): 334-341.

Polsaram, P. and W. Thephasdin Na Ayutaya. 2000. **The Development of Bachelor' s Degree Learning Process.** Bangkok: Aroon Press Ltd.

Pomeroy, D. 1993. "Implications of teachers' beliefs about the nature of science: Comparison of the beliefs of scientists, secondary science teachers, and elementary teachers." **Science Education** 77: 261-278.

Punch, K. F. 1998. **Introduction to Social Research: Quantitative and Qualitative Approach**. London: Sage.

Ragsdale, F. R. and K. M. Pedretti. 2004. "Making the rate: Enzyme dynamics using pop-it beads." **The American Biology Teacher** 66 (9): 621-626.

Roadrangka, V. and P. Dechakoop. 1989. **Science Process Skills Activities for Teachers**. Bangkok: Institute of Academic Development.

Roberts, R. 2004. "Using different types of practical within a problem-solving model of science." **School Science Reviews** 85 (312): 113-119.

Roth, W. and A. Roychoudhyry. 1993. "The development of science process skills in authentic contexts." **Journal of Research in Science Teaching** 30 (2): 127-152.

Rubba, P.A. and W.L. Harkness. 1993. "Examination of preservice and in-service secondary science teachers' beliefs about science-technology-society interactions." **Science Education** 77 (4): 407-431.

Rudd, II R. A., B. M. Hand and T. J. Greenbowe. 2002. "Restructuring the chemistry laboratory report using the science writing heuristic." **Journal of College Science Teaching** 31 (4): 230-234.

Russell, C. P. and D. P. French. 2001. "Factors affecting participation in traditional and inquiry based laboratories." **Journal of College Science Teaching** 31 (4): 232-235.

Sadler, T. D., F. W. Chambers and D. L. Zeidler. 2004. "Student conceptualization of the nature of science in response to a socioscientific issue." **International Journal of Science Education** 26 (4): 387-409.

Sanger, M. J., D. M. Brecheisen and B. M. Hynek. 2001. "Can computer animation affect college biology students' conception about diffusion and osmosis?" **The American Biology Teacher** 63 (2): 104-409.

Sander, M. 1993. "Erroneous ideas about respiration: The teacher factor." **Journal of Research in Science Teaching** 30 (8): 919-934.

Salta, K. and C.Tzougraki. 2004. "Attitudes toward chemistry among 11th grade students in high school in Greece." **Science Education** 88: 535-547.

Schofield, J. W. 1993. "Increasing the gerneralizability of qualitative research." In M. Hammersley (ed.). **Social Research: Philosophy, Politics and Practice**. London: Sage.

Screen, P. 1988. "A case for a process approach: The Warwick experience." **Physics Education** 23: 146-149.

Schutt, R. 2003. **Theories and Philosophy for Social Research** (Online). www.pineforge.com/Schutt%20Chp.%203%20Final%20Pdf_4122.pdf, May 9, 2005.

Schwandt, A. S. 1998. "Constructivist, interpretivist approaches to human inquiry." In N.K. Densin and Y.S. Lincoln (eds.). **The Landscape of Qualitative Research: Theories and Issues**. California: Sage.

Séré, M. G. 2002. "Towards renewed research questions from the outcomes of the European project labwork in science education." **Science Education** 86 (5): 624-644.

Shepardson, D. P. and E. L. Pizzini. 1994. "Gender, Achievement, and Perception towards Science Activities." School Science and Mathematics 94 (4): 188-193.

Shiland, T. W. 1999. "Constructivism: The implication for laboratory work." **Journal of Chemical Education** 76 (1): 107-109.

Shulman, L. S. and E. R. Keislar. 1966. **Learning by Discovery: A Critical Appraisal.** Chicago: Rand McNally & Company.

Silvius, J. E. and B. C. Stutzman. 1998. "A botany laboratory inquiry experience." **Journal of College Science Teaching** 28 (3): 193-197.

Simpson, G. 2001. "Learner characteristics, learning environments and constructivist epistemologies." **Australian Science Teachers Journal** 47 (2): 17-24.

Simpson, W. D. and E. A. Marek. 1988. "Understanding and misconceptions of biology concepts held by students attending small high school and students attending large high school." **Journal of Research in Science Teaching** 25 (5): 361-374.

Solomon, J. 1980. **Teaching Children in the Laboratory**. London: Croom Helm.

