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NAME: Miss Yaowares Chaiyen

THIS THESIS HAS BEEN ACCEPTED BY

THESIS ADVISOR

(Assistant Professor Naruemon Yutakom, Ph.D.)

COMMITTEE MEMBER

(Professor Vantipa Roadrangka, Ph.D., Ed.D.)

COMMITTEE MEMBER

(Miss Pensri Bunsawansong, Ph.D.)

COMMITTEE MEMBER

(Associate Professor Bronwen Cowie, Ph.D.)

DEPARTMENT HEAD

(Associate Professor Porntip Chaiso, Ph.D.)

APPROVED BY THE GRADUATE SCHOOL ON _____

DEAN

(Associate Professor Vinai Artkongharn, M.A.)

THESIS

**TEACHING AND LEARNING ABOUT CHEMICAL EQUILIBRIUM:
CONSTRUCTIVIST-BASED PERSPECTIVES**

YAOWARES CHAIYEN

**A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
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This interpretive research aims to improve teaching and learning about chemical equilibrium through constructivist-based perspectives in a manner consistent with the National Education Act B.E. 2542 (Revised in B.E. 2545). The study is divided into 2 phases: an Exploratory Phase, and a Development and Implementation of the Learning Unit Phase. In Phase I, 125 high school students from three schools in Chanthaburi Province were asked to complete a survey, and a questionnaire to find out their learning outcomes which were conceptions, science process skills, and attitudes toward chemical equilibrium concepts and teaching and learning. These data informed the development of the learning unit. In phase II, the Chemical Equilibrium Learning Unit (CELU) was developed and implemented in the classroom to improve teaching and learning about chemical equilibrium concepts for Thai Grade-11 students. Three teachers and 148 students from three schools participated in this study phase. Data collection through classroom observations, interviews, and documents were analyzed to investigate the effects of the CELU on teaching and learning.

Findings from Phase I showed that most of the Thai high school students' learning outcomes seemed to be far from meaningful learning about chemical equilibrium concepts as this was described in the National Science Curriculum Standard. These findings suggested that teaching and learning about chemical equilibrium needed to be improved. The CELU took into account the findings of Phase I and was developed to prompt students to be active and to develop their learning outcomes. The findings of Phase II on the implementation of the CELU suggest that giving opportunities for the teachers to work collaboratively with a researcher is important to the success of an innovation. The findings from Phase II showed that each teacher had their own way of implementing the CELU based on their beliefs about teaching and learning. When teachers emphasized students' existing ideas, active learning, and social processes such as discussion in groups or in the whole class, they tended to be successful in promoting students' learning outcomes about chemical equilibrium. Providing opportunities for students to engage with hands-on and minds-on activities positively impacted on students' learning outcomes across the range of abilities. It could be concluded that the constructivist-based learning unit of the CELU was generally effective for improving students' learning outcomes about chemical equilibrium in Chanthaburi Province.

Student's signature

Thesis Advisor's signature

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CHAPTER I

INTRODUCTION

Overview of the Chapter

Chapter one initially describes the background and problem area of the research study. Then, research purposes, research questions and anticipated outcomes are presented. To understand the scope of this research study, delimitation of the study and definition of term are clarified. The last section of this chapter provides a summary of this chapter and a brief description of the overview of research study.

Background of the Study

1. Learning Reform

Learning reform is regarded as the heart of educational reform in the Thai educational context (Office of the National Education Commission [ONEC], 2001). The reform of learning in Thai school aims to provide benefits for Thai people, and to help them participate in a knowledge-based society in which there is lifelong education for all (ONEC, 2001). Section 22 of the National Education Act B.E. 2542 (1999, revised B.E.2545: 10) states:

Education will be based on the principle that all learners are capable of learning and self-development and are regarded as being most important. The teaching-learning process will aim at enabling learners to develop at their own pace and to maximize their potential.

As stated above, learners are emphasized to be the most important person in the learning process. The needs of learners are seen as an important factor in the process of teaching and learning which is known as learner-centred. Teaching and

learning process should provide to be consistent with the characteristics of each learner by considering about the content, encouraging learners to improve their thinking skills, or as described in Section 24 of the National Education Act (ONEC, 1999). Then, the teacher is encouraged to develop his or her own materials for promoting learner-centered education. Activities, experiments or hands-on experiences will be emphasized in addition to the needs and potential of learners. Therefore, it could be said that to reform the process of learning, the teacher acts as facilitator who assists learners to learn by constructing knowledge themselves (Office of Education Council [OEC], 2004).

In summary, the goal of learning reform in Thailand aims to realize the potential of Thai people to develop themselves for a better quality of life. It could be said that learning reform in Thailand resulted in focusing on learners as the centre of teaching and learning process which are emphasized the promotion of learner's conceptions, skills, problem-solving skills, and so on. Consequently, the learning reform significantly impacts on the processes of raising educational quality. Teaching and learning about science and technology is one of dimensions that are directly impacted due to learning reform in order to prepare Thai people to be engage lifelong learning and to pursue the changes of society from agricultural to be semi-industrial society.

2. Current Situation of Science Education in Thailand

Thailand seems to be unsuccessful in teaching and learning science. As being seen from results of the Academic Olympic Competition in science subjects during 1995 – 1999, it showed that Thailand was in the last in comparison to other countries in Asia: China, Taiwan, Vietnam, Korea, and Singapore (ONEC, 2001). Similar to the findings from the 1999 Third International Mathematics and Science Study – R (TIMMS - R), Thailand was ranged in 24th from international average from 38 nations that participated in TIMMS – R (National Center for Education Statistics [NCES], 2000). The findings from TIMMS also showed that average scores of Thai students

were lower than mean scores of 38 nations. A research paper of the International Institute for Management Development Institute (IMD) also revealed that in 2004, Thailand's competitiveness in science and technology was ranked in the 49th from 49 countries, even though over the past 20 years, there has been a vast research effort to improve student learning in science topics (Bhumirat, 2001). This implies that within ten years ago, the quality of teaching and learning science is far from satisfactory. One reason resulting in those problems might generate from current teaching and learning processes. These processes might not give due recognition to the learning process, whereby learners are given opportunities for analytical thinking, self-expression and acquiring knowledge themselves. Instead, most of science teaching processes in Thailand mostly put the emphasis on content. Teaching and learning process usually uses routine and repetitious methods of transferring knowledge. Learners are therefore accustomed to following examples, obedience, and sitting still. As a consequence, they lack training in scientific thinking (ONEC, 2001). Consequently, Thailand has not attached great importance to the status and the development of its science and technology. If Thailand aims to be sustainable development through science and technology, it urgently needs to improve seven areas: science curriculum; teaching and learning process; teacher education; learning materials; learning resources; assessment of student outcomes; and student achievement (Bhumirat, 2004; Boonklurb, 2001).

Problem Area

Within the science subject area, chemistry is a basic subject in science that all students must learn. Science students studying chemistry at the high school level need to learn concepts of the structure and properties of matter; states of matter and stoichiometry; chemical kinetics and chemical equilibrium; electrochemistry; and chemistry and life (IPST, 2003). Chemical equilibrium is one of the most important concepts in chemistry. It is fundamental concept for student to understand other chemical concepts such as acid and base, oxidation and reduction reaction, and solubility (Bergquist and Heikkinen, 1990). The chemical equilibrium concepts has

five main topics: changes to be equilibrium; equilibrium in chemical reaction; equilibrium constant; factors affecting equilibrium condition and Le Châtelier's principle; and chemical equilibrium in living things and in industrial applications (IPST, 2003).

However, numerous research studies reveal that there are some problems in learning chemical concepts in Thailand (e.g. Lapboonrueng, 2000, Thammachat, 2002). Likewise, in the aspect of chemical equilibrium concepts, Thai students also were reported in having difficulties understanding the concept. For example, in Romaneepikul's study (1997), students had got low achievement for the topic of chemical equilibrium, achieving only about 60 per cent in spite of teaching by CAI. Romaneepikul (1997) suggested that the problems of learning might be generated from the student difficulties with algorithmic calculations, and their lack of basic knowledge about mathematics and chemistry. Therefore, it could be said that difficulties in learning are generated from deficiencies or inadequacies in students' knowledge structure; the demands and complexity of learning tasks in terms of information processing compared with students' information handling capacity; the use of analogies, scientific language, and related communication problems in science education; and, information overload (Driver and Scott, 1996). For example, Gussarsky and Gorodetsky (1990) revealed that students may confuse scientific terms and everyday words. Gabel (1998) also claimed that scientific understanding requires linkages between scientific concept and other related concepts. In aspect of chemistry, they also have to use imagination to relate the macroscopic and microscopic levels.