Songer, C. J. and J. J. Mintzes. 1994. "Understanding cellular respiration: an analysis of conceptual change in college biology." **Journal of Research in Science Teaching** 31 (6): 621-637.

Spencer, R., J. V. Jordan and J. Sazama. 2004. "Growth-promoting relationships between youth and adults: A focus group study." **Families in Society** 85 (3): 354-362.

Stavy, R., Y. Eisen and D. Yaakobi. 1987. "How students aged 13-15 understand photosynthesis." **International Journal of Science Education** 9 (1): 105-115.

Sudman, S. and N. M. Bradburn. 1982. **Asking Questions**. California: Jossey-Bass Publishers.

Suits, J. P. 2004. “Assessing investigative skill development in inquiry-based and traditional college science laboratory courses.” **School Science and Mathematics** 104 (6): 248-257.

Sundberg, M. D., J. E. Armstrong, M. L. Dini and E. W. Wischusen. 2000. “Some practical tips for instituting investigative biology laboratories.” **Journal of College Science Teaching** 29 (5): 353-359.

Suntherland, D. and R. Dennick. 2002. “Exploring culture, language and the perception of the nature of science.” **International Journal of Science Education** 24 (1): 1-25.

Tairab, H. H. 2001. “How do pre-service and in-service science teachers view the nature of science and technology?” **Research in Science & Technological Education** 19(2): 235-250.

Tamir, P. 1974. “An inquiry oriented laboratory examination.” **Journal of Educational Measurement** 11: 25-33.

______. 1989. “Training teaching to teach effectively in the laboratory.” **Science Education** 73 (1): 59-69.

______. 1991. “Practical work in school science: an analysis of current practice.” In B. Woolnough (ed.). **Practical Science**. Buckingham: Open University Press.

Tapper, J. 1999. “Topics and manner of talk in undergraduate practical laboratories.” **International Journal of Science Education** 21 (4): 447-464.

Tasker, R. and P. Freyberg. 1985. “Facing the mismatches in the classroom.” In R. Osborne and P. Freyberg (eds.). **Learning in Science**. Auckland: Heinneman.

Terhart, E. 2003. “Constructivism and teaching: A new paradigm in general didactics?” **Journal of Curriculum Studies** 35 (1): 25-44.

Terwel, J. 1999. “Constructivism and its implications for curriculum theory and practice.” **Journal of Curriculum Studies** 31 (2): 195-199.

Thomas, J. A. and J. E. Pedersen. 2003. “Reforming elementary science teacher preparation: What about extant teaching beliefs?” **School Science and Mathematics** 103 (7): 319-330.

Tien, L. T., D. Rickey and A. M. Stacy. 1999. “The MORE thinking frame: Guiding students’ thinking in the laboratory.” **Journal of College Science Teaching** 28 (5): 318-324.

Tobin, K. 1986. “Student task involvement and achievement in process-oriented science activities.” **Science Education** 70 (1): 61-72.

Tobin, K. and D. Tippins. 1993. “Constructivism as a referent for teaching and leaning.” In K. Tobin (ed). **The Practice of Constructivism in Science Education**. Washington DC: AAAS Press.

Toh, K. 1991. “Factors affecting success in science investigation.” In B. Woolnough (ed.). **Practical Science**. Buckingham: Open University Press.

Trowbrideg, J. E. and J. J.Mintzes. 1988. “Alternative conceptions in animal classification: A cross-age study.” **Journal of Research in Science Teaching** 25 (7): 547-571.

Tsai, C.C. 1999. ““Laboratory exercises help me memorized the scientific truths”: A study of eighth graders scientific epistemological views and learning in lab activities.” **Science Education** 83: 654–674.

Tsai, C.C. 2002. “Nested epistemologies: Science teachers’ beliefs of teaching, learning and science.” **International Journal of Science Education** 24 (8): 771-783.

Tynjälä, P. 1999. “Towards expert knowledge? A comparison between a constructivist and traditional learning environment in the university.” **International Journal of Educational Research** 31: 357-442.

Tytler, R. 2002. “Teaching for understanding in science: constructivist/conceptual change teaching approaches.” **Australian Science Teachers’ Journal** 48 (4): 30-35.

Veal, W. R. 2004. “Beliefs and knowledge in chemistry teacher development”. **International Journal of Science Education** 26: 329-351.