It could be seen that not only Thai students have difficulties in learning chemical equilibrium concepts, but international students also have difficulties in acquiring chemistry concepts. Numerous research studies have identified student misconceptions for concepts in chemical equilibrium (Bergquist and Heikkinen, 1990; Chamaco and Good, 1989; Huddle and Pillay, 1996; Kousathana and Tsaparlis, 2002; Quilez-Pardo and Solaz-Portoles, 1995). Those misconceptions included confusion

about the dynamic and reversible nature of chemical equilibrium, the equilibrium constant, or the use of Le Châtelier's principle (Huddle and Pillay, 1996).

Research suggests that many students have difficulty in understanding the dynamic and reversible nature of chemical equilibrium because of its rather abstract character. The dynamic nature of chemical equilibrium requires students to understand that two opposite chemical reactions are taking place at the same time, in spite of the fact that this cannot be deduced easily from observations (van Driel *et al.*, 1999). Because of this, students fail to understand the dynamic nature of chemical equilibrium, instead believing that a chemical reaction must be observable, and chemical equilibrium is often perceived as static, that is, nothing happens in a system when it is a state of chemical equilibrium (van Driel, 2002).

Another topic of chemical equilibrium that students found difficult to understand is related to the equilibrium constant. Students are confused over the meaning of equilibrium constant by describing it as varying in value while at constant temperature and assuming that the value changes with different amounts of reactants or products (Bergquist and Heikkinen, 1990; Chamaco and Good, 1989). Students can solve numerical problems about the equilibrium constant by the application of an algorithm memorized through rote learning. However, students do not really understand what manipulating algebraic symbols or other symbols really mean in relation to the actual chemical system being studied (Nakhleh, 1992). Thus, correct responses to numerical problem in equilibrium do not necessarily reveal whether or not a student understands chemical equilibrium, but only indicates that the student can compute equilibrium constants, or calculate equilibrium concentrations (Bergquist and Heikkinen, 1990).

The use of Le Châtelier's principle is one of the most difficult topics in chemical equilibrium (Quilez-Pardo and Solaz-Portoles, 1995). Even if students have a scientific understanding of the dynamic and reversible nature of chemical equilibrium, they may be not be able to use that knowledge to solve problems by

application of Le Châtelier's principle (Nakhleh, 1992). For example, they may apply mechanical reasoning based exclusively on Le Châtelier's principle, even when a solid is added to a heterogeneous system at equilibrium, or an inert gas is added to a homogeneous system at equilibrium (Bergquist and Heikkinen, 1990; Furio *et al.*, 2000).

Thus, research reports of students' misconceptions and the complexities of chemical equilibrium concepts point to some problems about the teaching and learning of chemical equilibrium (Treagust and Tyson, 1999). These difficulties might be generated from the specific content (Bergquist and Heikkinen, 1990; Camacho and Good, 1989). Since students have had little conscious interaction with systems at equilibrium, it is difficult for high school students to comprehend (Chiu *et al.*, 2002). It is possible that teachers and students overlook the specific nature of content in this topic and this causes them to oversimplify their interpretation of certain problems.

The literature suggests that students from different educational contexts hold similar misconceptions about chemical equilibrium. However, teaching and learning about chemical equilibrium in educational reform era of Thailand not only aims to encourage students to acquire scientific understanding; but science process skills, scientific attitudes, and attitudes towards science are also claimed as crucial learning outcomes (IPST, 2003). Science process skills are seen as a tool to acquire scientific knowledge and to reflect nature of science (Watson, 2000). Comparing to students' conceptions about chemical equilibrium, teaching and learning to promote students acquiring science process skills and attitudes still have some problems as well. For example, the study of Jantravut (1995) revealed that science process skills of Thai high school students were ranged to be moderate. These might impact on students' acquiring of scientific conceptions as Jantravut (1995) suggested, the findings from her study reflected that students who are different in learning achievement will significantly differ in science process skills as well.

In summary, it is found that, in aspect of teaching and learning chemical equilibrium in current Thai educational context, the quality of teaching and learning needs to be improved in order to promote students' conceptions, science process skills, and attitudes. Those three factors are known as learning outcomes. How to improve teaching and learning about chemical equilibrium could be suggested by oversea research study. It could be seen that various teaching strategies based on constructivism have been used to elucidate the structure of domain knowledge about chemical equilibrium successfully (Benerjee, 1995; Chiu *et al.*, 2002; Treagust and Tyson, 1999; van Driel, 2002; Wilson, 1994). Within constructivist-based perspectives, it is acknowledged that learning results from the addition of new elements of knowledge to pre-existing knowledge structures, and the re-organization of prior structures to accommodate new elements. Constructivist-based teaching methods emphasize the engagement of the student in the learning process, and the importance of prior knowledge or conceptualizations for new learning. In such a model, the teacher becomes a facilitator and coach rather than knowledge dispenser (Yager, 1991). Constructivist-based teaching approaches also use students thinking, experiences, and interests to drive lessons, and cooperative learning strategies that emphasize collaboration, and respect individuality (Yager, 1991). For example, Huddle and White (2000) used analogies, an equilibrium game, to teach dynamic equilibrium and Le Châtelier's principle. Similarly, concept mapping and conceptual change have also been used to teach chemical equilibrium (Chiu *et al.*, 2002; Wilson, 1994).

However, Thailand is the country that justly pound of its own unique society. Since the uniqueness of Thai society, it is necessary to adapt constructivist-based perspectives of teaching and learning to be appropriate for Thai context by considering from current Thai science teaching and learning about chemical equilibrium. This study aims to develop teaching and learning about chemical equilibrium to be consistent with National Science Curriculum standards in order to enhance Thai high school students' learning outcomes. To reach this aim, the learning unit about chemical equilibrium is developed using current Thai educational context

and constructivist-based perspectives of teaching and learning as important frameworks. Then, the research study put emphasis on the investigation of Thai high school students' learning outcomes about chemical equilibrium in the current educational situation, and seeks to develop learning units about chemical equilibrium to improve the quality of teaching and learning about chemical equilibrium concepts.

Research Purposes

According to the National Science Curriculum Standard, chemical equilibrium is placed for Thai Grade-11 students. To be consistent with learning reform and the National Science Curriculum Standard, this research aims to improve teaching and learning about chemical equilibrium for Thai Grade-11 students. In this study, the exploration of Thai high school students' learning outcomes about chemical equilibrium is firstly address in order to understand the Thai current situation of learning and teaching chemical equilibrium. To promote students' learning outcomes about chemical equilibrium, the learning unit in this concept is necessary to be developed for implementing in Thai educational context. Effect of the implementation of the learning unit also will be studied for finding out an effectiveness of the learning unit.

Research Questions

The research study aims to answer these following questions.

1. What are Thai high school students' learning outcomes for the topic of chemical equilibrium in the current educational situation in Thai high schools?
2. How do Thai chemistry teachers implement a constructivist-based learning unit of chemical equilibrium into their classrooms?

3. How do Thai Grade-11 students learn chemical equilibrium concepts during the implementation of this constructivist-based learning unit?

4. What are the Thai Grade-11 student learning outcomes of chemical equilibrium after a constructivist-based learning unit?

Anticipated Outcomes

1. Chemistry teachers will have an exemplary learning unit of chemical equilibrium for Thai high school students in order to improve students' learning outcomes. Teachers might use the learning unit as a guideline for developing their own learning unit for teaching chemical equilibrium concepts or other related concepts as appropriate for their classroom context.

2. Science educators might be able to use this research study as a guideline for improve teaching and learning science to be consistent with the National Science Curriculum Standard and learning reform. The process of the development of the learning unit about chemical equilibrium in this study might clarify for science educators how to transform the National Science Curriculum to be an effective school-based curriculum.

3. Curriculum developers might use the findings from an exploration of students' learning outcomes to reflect the quality of teaching and learning about chemical equilibrium in current Thai educational situation. These findings could be useful data for developing teaching and learning about chemical equilibrium or related concepts.

Delimitation of Research Study

This research study aims to improve teaching and learning about chemical equilibrium to be consistent with learning reform in Thailand. It was conducted during Thai academic year 2004 – 2005. Participants of this study were selected by purposive sampling in which those participants consisted of three chemistry teachers and high school students from three public schools in Chanthaburi Province. All schools were in an interval of changing of science curriculum, from the former science curriculum to the National Science Curriculum Standard.

The scope of this study concerns with the finding current Thai high school students' learning outcomes about chemical equilibrium to know the profile of Thai high school students' conceptions, skills, and attitudes. Chemical equilibrium is a concept of chemistry which consists of five topics: changes to be equilibrium, equilibrium in chemical reaction, the equilibrium constant, factors affecting equilibrium condition and Le Châtelier's principle, and chemical equilibrium in living things and in industrial application. Then, the learning unit will be developed and implemented by those three chemistry teacher to find out the way of implementing the learning and the impact of the learning unit on students' learning outcomes.

Definition of Terms

1. Students' Learning Outcomes

Students' learning outcomes consists of three domains: students' conceptions of chemical equilibrium; students' capability in science process skills; and, students' attitude toward chemical equilibrium concepts and teaching and learning.