Von Glassersfeld, E.V. 1993. “Questions and answers about radical constructivism.” In K. Tobin (ed). **The Practice of Constructivism in Science Education**. Washington D.C.: AAAS Press.

Wandersee, J. H., J. J. Mintzes and J. D. Novak. 1994. “Research on alternative conceptions in science.” In D. L. Gabel (ed.). **Handbook of Research on Science Teaching and Learning** (pp. 179-210). New York: Macmillan.

Watt, M. 1991. **The Science of Problem-Solving**. London: Cassell Educational Limited.

Wellington, J. 1989. **Skills and Process in Science Education**. London: Routledge.

_____. 1998. **Practical Work in School Science: Which Way Now?.** London: Routledge.

Wellington, J. 1999. “Conveying messages about the nature of science: practical approach.” **Teaching and Learning Secondary Science: Contemporary Issues and Practical Approaches**. London: Routledge Falmer.

Westbrook, S. L. and E. A. Marek. 1991. “A cross-age study of students’ understanding of the concept of diffusion.” **Journal of Research in Science Teaching** 28 (8): 649-660.

Wheatley, G. H. 1991. “Constructivist perspectives on science and mathematics learning.” **Science Education** 75 (1): 9-21.

White, R. T. 1996. “The link between the laboratory and learning.” **International Journal in Science Education** 18 (7): 761-774.

William, M.K. 2002. **Qualitative Validity** (Online). www.socialresearchmethods. net/ kb/qualval.htm, April 17, 2005.

Woolnough, B. E. 1998. “Authentic science in schools, to develop personal knowledge.” In J. Wellington (ed.). **Practical Work in School Science: Which Way Now?**. London and New York: Routledge.

Yager, R. E. 1991. “The constructivist learning model.” **The Science Teacher** 58 (6): 52-57.

Yin, R. K. 1984. **Case Study Research: Design and Methods**. California: Sage.

Yip, D. 1998. “Identification of misconceptions in novice biology teachers and remedial strategies for improving biology learning.” **International Journal of Science Education** 20 (4): 461-477.

Zeidler, D., K. Walker, W. Ackett and M. Simmons. 2002. "Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas." **Science Education** 86 (3): 343–367.

Ziman, J. M. 1980. **Teaching and Learning about Science and Society**. New York: Cambridge University Press.

Zion, M., D. Shapira, M. Slezak, E. Link, N. Bashan, M. Brumer, T. Orain, R. Nussinovitch, B. Agrest and R. Mendelovici. 2004. "Biomind – a new biology curriculum that enables authentic inquiry learning." **Journal of Biological Education** 38 (2): 59-67.

APPENDICES

APPENDIX A

Biology Concepts and Science Process Skill Questionnaire

1. If you were a biology teacher and one of your students in your class drew a picture of a green plant cell as shown in Figure 1, and you noticed that there were components that the student labeled incorrectly.

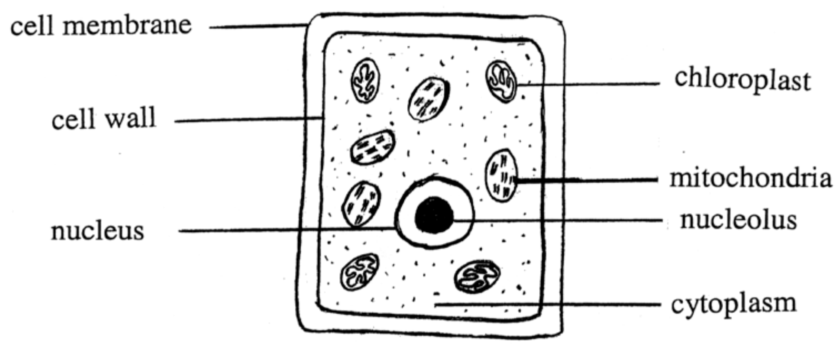


Figure 1

Which components are labeled incorrectly?

- ☑ cell wall
- ☐ cytoplasm
- ☑ chloroplast
- ☐ nucleolus
- ☑ cell membrane
- ☑ mitochondria
- ☐ nucleus

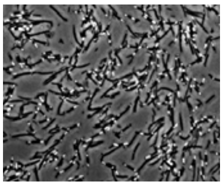
For these components that the student had drawn incorrectly, please explain below to the student, using your knowledge of the cell components, why these are not the correct labels.