1.1 Students' Conceptions of Chemical Equilibrium

Students' conceptions of chemical equilibrium are students' ideas on the concept of chemical equilibrium. To assess students' conceptions, students are asked to define, explain, or solve the problem about chemical equilibrium concepts to present their understanding about the given situations.

1.2 Students' Capabilities of Science Process Skills

Students' capabilities of science process skills refers to students' ability in attaining integrated skills which consist of five processes: identifying and control variables; interpreting data; formulating hypotheses; defining operational definition; and, experimenting. These skills could be assessed from testing.

1.3 Students' Attitudes toward Chemical Equilibrium and Teaching and Learning

Students' attitudes toward chemical equilibrium and teaching and learning refers to the concept which represents the emotional orientation of students to respond favorably or unfavorably to chemical equilibrium concepts and the strategies using for teaching and learning in Grade 11. They deal with the difficulty of chemical equilibrium concepts; the usefulness of chemical equilibrium concepts; the interest of chemical equilibrium concepts; and the preferences of teaching and learning and they could be assessed from testing, or journal writing.

2. Constructivist-Based Perspectives of Teaching and Learning

Constructivist-based perspectives of teaching and learning are strategies of teaching and learning which are consistent with social constructivism. Constructivist teaching and learning processes emphasize that students need to be active in the learning process. Finding out students' existing knowledge, doing hands-on and

minds-on activities, promoting social process, and using various methods for assessing students' learning outcomes are crucial component of this way of teaching and learning.

3. Chemical Equilibrium Learning Unit (CELU)

The Chemical Equilibrium Learning Unit (CELU) is a package of planning for teaching and learning chemical equilibrium. The components of learning unit are: unit title, unit goal, rationale of developing, content outline, and specific lesson plans. The CELU aims to promote students' learning outcomes about chemical equilibrium to be consistent with the National Science Curriculum Standard. This package consists of instructional manual, students' worksheet and instructional medias and activities, and assessment procedures for chemical equilibrium conception. The unit put emphasis on providing several of teaching strategies to encourage students to be active learners by giving students opportunities to find out, refine, or solidify their existing knowledge to be consistent with scientific conceptions, and to promote science process skills and attitudes.

Summary of the Chapter and Overview of This Research Study

According to Thai learning reform era and Thai current educational context, teaching and learning for Thai high school students about chemical equilibrium was one of areas that needed to be improved to promote students' learning outcomes. Then, this research study aims to improve teaching and learning to be consistent with the National Education Act B.E. 2542 (revised B.E. 2545) and appropriate with Thai educational context. Constructivist-based perspectives of teaching and learning are suggested by previous studies to be successful in improving teaching and learning about chemical equilibrium. They are also consistent with the National Educational Act B.E. 2542 (revised B.E. 2545) in terms of providing learning opportunities for students to improve themselves by engaging with active learning, social processes and various assessment strategies. To achieve the aims of this study, the learning unit

about chemical equilibrium will be developed to promote student learning outcomes. The impacts of the implementation of the learning unit on teacher's teaching and students' learning are addressed.

Chapter 2 reviews that literature on (i) science education in Thailand (ii) various forms of constructivism; (iii) constructivist-based perspectives on teaching and learning science; and, (iv) teaching and learning chemistry. Those topics are discussed to clarify theory underpinning the research study.

Chapter 3 outlines the research methodology, which consists of: (i) introduction; (ii) philosophical assumptions guiding the research methodology; (iii) interpretivist research and qualitative research approach; (iv) research design associated with a qualitative research approach; and, (v) research design for this study.

Chapter 4 set out the data related to the first phases: exploratory phase. The findings were described in terms of students' conceptions about chemical equilibrium, students' capability of science process skills, and students' attitude toward chemical equilibrium concepts and teaching and learning.

Chapter 5 presents the guiding principles relating to the development of the Chemical Equilibrium Learning Unit (CELU). The framework of the CELU also is presented.

Chapter 6 presents the finding from the implementation of the CELU from three case studies in terms of the teachers' implementation of the CELU in their own classroom, students' learning during and after implementing the CELU. The last section of Chapter 6 is a cross case analysis among those three case studies.

Finally, Chapter 7 presents discussion, summary and outlines implications in teaching and learning chemical equilibrium based on constructivist-based perspectives.

CHAPTER II

LITERATURE REVIEW

Overview of the Chapter

The previous chapter provided an overview on the importance of the research questions within the context involving in the study. Building on from this, this chapter provides a review of relevant literature for the thesis arguing the importance of this research in worldwide context.

This chapter begins with a discussion of science education in Thailand. Then, various form of constructivism is focused on individual and social constructivist-based perspectives. This is followed by a discussion of constructivist-based perspectives on teaching and learning science. After that, discussion of teaching and learning chemistry emphasizing for chemical equilibrium concepts is introduced. Overall of those topics are synthesized. Subsequently, the research argue is concerned with constructivist-based perspectives of teaching and learning which emphasizes individual differences, and social processes could promote students to attain expected learning outcomes about chemical equilibrium.

Science Education in Thailand

Nowadays, scientific knowledge has a significant effect on the development of technology, the quality of life, natural resources and the environment, and the economy (Bhumirat, 2001). Knowledge of science and technology should also be developed to enhance global competitiveness. Thailand is a country which is inevitable to that competitiveness. To achieve this, people must have enough science literacy to be able to select and use appropriate, environmentally friendly technologies in a way that is in harmony with nature (Bhumirat, 2001).

It could be said that science and technology regard as a crucial tool to acquire scientific knowledge. Then, the teaching and learning of science is an important factor in promoting scientific literacy and in improving people's quality of life, creating a nation capable of competing with others in an age of globalization (National Economic and Social Development Board [NESDB], 2002). In order to be successful in the development of quality of life and in the preparation of person to be scientific literate people, it is necessary to emphasize the quality of teaching and learning, especially in science and technology area (Institute for the Promotion of Teaching Science and Technology [IPST], 2003).

In 2003, The Institute for the Promotion of Teaching Science and Technology (IPST) had developed the new science curriculum for Thai students in accordance with the principles and guidelines stated in the policy of educational reform as indicating in the National Education Act B.E. 2542 (revised B.E. 2545). These are known as the *National Science Curriculum Standard* which was launched for improving teaching and learning science to be consistent with the promulgation of the National Education Act B.E. 2542 (revised B.E. 2545). There are three aspects of visions of science learning which are stated as follows (The Institution for the Promotion of Teaching Science and Technology [IPST], 2003).

- Learning science should be a developmental process so that the learner acquires proper knowledge, process, and attitudes;

- Learning science should be life long process so that one will be able to make use of what one learns in science for one's daily and professional life continuously because our natural world changes constantly and science also grow with it;

- Basic science learning is for greater understanding, better appreciation of nature and the environment. This viewpoint should make the learners integrate various and diverse disciplines leading to creativity in the development of the quality

of life. It should also enhance our ability to collaborate to manage the natural world more sustainable.

The characteristic of science content could be divided into two parts. The first part is the fundamental science that must be attained by all students. This part has been divided into eight strands based on the subjects of chemistry, biology, physics, earth science, astronomy, and space. The second part is the advanced science which must be met by those students who need more background in science and technology for further education (e.g., tertiary education). Consequently, for science students at the high school level, it is necessary to learn more science subjects which are called advanced science in order to be basic knowledge for learning at tertiary level such as in pure science fields (e.g. chemistry, physics, or biology); applied sciences (e.g. food sciences, or biotechnology); technology (e.g. engineering); and other science-related field.

The National Science Curriculum Standard is viewed as a crucial framework for improving science education in Thailand. It is launched to response the National Education Act B.E. 2542 (1999) to reform teaching and learning in aspect of science and technology. Within the National Science Curriculum Standard, goals of science education and scopes of science subject areas which are called *Strand* are presented. Learning units for each *Strand* are exemplified for the teachers to understand how to develop and implement the National Science Curriculum Standard into the classroom. These show that the National Science Curriculum Standard is flexible enough for schools to create learning activities appropriate for the characteristics of their students, learning resources, or local wisdom. How to develop and implement learning unit for each science concept effectively is a challenging issue for science teachers. To be successful in creating a learning unit, how students learn is an important issue to be considered. The next section provides details about constructivism which currently influences to science education.

Various Forms of Constructivism

Constructivism is widely used in science education but it is seen as to be difficult to define. There are 15 different types of constructivism related to science education (Good, Wandersee and St Julien, 1993). Although these types of constructivism are different and essential variations on each theme, Wheatly (1991) points out that, there is a consensus on the fundamental basis of constructivism.