- ***Cell wall and cell membrane were labeled incorrectly. The labeled part as Cell wall in the picture should be cell membrane, vise versa. Because the outer part that is the strongest part of the cell is cell wall and the next inner part is cell membrane.***

- ***Chloroplast and mitochondria were labeled incorrectly. The labeled part as chloroplast in the picture should be mitochondria, vise versa.***
  Because chloroplasts have chlorophyll that arrange in stack and inside mitochondria there is a folded membrane called cristae.

- ***Cytoplasm, nucleus and nucleolus were labeled correctly.***

2. Figure 2 shows example of organisms that you have studied in the Laboratory in Biology course.

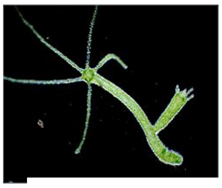


1. bacteria

2. mushroom

3. blue green algae

4. starfish



5. hydra

6. fern

Figure 2

Please categorize the cells as prokaryotic or eukaryotic and please explain why you categorize them as prokaryotes and eukaryotes

2.1 Prokaryote(s) is/are organism(s) no. ***1 and 3***

- Prokaryotes are the organisms that are composed of the cells with no nuclear membrane and have no membranous organelles.

2.2 Eukaryote(s) is/are organism(s) no. ***2, 4, 5 and 6***

- Eukaryotes are the organisms that are composed of the cells have a true nucleus enclosed by a membranous nuclear envelope and membranous organelles.

3. Figure 3 below shows a container that is divided by a semi-permeable membrane. Side 1 contains 20% saltwater, and Side 2 contains 40% salt water. Salt cannot pass through the membrane.

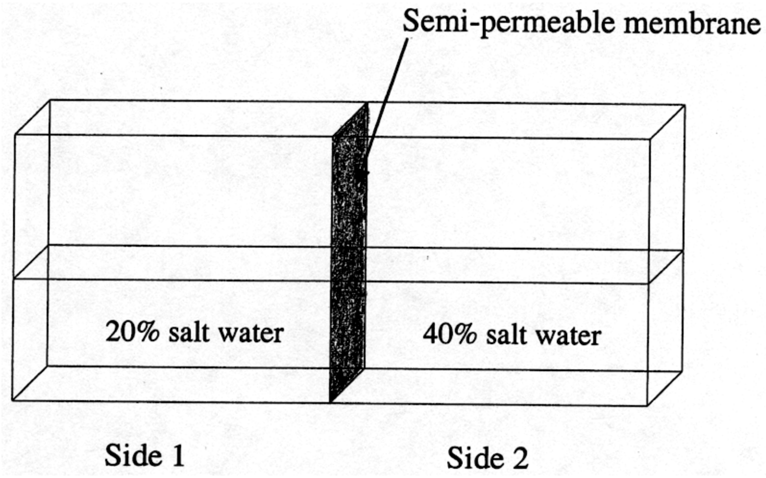


Figure 3

3.1 If the container is left for a period of time, do any changes happen within the container?

- Water from Side 1 will move to Side 2 resulting in the volume of the solution in Side 2 increases and the concentration of the solution in Side 2 decreases.

3.2 Why/why not?

- The concentration of salt water in Side 1 (higher in water concentration) is less than Side 2 (lower in water concentration) so the water osmosis through the semi-permeable membrane from Side 1 to Side 2

4. Pranee cut a root of a plant and she observed the root cells by a light microscope. The cell she has seen is shown in Figure 4 below. Then she put the plant root in 30% salt water for 30 minutes; she cut another root sample from the plant and observed the cells. What do you think the second root cell will look like under the microscope?

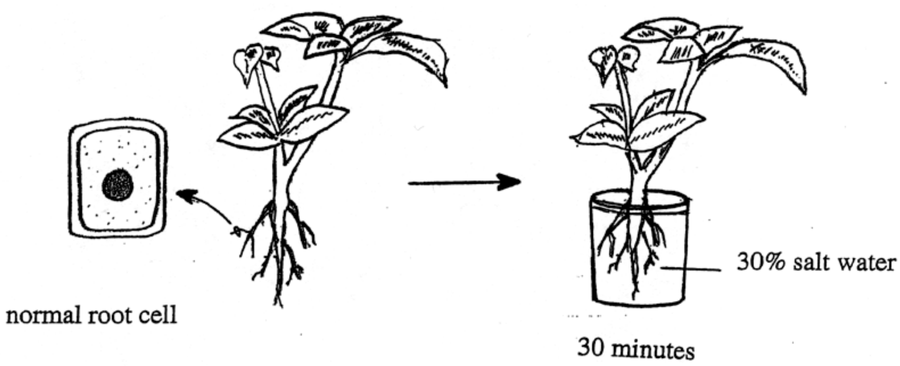
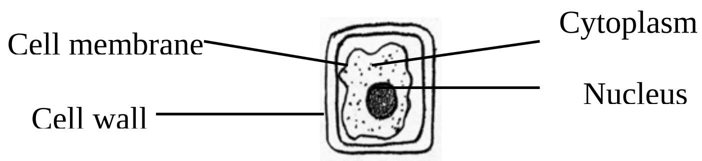