Constructivism sees learning as a process of personal construction, which grows out of individual's experiences (Wheatley, 1991). Pope and Gilbert (1983) state that significant learning is likely to occur only if the facts constructed by the learners which are seen as having personal relevance. However, not only an individual's experiences influence the learning process, Wheatley suggests that social interaction also influences this process. Similarly, Matthews (1997) distinguishes constructivism in science education into two varieties; personal and social which are described below.

1. Individual Constructivist-Based Perspectives

The term constructivism of the personal variety emphasizes the individual construction of knowledge and concepts which has its origins in theories of cognitive development by Piaget and the radical constructivism of von Glasersfeld (Matthews, 1993). Personal or individual constructivist-based views of learning address the process of constructing knowledge in the learner's head. Piaget's genetic epistemology is deemed to be the origin of these views (Leach and Scott, 2002). Piaget studied the development of thought in children. His research suggested that knowledge is constructed as the learner strives to organize his or her experiences in terms of pre-existing mental structures or schemes. Piaget believed that knowledge is acquired as the result of a life-long constructive process in which learners try to organize, structure, and restructure their experiences in terms of existing schemes of thought. Consequently, learning involves construction and elaboration schemes based

on experiences (Wheatley, 1991). Von Glasersfeld (1993) argues that constructivism focuses on the way the knower constructs viable knowledge individually, and this constructed knowledge can be only known in a personal and subjective way (see also, Tobin and Tippins, 1993).

From a constructivist-based perspective, knowledge is actively built up by the cognizing subject rather than passively received (Wheatley, 1991). Learning always involves a learner constructing their own understanding of knowledge, which provided a link between new knowledge and existing knowledge. Pines and West (1986) suggest that a constructed knowledge of “private understanding” is some part of a public knowledge.

There are two aspects of individual knowledge; spontaneous knowledge; and formal knowledge (Pines and West, 1986: 586). The former has been referred to knowledge that the child has before reaching school, and beginning formal instruction. This kind of knowledge can impact on what the child will learn. The other kind of knowledge, formal knowledge, is “someone else’s interpretation of the world, someone else’s reality”, which is influenced by instruction or by school setting. Pines and West also suggest that the acquisition of formal knowledge is inevitably influenced by spontaneous knowledge, because formal instruction interacts with existing knowledge. Therefore, learning is viewed as the active construction or creating of knowledge, on the basis of existing knowledge and in individual, rather a transfer of knowledge (Duit and Treagust, 1998).

Personal constructivist-based perspectives strongly influenced learning models in the late of 1980s. A well-known example is the generative learning model proposed by Wittrock (cited in Osborne and Freyberg, 1985), and the conceptual change model proposed by Posner, Strike, Hewson, and Gertzog (1982).

1.1 Generative Learning Model

The generative learning model focuses on the learners having to actively construct or generate meaning from sensory inputs (Osborne and Wittrock, 1983). Some inputs are selected and attended, but others are ignored, depending on inherent meaning. The learners generate the links between new inputs and memory store and construct their own meaning which may be different from teacher's meaning. The constructed meanings are restructured or reinterpreted, unless they already relate well to other ideas in cognitive structure. According to this model, the processes of constructing meaning in each individual are seen as the way learners construct new ideas being based on a person's existing ideas and sensory inputs.

1.2 Conceptual Change Model

Theories of conceptual change, which focus on describing individual learners' mental structure or on describing the mechanisms that drive changes in individuals' mental structure, are viewed as individual views of learning (Leach and Scott, 2002). A model of conceptual change has been proposed by Posner *et al.* (1982). This model shares some characteristics with generative learning model in terms of the modification or restructuring of ideas. There are two major components to the conceptual change model (CCM); *conditions* that need to be met in order for a learner to experience conceptual change; and the *conceptual ecology* or individual's current concepts that provides the context in which the conceptual change occurs, and influences the change, makes meaningful (Hewson and Thorley, 1989).

According to the CCM, there are four conditions that foster conceptual change. The current conceptions must be dissatisfaction and any new conceptions must be intelligible, initially plausible, and fruitful (Posner *et al.*, 1982).

1. There must be *dissatisfaction with existing conceptions*. Before changing the old conceptions, learners must recognize that their existing conceptions are not appropriate to solve the problem.
2. A new conception must be *intelligible*. The individual must be able to grasp new concept with his experiences.
3. A new conception must appear *initially plausible*. An adopted new conception must be used to the problems at least.
4. A new concept should suggest the possibility of a *fruitful* research program. A new conception should be extended to other situation potentially and to open up new areas of inquiry.

An individual conceptual ecology consists of many different kinds of knowledge, which are important determinants of the direction of learning: anomalies; analogies and metaphors; epistemological commitments (explanatory ideas or general view about the character of knowledge); metaphysical beliefs and concepts (metaphysical beliefs about science or metaphysical concepts of science); and other knowledge (knowledge in other fields or competing concepts).

Critically speaking, the conceptual change model seems to neglect social issues. Strike and Posner (1992) claimed that learner's conceptions of ecology should be viewed much more in terms of a dynamic system than in their initial theory. However, some authors find such a view too limited, instead seeing learning as embedded in a social and cultural context (Vygotsky, 1986). Bell (1993) considers that context is a crucial factor in the construction of knowledge as both personal and social knowledge.

2. Social Constructivist-Based Perspectives

A constructivist-based perspective not only focuses on the individual students' understanding, but also includes the role of language and culture in the construction of knowledge. This is known as social constructivism or socio-cultural learning (Tytler, 2002a; 2002b). Constructivism of the social variety, where emphasizes the importance of group work for development and validation of ideas, has its origin in the work of Vygotsky (1986) about 'thought and language'. A social constructivist-based perspective focuses on the interdependence of social and individual processes in the co-construction of knowledge (Palincsar, 1998). Knowledge, from a social perspective, is viewed as something involving an individual and their social setting (Duit and Treagust, 1998). This perspective places more emphasis on the social context of learning than on individual mental processes.

Vygotsky (1986) suggests that constructing new meanings takes place in an area of cognitive structure, that is prepared to accept new ideas, where he called the "zone of proximal development" (ZPD). From these perspectives, cognition is a collaborative process, while thought is internalized discourse. Language is a key aspect of social perspectives because it seems to be a useful negotiation tool for learners to reach consensus ascent new meanings. Since knowledge not only involves in individual dimension but also social dimension, learning environment is necessary to provide discourse opportunities for learners to share their ideas with peers, both in small group and within the society of the classroom (Wheatly, 1991).

To illustrate a learning model based on social perspectives, the so-called constructivist-based analytical model was first presented by Appleton (1997), derived from both constructivist theoretical considerations, and classroom practice. This model is an iterative system based on individual existing ideas, processing information, seeking information, and the social context (Figure 2.1). Useful learning can not be examined only from the way a learner integrates a new concept meaning into existing knowledge, but also from the linking between school experience and real

world situation. This constructivist-based analysis model includes the role of social context in the learning of science. The social context influences the learner's pathways of thinking, interpretation of experiences and consequent learning. The learner has to be in the context of classroom and of school. The learner may use learning experiences to interpret and modify the new experience.