Figure 4

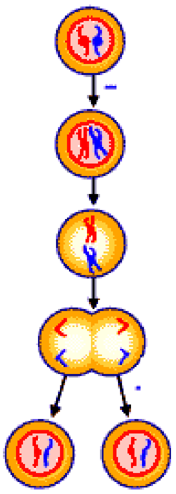
4.1 The root cell after 30 minutes in salt water will look like
(Please **<u>draw your own cell</u>** and **<u>label</u>** cell wall, cell membrane, cytoplasm and nucleus)



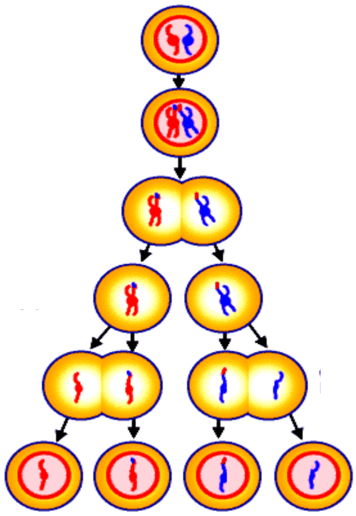
4.2 Why do you think the root cell will look like in the picture you have drawn?

- ***Water inside the cell moves to outside because the concentration inside is less than outside the cell so the volume of cell water decreases. And because of it has cell wall is which is the strong part of the cell, its structure is not changed so the cell size remain the same.***

5. There are two types of cell division; Division A and B as shown in Figure 5.



Division A



Division B

Figure 5

5.1 What types of **organisms** can Division A occur in?

- All types of organisms including bacteria, fungi, protists, plants and animals.

Why?

- Because Division A is mitosis, mitotic division is for growth and maintaining the body. And these occur in all types of organisms.

5.2 What type of **organisms** can Division B occur in?

- All types of organisms that have sexual reproduction which are the organisms in Kingdom Protista, Fungi, Metaphyta and Animalia.

Why?

- Because Division A is meiosis, meiotic division is for producing sex cells. So it occurs in the organisms that have sexual reproduction.

5.3 Consider the following cells; cells in root apical meristem, cells in shoot apical meristem, intestine epithelium, dermal cells, oocyte and spermatocyte. Which cell(s) can Division A occur in?

- Cells in root apical meristem, cells in shoot apical meristem, intestine epithelium, and dermal cells

5.4 Consider the following cells; muscle cells, nerve cells, intestine epithelium, plant leave cells and plant root cells, oocyte and spermatocyte. Which cell(s) can Division B occur in?
- Oocytes and spermatocytes

5.5 After each type of cell division has finished, the amount of genetic information in a new cell compared to the original cell will be:

- Division A ☐ less ☑ the same ☐ more

Why?

- ***Mitosis occurs in somatic cells which need to maintain chromosome number and the property of genetic materials for keeping the cells work effectively.***

5.6 After each type of cell division has finished, the amount of genetic information in a new cell compared to the original cell will be:

- Division B ☑ less ☐ the same ☐ more

Why?

- ***Meiosis occurs in a sex cell that will combine with another cell from the opposite sex to produce a zygote and the zygote will divide to become embryo and then a body. So the sex cell have to be reduced the half number of the chromosomes of a somatic cell.***

6.

Chatchai grew a banana tree in his backyard. Six months passed, his banana tree had flowers and bananas on it. He found some banana seeds when he tasted one of his bananas. Near his banana tree, there were some little banana trees.