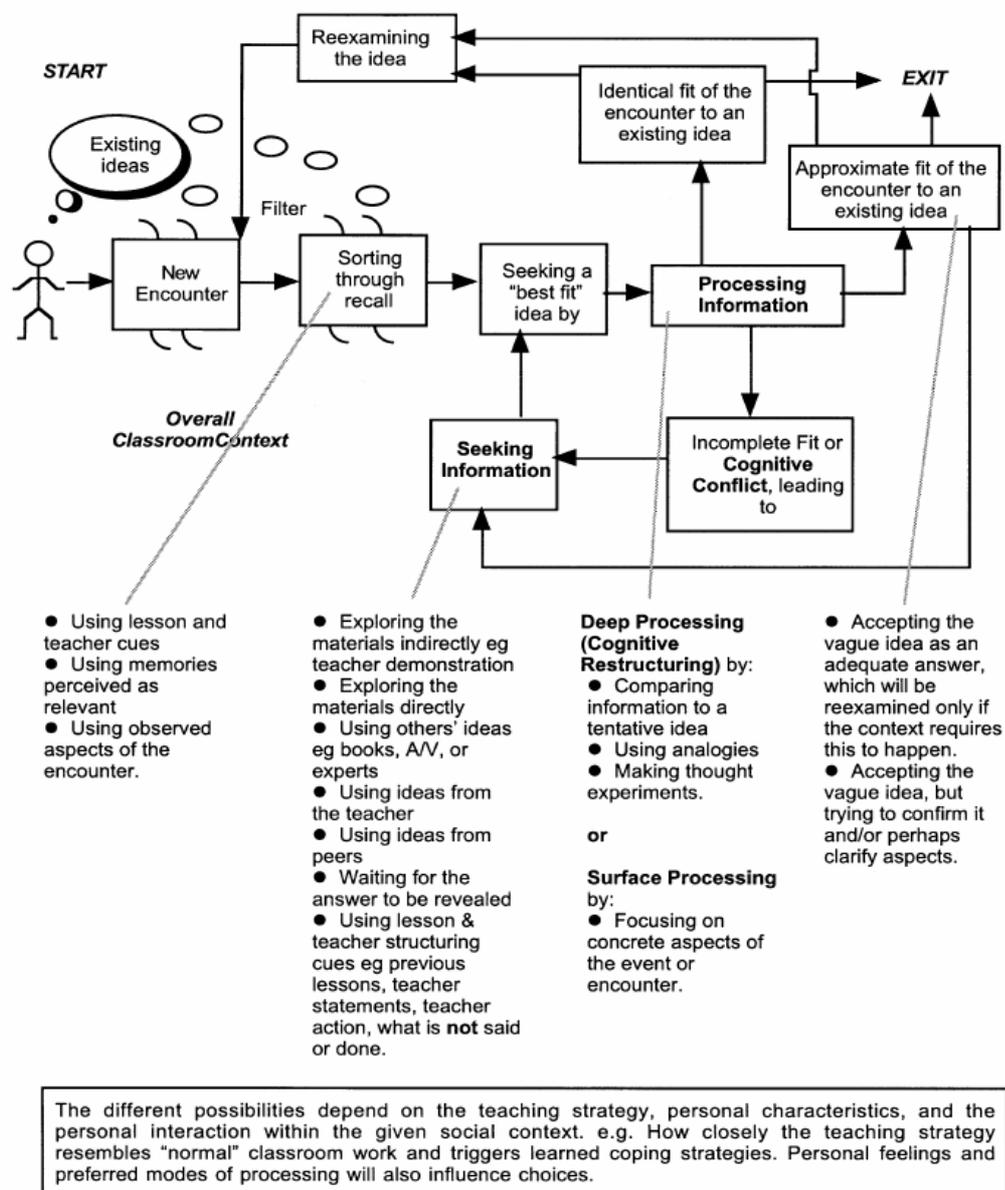


Figure 2.1 Constructivist-Based Analysis Model of Learning

Source: Appleton (1997: 307)

The core tenet of a constructivist-based view of learning is that learners construct their understanding of experiences. This constructed their understanding depends on what that individual already knows and believes, and an individual's existing knowledge about the topic (Fensham, Gunstone, and White, 1994; Gunstone, 1995). A reality in constructivist view can be only known in a personal and subjective way. There is no way to know what the reality is actually like and thus the real world can be known only through a learner's experiences (Tobin and Tippins, 1993; Wheatley, 1991). A further key aspect of constructivism is that the reality about the world outside is viewed as "human construction" (Duit and Treagust, 1998: 8).

3. Constructivism as a Referent or Method

Constructivism is a set of belief about knowledge involving an assumption that a reality exists, but that we cannot know what that reality is actually like. Constructivism, therefore, focuses on the way in which learners construct viable knowledge rather than concerns over the question of knowledge as a representation of truth (von Glaserfeld, 1993). From a constructivist perspective, learning involves a way of making sense of experience. Learners use their own experience to construct understanding that makes sense to them by providing linkages between existing knowledge and new experiences. Learning is also enhanced by social interaction, which encourages students to present their thinking and refine their understanding by communicating them with those others.

Constructivism can be used as both a referent and a method (Tobin, Tippins, and Gallard, 1994). In the way of using constructivism as referents, the purpose is to represent a method of teaching to build a classroom that maximize student learning. In contrast, using constructivism as method is to use it as a tool for critical reflection to provide a suitable role of teachers and students in learning (Tobin and Tippins, 1993). When used as a method, activities which facilitate learning are planned and implemented into the classroom. Therefore, the term of constructivism is not only

used for presenting a view about learning, but also used to present a framework of how to teach.

The usual way of using constructivism as a method, is to decide which teachers' and learners' roles are suitable in the given situation. For example, in the teaching of science, the role of teacher is seen as that of a facilitator rather than transmitter of knowledge. Science teachers, from a constructivist-based perspective, have to assume many roles, taking into account the ideas of learners, and the processes by which they construct new ideas (Osborne and Freyberg, 1985). In order to facilitate each individual's personal and social construction processes, Treagust *et al.* (1996) suggest that the classroom interaction should be established which can support each individual's exploration and negotiation to reach consensus of ideas within the social-cultural context.

Using constructivism as a referent is to represent a method of teaching to establish maximum learning opportunities for students. In this way, a teacher should be aware of the importance of students' existing knowledge, and the role of social interaction (Tobin *et al.*, 1994). Similarly, Hudson and Hudson (1998) suggest situations that might support students construct their conceptual understanding. These situations involve identification students' ideas and views; creation opportunities for students to explore their ideas and test their robustness in explaining phenomena, accounting for events and making prediction; providing stimuli for students to develop, modify, and where necessary change their ideas and views; and supporting their attempts to re-think and reconstruct their ideas and views.

4. Summary of Forms of Constructivism: Relevance to This Study

In summary, constructivism has a major influence in field of science education. Within various form of constructivism, there are no certain ways of knowing as each individual may understand the same thing in different ways. Experience and view point affect how everyone perceives the worlds, the reality seen

as a personal construction. The understanding of the world in each individual is not held to be absolutely true or false because there is no way to know if everyone's ideas about the nature of reality are congruent. Constructivist-based perspectives, therefore, concern about what is generally agreed upon by the majority of scientific community rather than talking about what is scientifically true.

Constructivist-based perspectives argue that learner make sense of his or her own world and knowledge acquisitions. Constructivist-based views of learning emphasize the learners' construction of their own meaning for a new concept, by using their own existing knowledge. The process of learning can occur in two ways; dealing a new concept with existing knowledge, or reorganizing what is already known. These characteristic views of learning are known as individual constructivist-based perspectives.

Learning within constructivism, is also influenced by the social context and social interaction. The social origins of learning and the fundamental role of language in learning are recognized, alongside the essential personal sense-making or interpretative step. Thus, learning can be most usefully seen as a social, interactive process involving the communication and negotiation of meaning, and a learner's interpretation. The next section describes in detail of teaching and learning science within constructivist-based perspectives.

Constructivist-Based Perspectives on Teaching and Learning Science

1. Learning Science

The views of process of learning science, within constructivist-based perspectives, differ in that the individual meaning depends on a learner's existing knowledge (Fensham *et al.*, 1994). Learners are seen as who construct understanding of the world by themselves. The process of learning involves an interaction between

learners and learning experiences as Asoko, Leach, and Scott (1995: 47) suggestion that:

Learning involves the learners in making sense of things in terms of their existing ideas, though this will sometimes involve moving beyond their current interpretive framework to one which is better able to make sense of their experiences, including the recent experiences deliberating provided by their science teachers.

Generally, learning science involves three important components. The first of those is the content of science, the basic concepts, and scientific knowledge which is called ‘conceptual understanding’ in this research. The other two important dimensions of science in addition to conceptual understanding are the science process skills and attitudes. Three of those are described below.

1.1 Conceptual Understanding

It is inevitable that each learner has had different experiences, and these experiences influence the way students understand natural phenomena and events in the world around them. Furthermore, in science lesson, students come to science classroom with various backgrounds and experiences which are quite different depending on the age and the experiences of the students (Asoko *et al.*, 1995). For example, Gunstone (1995) suggests that a variety of constructed understandings about particular model of matter derive from the use of different existing ideas to interpret what was to be learnt. To illustrate, Gunstone’s found that students drew different characteristics of air particles in a stoppered conical flask because they had different assumptions about the particles. A few students did not draw air particles in any form because they, perhaps, did not accept that air could be seen, or because they were not familiar with the particle model of the matter. This finding from the work of Gunstone (1995) is consistent with the general nature of children’s ideas identified by Osborne and Freyberg (1985). Osborne and Freyberg summarized the general finding about

children's ideas in science from classroom observations into three patterns (Osborne and Freyberg, 1985: 12):

1. From a young age, and prior to any teaching and learning of formal science, children develop meanings for many words used in science teaching and views of the world which relate to ideas taught in science;

2. Children's ideas are usually strongly held, even if not well known to teachers, and are often significantly different to the views of scientists; and

3. These ideas are sensible and coherent views from the children's point of views, and they often remain uninfluenced or can be influenced in unanticipated ways by science teaching.

In the late of 1990s and the early of twenty-first century, it is characterized by extensive research in the field of the views of natural phenomena and meanings for scientific words held by children. These views and meanings are called "children's science" (Gilbert, Osborne, and Fensham, 1982), and Bell (1993) use the term "children science" to refer to "alternative conceptions" which are a part of conceptual understanding and science learning. Children's science develops as children attempt to make sense of the world in which they live in terms of their experiences, their current knowledge, and their use of language (Schollum and Osborne, 1985).

According to children' science, from Freyberg and Osborne's (1985) perspectives, learning science is about making sense of the world rather than finding out about the world. It can be seen that students learn science by "making sense of their own world", another term "making sense of the world" has become the gathering call of a constructivist-based perspective to learning (Hudson and Hudson, 1998).