Figure 6

6.1 Where do you think the seeds are from?

- ***The seeds are from sexual reproduction that occurs in the banana flowers. Meiosis occurs to produce sex cells; pollen and ovum. When 2 opposite sex cells combine, they produce zygote that will become embryo. The seeds grew from ovule in ovaries.***

6.2 Where do you think the little banana trees are from?

- The little banana trees are from budding, a type of asexual reproduction.

7.

Amara put soil and fertilizer in the pot and grew a plant in it. She left it outside her house in the area where sunlight could reach the plant and watered it every day.

Figure 7

7.1 Where does the plant get its energy from?

☐ soil ☑ sun ☐ water ☐Carbon dioxide

7.2 What condition(s) can the plant photosynthesize?

☑ in sunlight ☑ in light from a bulb ☑ in light all time

☐ in the dark

7.3 What is(are) the plant food? (Tick any that apply)

☐ soil ☐ water ☐chlorophyll

☐ Carbon dioxide ☐ oxygen ☑ carbohydrate

☐ fertilizer ☐ light

7.4 When does the plant respire?

☐daytime ☐nighttime ☑ daytime and nighttime

☐ the plant does not respire

7.5 Amara brought her plant into her house and kept it in a dark cupboard for 48
hours. An iodine test on a leaf then showed that no starch was present. Next,
Amara left her plant in the light for 48 hours. Then she tested another leaf from her plant with iodine, and she found that starch was now present.
If this was true, what would you explain about Amara's experiment?

- When the plant was left in the dark, it couldn't photosynthesize so it used stored food in its leaves and trunk. So when Amara tested the starch at the first time she couldn't find starch on a leaf of her plant kept in the dark (or it was too small to see), After that she left her plant in the light, so the plant could photosynthesize and store the food in form of starch. Then she could find starch on the leaf when she tested at the second time.

8.

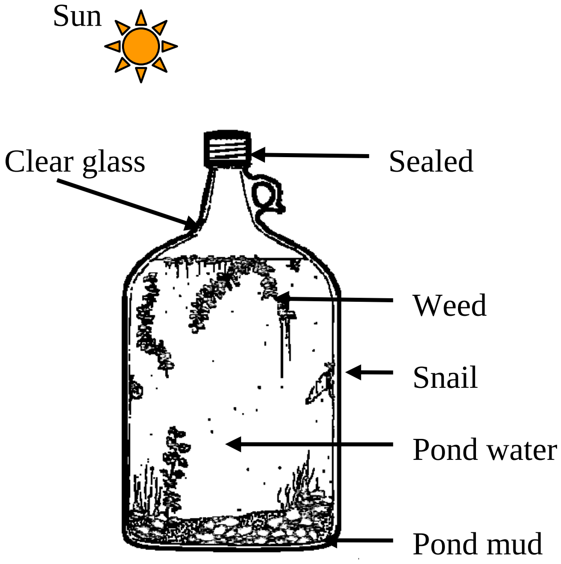


Figure 8

Mayuree wanted to build her own ecosystem. She collected some mud and water from a pond near her house. She also brought some weeds and snails from the pond. She put all of those in a big transparent bottle and sealed it with a lid. Then she put it near a window in her room to expose the bottle to the light.

8.1 Do you think Mayuree's bottle is an ecosystem? ☑ Yes ☐ No

Please explain your answer

Mayuree's bottle is an ecosystem because it has abiotic and biotic components, abiotic components are soil, pond water, light and gas inside the bottle and biotic components are weeds, snails. These components are interrelate [such as the weeds use water, light, minerals(from pond mud) and carbon dioxide (from respiration of themselves and the snails) for photosynthesis, the snails eat the weeds and use oxygen (from the weeds' photosynthesis) for respiration].

8.2 Do you think the weeds and the snails would survive for a month in the bottle?

☑ Yes ☐ No ☐ Not sure

Please explain your answer

Because the organisms in the bottle get all of the components that they use for living. Food, gases and energy are cycling in the bottle so it make the ecosystem become equilibrium.

(Students may answer "Not sure" and give the reasons that the proportion of the organisms and the quality of pond water must be considered.)

8.3 Could the weeds photosynthesize in the bottle?

☑ Yes ☐ No

Because the weeds get water, light, carbon dioxide and mineral that are needed for photosynthesis.

8.4 Could the weeds respire in the bottle?

☑ Yes ☐ No

Because there are food supply and oxygen in the bottle.