However, the interesting question is whether students' making sense of their world is sufficient for learning science, based on a constructivist-based perspective. Scott, Asoko, Driver, and Emberton (1994) suggest that learning science can occur by requiring students to be socialized and to be enculturated into a scientific community. Students, from a constructivist-based view of learning, learn about scientific knowledge by reconstructing knowledge that is already constructed by scientists (Bell, 1993). Hudson and Hudson (1998) state that "the idea of science will not be acquired through everyday experiences or by conversations with non-scientists" (p. 35). Learning science, therefore, is not only making sense of the world by using everyday experiences but also involves introduction into what science knows or theoretical objects of science in terms of concepts, ideas, understandings, and theories (Hudson and Hudson, 1998). As Matthews (1993) points out, there is an important distinction to be drawn between the theoretical objects of science and the real world because the context for acquisition of knowledge is different. Scientists are able to study more closely and more productively than students because of the abstract and mathematical nature of scientific knowledge thought and the community-based rationality of scientific method of inquiry.

1.2 Science Process Skills

The development of scientific knowledge in the science classroom is a cognitively complex process (Germann, Aram, and Burke, 1996). The learning of science is not only emphasis on students' understanding, but science process skills, which are the process of doing science that scientists, use to find out scientific knowledge, also have been emphasized for helping students increase their scientific literacy at all level (Micikas, 1996). Learning with understanding in science involves testing the usefulness of possible explanatory ideas by using science process skills to make predictions or to pose questions, collecting evidence to test the predictions or answer the questions and interpreting the result (Harlen, 1999). Watson (2000) suggests that scientific concepts and theories are often counter-intuitive and have to be constructed in the classroom by talking or reading about phenomena as well as by

seeing them. It can be seen as students who have opportunities of doing practical science, have more understanding in science than the one who hardly have those opportunities. As Stohr-Hunt (1996) reveals, students who engaged hands-on activities every day or at least once a week scored higher on a standardized test of science achievement than students who engaged in hands-on activities once a month or less than once a month, or never. The more the students practice, the better they can understand science.

The science process skills consist of thirteen processes which include both basic science process skills and integrated science process skills (AAAS, 1968 cited in Enger and Yager, 2001). These science process skills are observing; using space and time relationships; classifying, grouping, and organizing; using numbers and quantifying; measuring; communicating; inferring; predicting; identifying and controlling variables; interpreting data; formulating hypotheses; defining operationally; and experimenting. The first eight skills are categorized as the basic science process skills which are appropriate for children in the primary, while the last five skills are categorized as the integrated science process skills which are appropriate for children at grades four and above (Enger and Yager, 2001; Mohd.Saat, 2004).

The science process skills are regarded as one of the hallmarks of science, and many educators argue that a science education without involving them fails to reflect the nature of science (Watson, 2000). The basic science process skills, which are prerequisites to the integrated process skills, provide the intellectual groundwork in scientific enquiry (Beaumont-Walters and Soyibo, 2001). The ability to use the basic science process skills is attributed to the ability to perform empirical-inductive reasoning or Piagetian concrete operational reasoning (Germann and Aram, 1996). The integrated science process skills are the terminal skills for solving problems or doing science experiments (Beaumont-Walters and Soyibo, 2001). The ability to carry out the integrated science process skills is attributed to hypothetical-deductive reasoning or Piaget's formal operational reasoning (Germann and Aram, 1996). Then,

science process skills have a crucial role to play in the development of lifelong learning (Harlen, 1999).

Since the science process skills is being as a tool to lead students an understanding of science as inquiry, internationally, many research studies have been conducted on students' acquisition of those skills (e.g. Germann, Aram, and Burke, 1996; Mattheis, Spooner, Coble, Takemura, Matsumoto, Matsumoto, and Yoshida, 1992; Stohr-Hunt, 1996). Harlen (1999) suggests that the strategies used to find out students' science process skills should be content-dominated. Science process skills should be used in relation to some content. It is difficult to find out these skills separately, since any task involving the skills will be influenced by the nature of the subject content as well as the ability to use the skills. As Harlen (1999: 131)) describes:

A simple example illustrates the point. A 10-year-old student might well succeed in designing and carrying through an investigation of whether the height to which a ball rebounds after being dropped depends on the type of surface on which it is dropped; yet the same student is likely to be unable to succeed if the question to be investigated concerns the effect of concentration on the osmotic pressure of a certain solution.

In summary, the case for this is essentially that the mental and physical skills that are described as science process skills have a central part in learning with understanding. Especially, Thai National Education Act acknowledge that learning does not end with formal education but has to be continued throughout life, requiring skills of finding, evaluating and interpreting evidence. Thus, the acquisition of the science process skills that students have learnt in their formal education is an important issue that the teacher and all stakeholders have to emphasize in order to improve the learning of science.

1.3 Attitudes toward Science

The affective domain plays an important role in learning science; the term attitudes and attitudes to science is seen as an issue that has been investigated for many decades (Francis and Greer, 1999; Haladyha, Olsen, and Shaughnessy, 1982; Moore and Foy, 1997). The term attitudes can be defined as “a concept which represents the emotional orientation of an individual to respond favourably or unfavourably to thing, people, places, events, or ideas” (Papanastasiou and Papanastasiou, 2004: 239).

There are many variety of way to define the term attitudes toward science in the literature. For example, Gardner (1975: 2) defines attitudes toward science as “a learned disposition to evaluate in certain ways objects, people, actions, situations or propositions involved in the learning of science”. A similar meaning of ‘attitudes toward science’ is given by Laforgia (1988), as a learner response, evaluating their feelings within the environment related to science learning. Attitudes toward science involves an attitudes object such as ‘science lesson’, ‘scientists’, method of teaching science’, or ‘the subject of science’ (Haladyna and Shaughnessy, 1982).

Consideration of a number of studies carried in the area of attitudes toward science, suggest that there is a general argument that a positive attitudes toward science is an important factor in determining students’ success in learning science (Osborne, Driver, and Simon, 1998; Ramsden, 1998; Bennett, Rollnick, Green, and White, 2001). Much of the interest in this field of studies is related to motivation of students to be interested in science, their attitudes toward science, their views of scientists, and their desire to become scientists (Moore and Foy, 1997).

Research involving factors affecting student attitudes has been focused on gender, ethnicity, intelligence, and teaching strategies (Francis and Greer, 1999; Koballa, 1990). A review of the literature by Gardner (1975) suggests that there are less studies about gender differences (at that time). Interestingly, this research does

point to widely different attitudes toward science between males and females. For example, Jones, Howe, and Rua (2000) claim that gender differences can affect to students' attitudes toward science, reporting that more female than male students focused science difficult to understand, and more males reported that science was more suitable for them.

Other factors which have studied included the effects on student attitudes in academic achievement. Commonly, it seems that students who do well in science usually have positive attitudes toward science. Cukrowska *et al.* (1999), in longitudinal research of these relationships, reported that there is a substantial positive relationship between attitudes and academic achievement in first-year chemistry. Likewise a positive perception toward chemistry is a major factor in student success (Cukrowska *et al.*, 1999).

The strongest direct influence on student attitudes toward science is that of teaching (Papanastasiou and Papanastasiou, 2004). Haladyna *et al.* (1982), found a correlation between teacher variables and attitudes to be high, especially at the seventh- and ninth-grade levels. These teacher variables included: respect for the teacher, teacher support for individual students, teacher use of praise, teacher commitment to learning, and fairness. Teachers play an important role in each student's learning process, and the quality of instruction correlates directly with the quality of science education, and the nature of science instruction strongly affects student attitudes toward science (Freedman, 1997).

Peer groups also have been reported to be an important influence on student attitudes (Keeves, 1975). A friendship as for adolescence students, however, the extent of effect of peer groups in an international context is not clear, in contrast with effects of teacher or student attitudes.

Studies of the students' attitudes toward science by Ramsden (1998) follow topics such as: science is considered to be difficult and not relevant to the lives of most people; science is supposed to cause social and environmental problems;

science is more attractive to males than females; the interest in science decreases over the years of secondary schooling; and the more negative views are associated with the physical sciences rather than biological sciences.

Although, there is a substantial body of research concerning attitudes, there are problems associated with deciding how to evaluate attitudes effectively. Bennett *et al.* (2001) suggests the general problems associating with measurement include:

- A lack of precision over definitions of key terms;
- Poor design of instruments and of individual response items within instrument;
- Failure to address matters of reliability and validity appropriately;
- Inappropriate analysis and interpretation of data;
- Lack of standardisation of instruments;
- Failure to draw on ideas from psychological theory; and
- Failure to formulate the research with reference to theory on the construction of data collection tools.

In the process of constructing attitudes instruments, Gardner (1975) claims that there are two common problems; lack of any theoretical construct, and confusion of various theoretical constructs.

- Lack of any theoretical construct

- The items within the scale must all be related to a single attitudes object to reflect the respondent's position on some well – defined attitudes continuum. A disparate collection of items, reflecting attitudes toward a wide variety of attitudes objects, does not constitute a scale, and cannot yield a meaningful score.

- Confusion of various theoretical constructs
 - Instruments have frequently been constructed which contain two or more logically and psychologically distinct variables; the distinctions are either not perceived, or ignored, and all the items responses are summed to yield a single score. To avoid this problem, logical analysis ought to be enough to show that these are distinct variables which ought to be measured separately and not mixed together into a single score.

Eagly and Chaiken (1993) view attitudes as composing of three main components: the cognitive; the behavioural; and, the affective. The cognitive component is based on a set of beliefs about the attributes of the attitudes' object. The behavioural component has its basis in the way people act toward the object which can be assessed directly by observed behaviours. The last component, the affective, includes feelings about objects and seems to be relevant to the studies of attitudes more than the other two components (Fishbein and Ajzen, 1975).

The majority of the existing studies usually related to attitudes toward science, and general in nature few have focused to attitudes toward the subject of science. For example, the well-known instruments which are widely used for assessing student attitudes toward science are the Scientific Attitudes Inventory II (SAI II) (Moore and Foy, 1997), and Test of Science Related Attitudes (TORSAs) (Fraser, 1987). Ramsden (1998) comments that the use of 'science' as a board term to refer to biology, chemistry, physics, and possibly other areas is ambiguous. It has been suggested that research of students' attitudes must focus on the separate disciplines

within science rather than on science, because students, particularly a girl, respond more positively to biological sciences than to, for example, physical sciences.

Chemistry is one of a particular discipline that there have been found a few investigations in science education as to the association between student attitudes and chemistry achievement (Salta and Tzougraki, 2004). Some research done relating to these studies almost involved the process of developing instrument for investigating students' attitudes toward chemistry, for example, Questionnaire on Chemistry-Related Attitudes or QOCRA (Wong, Young, and Fraser, 1997), Attitudes Toward Chemistry Questionnaire (Salta and Tzougraki, 2004), Chemistry Attitudes and Experiences Questionnaire (CAEQ) (Dalgety, Coll, and Jones, 2003), to gain a deeper understanding of factors which may be useful in informing decisions made about the structure of teaching sessions (e.g. Bennett *et al.*, 2001).

As Ramsden (1998) comment, to evaluate effectiveness of learning science in the area of chemistry, the term 'attitudes toward chemistry' should be used rather than 'attitudes toward science' to uncover vague of terminology in an instrument. Therefore, 'attitudes toward chemistry' is one of variables which will be addressed to investigate the effectiveness of teaching and learning chemical equilibrium concepts at the eleventh grade in Thai current educational system. On the basis of these three components, the concept of attitudes was investigated by developing the Questionnaire on Students' Attitudes toward Chemistry for this study. It was a modification of some questionnaires from the literature review relating to the study of attitudes done in science education. The process of development was describes in Chapter III: Methodology.

Student attitudes are one of important variables in determining the student success of learning science. Since, the function of science education goes further than the provision of future scientists and service to the institution of science, especially in Thai educational system, the aim of learning science is to enhance scientific literacy (IPST, 1999). Thus, the challenging questions that the science teachers need to ask of

their practice is “how can [the teacher] make science more appealing?” (Simon, 2000: 116).

2. Implications of Constructivist-Based Perspectives on the Teaching of Science

Within constructivist-based perspectives, the theory of learning relies on the common idea that learning is an interaction between ideas which are already in the learner’s mind and new idea introduced by learning activities. Many authors feel that teaching methods should be informed by views of learning (e.g. Leach and Scott, 2000; Scott *et al.*, 1994). Learning science involves socialization into a particular way of looking at the world. It is not a matter of discovering what the world really is (Scott *et al.*, 1994). These highlight a very important distinction between discovery learning and constructivist-based perspectives of learning. Leach and Scott (2000) claim that planning of the teaching of science based on discover approaches involves breaking the subject matter down into clear, logical steps and then thinking how these might be best explained to the students, but learning demands might never be identified through this approach. Then, the constructivist-based teaching of science involves establishing an argument for science view which is generated from empirical findings, and helping students to construct the particular way of understanding science within scientific community (Scott *et al.*, 1994). Asoko *et al.* (1995) suggested that the way of matching constructivist-based perspectives of learning to effective science teaching should recognize two aspects as following:

- Finding what the learner’s knowledge and understanding are and providing learning experiences which state from there;

- Giving the opportunities activity to test, refine, and consolidate their understanding in new learning contexts (Asoko *et al.*, 1995:64).

These two aspects, the decisions relating to a planning of teaching require the teacher to consider: the nature and status of students’ existing ideas and understands;

the nature of the science learning goals set for the topic; and the nature of the intellectual demand for the students in developing the science view from existing understandings (Scott *et al.*, 1994).

Ramsden and Harrison (1995) suggest effective strategies of teaching science in terms of planning learning activities that can lead to elicit existing ideas and related to learner's experiences; establishing a classroom environment to support learning; providing a wide range of learning activities which will encourage learner activity to try out his or her own ideas in new situations in various ways. Techniques for gathering information about students' existing ideas and skill include: on-the-spot-observation of students' actions; asking questions designed to probe understanding of ideas and processes; and collecting products such as students' report, notes, or drawing (Leach and Scott, 2000). To establish classroom environment for supporting learning, the most important feature of an approach to science classes, which addresses the difficulty of changing ideas, is conversation (Carr *et al.*, 1994). The teacher and students talk toward the understanding of scientific ideas. Leach and Scott (2000) suggest a typology of conversation to control teaching and learning events in the classroom as: making knowledge as significant and joint; cued elicitation of students' contributions by asking questions while simultaneously providing explicit clues to the information required; and paraphrasing students' contributions and offering reconstructive recaps where the teacher reinterprets what students have said in order to maintain a strict control over the content of developing common knowledge. These activities require not only students' statement in representing their own understanding, but also perhaps requiring students to do exercises. Teaching informed by constructivist-based perspectives, thus include practical activities, and classroom discussion, within an open and unthreatening environment, for changing the ideas through conversation (Carr *et al.*, 1994). These are recognized as important, because the ways that students understand differ from those intended (Scott *et al.*, 1994). Carr *et al.* (1994) suggest that for learners to construct their own understanding, they also need time to consider their existing knowledge, explore new ideas, and link them to other existing ideas.

Teaching and Learning Chemistry

1. Introduction

In the early part of the twenty-first century, there has been an increasing interest in determining student understandings of science conceptions and scientific events. The science education literature includes numerous research studies of secondary and tertiary students' understandings of scientific phenomena (e.g., Chin and Brown, 2000; Harrison *et al.*, 1999; Johnson, 2000; Ozmen and Ayas, 2003). These studies suggest that students' understandings are quite different or inconsistent with the scientific conceptions that they are expected to learn. One of the terms used to describe these students' understandings is "alternative conceptions" (Garnett, Garnett and Hackling, 1995). In the literature, alternative conceptions are variously called common students misunderstandings (Bergquist and Heikkinen, 1990), Limited of Inappropriate Propositional Hierarchies or LIPH's (Novak, 2002), or misconceptions (Nakhleh, 1992; Treagust, 1988). In this study, the term "alternative conceptions" will be used to refer to students' conceptions which differ significantly from these generally accepted by scientists.

In an area of chemistry education research, the nature of the subject itself is seen as complexity which may be generated from the ways of representations of matters (Gabel, 1999). As Jonestone (1991) states, matter can be represented at three levels: macroscopic, microscopic, and symbolic levels. Some studies suggest that the students' lack of understanding chemistry concepts occurs at all three levels (e.g., Bodner, 1991). Gabel (1999), for example, claims one reason of the difficulty in learning chemistry is that students make observations at the macroscopic level, but they are expected to explain what they observe at the microscopic level. Gabel also suggests that the use of mathematical symbols, formulas, and equations to express relationships between macroscopic and microscopic level can be additional factors of complexity. Learning chemistry, from a constructivist-based view of learning, requires learners to link many concepts which are related to others including their existing

ideas (Gabel, 1998). Students have to link what they know in macroscopic world with microscopic level. This makes learning chemistry more abstract.

Within the domain of chemistry, the literature suggests that the topics of the particulate nature of matter, covalent bonding, molecules and intermolecular forces, chemical equations, chemical equilibrium, acids and bases, oxidation and reduction, and electrochemistry give learners the most difficulty (Garnett *et al.*, 1995). Concepts of chemical equilibrium also have been associated with learning difficulties, (van Driel and Graber, 2002) for secondary school students (e.g. Kousathana and Tsapalis, 2002), higher education students (e.g., Thomas and Schwenz, 1998; Voska and Heikkinen, 2000), and even for chemistry teachers (Benerjee, 1991). It is not surprising, then, that many research studies in this field are interested in discovering the students' alternative conceptions for chemical equilibrium, and looking at why many students have great difficulty in successfully developing a scientifically accepted understanding of chemical equilibrium (e.g., Camacho and Good, 1989; Evrard *et al.*, 1998; Pedrasa and Dias, 2000).