8.5 What kind of organism(s) is(are) there in the bottle? Tick box(es) that apply

☑ producers ☑ consumers ☑ decomposers

9. A group of Thai scientists discovered three new medicines for curing chickens that are infected by bird-fever virus in their laboratory. They would like to test their medicines in a chicken farm. One of the volunteering farm owners has 1,200 infected chickens. If you were a scientist in the group and the other members would like you to propose an experiment to test the medicines, what experiment would you do?

   Please write a plan for an experiment to help you find out the effectiveness of the medicines.
   Suppose the names of the three medicines are A, B and C
   Hypothesis:
   - ***A (or B or C) can cure-bird fever disease more effective than the other two medicines***
   - ***The three medicines have the same effectiveness to cure the disease***
   - ***The three medicine can't cure the disease in the farm***

   Possible experiment procedure
   1. ***Random the chickens into 4 groups, 150 chickens/group. Give medicine A for group 1, medicine B for group 2, medicine C for group 3 and no medicine for group 4. Experiment 2 replications for each group.***
   2. ***Feed each group of the chicken in separate areas, the areas must have same environment such as the same type and amount of food, same temperature, moisture and light.***
   3. ***Count the number of chicken that survive every week for 4 weeks, compare the number of each experiment group to the control group. Also consider the health of the survived chicken (strength, alertness, the color of feather, etc). The group that has healthier survived chicken than others will indicate the most effectiveness of the medicine treated for the group.***
   4. ***Table for collecting data***

group	*The number of survived chickens*				*Chickens' health*
	Week 1	*Week 2*	*Week 3*	*Week 4*	
1	*Rep 1*	*Rep 1*	*Rep 1*	*Rep 1*	
	Rep 2	*Rep 2*	*Rep 2*	*Rep 2*	
2	*Rep 1*	*Rep 1*	*Rep 1*	*Rep 1*	
	Rep 2	*Rep 2*	*Rep 2*	*Rep 2*	
3	*Rep 1*	*Rep 1*	*Rep 1*	*Rep 1*	
	Rep 2	*Rep 2*	*Rep 2*	*Rep 2*	
4	*Rep 1*	*Rep 1*	*Rep 1*	*Rep 1*	
	Rep 2	*Rep 2*	*Rep 2*	*Rep 2*	

10. Wittaya is conducting an experiment about enzyme activity and he gets the results as shown in Figure 9.

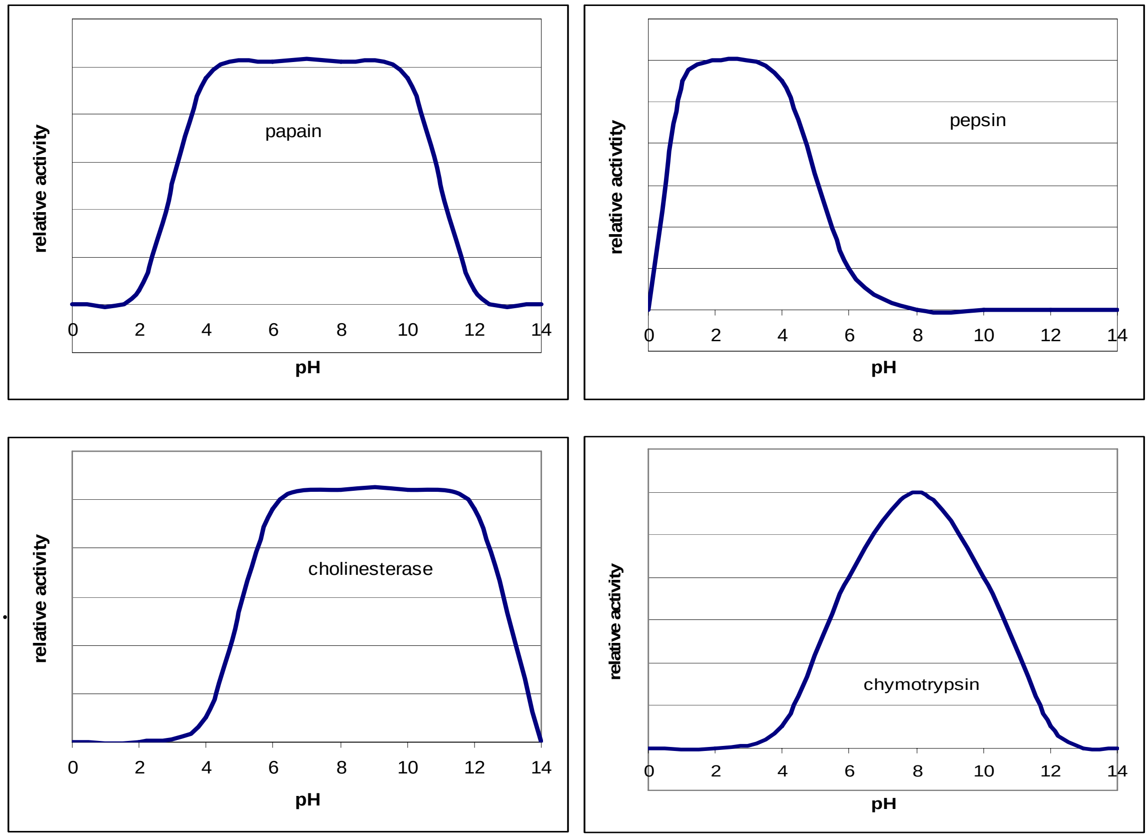


Figure 9

10.1 What is the question that Wittaya tries to answer by doing this experiment?

How do enzymes work at different pH values?

10.2 What is a possible hypothesis for his experiment?

Each enzyme can work effectively at different pH

10.3 What is his treatment for this experiment?

Types of enzymes and pH

10.4 What is the effect of this treatment?

Rate of enzyme activity

10.5 What are the constant factors for his experiment?

Enzyme and substrate concentration and temperature

10.6 What is the result of each type of enzyme? Are they similar or different?

Each enzyme can work effectively at different pH;
Papain works effectively at the range of pH 4-10
Pepsin works effectively at the range of pH 1-4
Cholinesterase works effectively at the range of pH 6-12
Chymotrypsin works effectively at pH 8

10.7 What should he conclude from his data about enzyme activity?

Each enzyme can work effectively at different pH

APPENDIX B

Views on the Nature of Science Questionnaire

Consider the given statements and decide whether you agree/disagree with them or you are not sure.

Please tick (✓) in the box that best indicates your views and please explain your views for the items that requiring reasons.

1) Science is a body of knowledge, such as principles, laws, and theories, which explain the world around us (matter, energy, and life).
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

2) Science is exploring the unknown and discovering new things about our world and universe and how they work.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

3) Science can investigate the supernatural and can possibly explain it.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

4) Science is understandable.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

5) Scientific knowledge has always changed with time.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

6) The scientific method ensures valid, clear, logical, and accurate results.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

7) The main motivation of scientists is to satisfy their curiosity.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

8) Scientists can use imagination and creativity to get results.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

9) Some scientific discoveries are made by accident.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

10) It's part of a scientist's job to ensure that no harm comes from discovery.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

11) Scientists are logical, objective, unbiased and open-minded.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

12) Personal feelings and moral values have no bearing on scientists' decisions.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

13) Society influences the direction of scientific discoveries.
☐ agree ☐ not sure ☐ disagree
Please give reason(s)
....
....

APPENDIX C

Attitudes towards Biology Inventory

Please tick (✓) in the box that best indicates your views.

	Statements	Strongly agree	agree	Not sure	disagree	Strongly disagree
1	Biology is useful for solving problems in everyday life.					
2	Biological knowledge is important for a country's development.					
3	Biology is difficult when it involves handling apparatus.					
4	Laboratory in Biology course is a difficult subject.					
5	Every citizen must have biological knowledge.					
6	It is useless to do experiments in biology.					
7	I would rather agree with what other people say than do an experiment to find out the information for myself.					
8	Biological knowledge is the cause of many of the world problems.					
9	There are too many facts to learn in the Laboratory in Biology course.					
10	Doing experiments is enjoyable.					
11	I like learning in Laboratory in Biology course.					
12	Doing biology experiments helps me learn more than finding out information from instructors.					
13	I think doing biology experiments is boring.					
14	People who understand biology are better off in our society.					
15	I would like to have fewer biology lessons.					
16	Laboratory in Biology course helps me understand biological concepts.					
17	I cannot use biology for my real life.					
18	I feel uncomfortable doing biological experiments by myself.					
19	Learning in Laboratory in Biology course helps me have more confidence to use scientific methods.					
20	Learning in Laboratory in Biology course helps me have more confidence to use scientific apparatus.					

BIOGRAPHICAL DATA

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