2. Students' Alternative Conceptions in Chemical Equilibrium

A review of the literature points to many alternative conceptions within the domain of chemical equilibrium (e.g., Benerjee, 1991; Huddle and Pillay, 1996; Kousathana and Tsapalis, 2002; Quilez-Pardo and Solaz-Portoles, 1995; Thomas and Schwenz, 1998; Voska and Heikkinen, 2000). Bergquist and Heikkinen (1990) phrases a summary of common students' alternative conceptions of chemical equilibrium from other research studies in the 1990s into four general areas of difficulties: confusion between amount and concentration; the appearance and disappearance of material; the meaning of the equilibrium constant; and, the use of Le Châtelier's principle. A few years later, a similar review was published by Garnett, Garnett, and Hackling (1995) which specific surveyed students' alternative conceptions about chemical equilibrium and identified sixteen alternative conceptions related to this topic. These alternative conceptions are categorized into six aspects of

student confusion: characteristics of chemical equilibrium; reaction rates; constancy of equilibrium constant; inappropriate use of Le Châtelier's principle; interrelatedness of the concentrations of reactants and products; and, effect of catalysts.

However, in Thai Science Curriculum, chemical equilibrium concepts consists of five main topics: the nature of an equilibrium system; the changes in chemical equilibrium; the equilibrium constant; the factors affecting an equilibrium system and Le Châtelier's principle; and, chemical equilibrium in living things and environment (IPST, 2004). For this study, in order to be useful for Thai science teachers or Thai science educators, the literature involving students' alternative conceptions about chemical equilibrium are categorized into five aspects matching the Thai Science Curriculum.

2.1 Nature of an Equilibrium System

Frequently, observed student alternative conceptions involve the failure of understanding of reversibility in chemical reaction. The students describe chemical reactions as only taking place in one direction and always proceeding to completion (van Driel *et al.*, 1998). Work by van Driel *et al.* (1998) revealed that most students consider the original substances to have vanished completely and forever, a chemical reaction is complete. Similarly, students fail to understand incomplete conversion, instead believing that the conversion of chemical reactions proceeds to completion. (Garnett *et al.*, 1995).

2.2 Changes in Chemical Equilibrium

Students have difficulty in understanding the dynamic nature of chemical equilibrium (van Driel *et al.*, 1998). Bergquist and Heikkinen (1990) found that college chemistry students often described equilibrium as an oscillating set of reactions, or as exhibiting pendulum-like behavior. They found that students believed that forward reaction goes to completion before the reverse reaction commences. It

also seems students have weak understanding of changes that occur to a system at equilibrium, if the concentration of an original reactant is increased. The other learning difficulty concerning dynamic nature of chemical equilibrium, is that students are confused about the rate of reactions in a chemical system (Garnett *et al.*, 1995). Some students believe that the forward reaction rate increases while the reverse reaction rate decreases as the reaction gets going (Niaz, 1995). Garnett *et al.* (1995) suggest that students who hold alternative conceptions of the rate of reactions seem to be unable to consider the forward and reverse reactions separately, and have a limited understanding of the particulate basis of chemical reactions.

2.3 Equilibrium Constant

The equilibrium constant also is one of the topics in chemical equilibrium where students hold alternative conceptions. Students show confusion over the meaning of K_c describing it as varying in value while at constant temperature, or as being independent of temperature. Kousathana and Tsapalis (2002) discovered that secondary students hold the alternative conception that an increase in temperature always increases the value of the equilibrium constant. Some students believe that the value of the equilibrium constant affects the rate of a reaction, thinking that the large value of the equilibrium constant implies a fast reaction (Benerjee, 1991). Additionally, work by Nakhleh (1992) shows that students do not understand what manipulating algebraic symbols or other symbols really means in relation to the actual chemical reactions or chemical system being studied. Students apply an algorithm memorized through rote learning. Although the students can compute the numerical number of the equilibrium constant or calculate equilibrium concentrations correctly, the correct responses do not necessarily confirm that students understand the concept of equilibrium constant (Bergquist and Heikkinen, 1990).

2.4 Factors Affecting an Equilibrium System and Le Châtelier's Principle

Several of the studies reported on students' inappropriate application of Le Châtelier's principle when considering the effect of changes in conditions on the concentrations of components in equilibrium systems and when predicting the effects on the rates of forward and reverse reactions (e.g., Benerjee, 1991; Kousathana and Tsaparlis, 2002; Quiliz-Pardo and Solaz-Portoles, 1995). There are widespread alternative conceptions related to the use of Le Châtelier's principle. One of these relate to the confusion between rate and the extent of reactions. Benerjee (1991) found that students and teachers have conceptual difficulties when applying Le Châtelier's principle. Students and teachers believe that increasing the temperature in an exothermic reaction decreases the rate of the forward reaction. The other alternative conceptions related to inappropriate use of this principle are revealed by Kousathana and Tsaparlis (2002), is that students arrive at wrong conclusions because they apply Le Châtelier's principle to predict the effect to position of the equilibrium when excess of solid reactant is added into a gaseous system at equilibrium and they think Le Châtelier's principle can be applied in all systems including heterogeneous systems. Similarly, Furio *et al.* (2000) used four qualitative tasks all involving the application of Le Châtelier's principle on finding out students' alternative conceptions about chemical equilibrium. They found that the procedural knowledge of students on those tasks was very poor. Students apply mechanically reasoning based exclusively on Le Châtelier's principle, even when solid is added to a heterogeneous system at equilibrium or inert gas is added to a homogeneous system at equilibrium.

2.5 Chemical Equilibrium in Living Things and Environment

Students' alternative conceptions in this topic related to the failure in an application of equilibrium principles to daily-life. Benerjee (1991) found that some students cannot explain how to obtain the high amount of ammonia in the production by Habor Process. They also hold alternative conceptions involving with acid-base and ionic equilibrium. For example, many students believed that there are no

hydrogen ions in an aqueous solution of sodium hydroxide, or in distilled water (Benerjee, 1991).

In summary, throughout the literature, it is found that alternative conceptions about chemical equilibrium is one of the difficulty conceptions in the field of chemistry, and they are widely held by students and chemistry teachers across educational levels, and in both western and other cultures. Thus, teaching chemical equilibrium in secondary school and undergraduate chemistry classes has always been challenging due to the enormous number of conceptual difficulties faced by students (Benerjee, 1995). Interesting questions challenging both teachers and science educators is that why students have difficulties in learning concepts of chemical equilibrium. The next section describes these difficulties in detail.

3. Problems Associated with Students' Alternative Conceptions in Chemical Equilibrium

In the field of chemistry, therefore, there have been considerable interest in discovering the reasons why many students have great difficulty in successfully developing a scientifically accepted understanding of chemical equilibrium (e.g., Bergquist and Heikkinen, 1990; Gussarsky and Gorodetsky, 1990; Nakhleh, 1992; Pedrosa and Dias, 2000). There are many reasons for students having difficulties in this area. These reasons can be addressed into: abstract nature of chemical equilibrium content, high degree of linkage with other conceptions, language difficulty, and rote learning.

3.1 The Abstract Nature of Chemical Equilibrium Content

The nature of an equilibrium system is an abstract conception. The dynamic nature of chemical equilibrium requires students to assume that two opposite chemical reactions are taking place in spite of the fact that this cannot be deduced from observation (van Driel, 2002). At an equilibrium state, the characteristics of

macroscopic properties (e.g. colour, concentration, pressure) are constant, while both the forward and reverse chemical reactions still take place equally, resulting in no net loss or gain of reactants and products. This is referred to “dynamic equilibrium” and hard for students to understand the dynamic nature of the equilibrium process (van Driel, 2002).

3.2 High Degree of Linkage with Other Conceptions

Chemical equilibrium is considered by many authors to be sophisticated conception because there are a large number of subordinate conceptions underpinning this conception: chemical change and physical change, chemical reaction, stoichiometry, laws of ideal gases, kinetics, thermodynamics, acidimetry, and mathematics (Camacho and Good, 1989; Quilez-Pardo and Solaz-Portoles, 1995; van Driel, 2002). Bergquist and Heikkinen (1990) argue that some students’ alternative conceptions in chemical equilibrium are generated from inability to grasp the proportional aspects of relevant conceptions such as concentration, limiting reagent or mathematical skills. A similar finding also was reported by Camacho and Good (1989), who found that earners who have alternative conceptions of the nature of chemical equilibrium had many knowledge gaps among the relevant knowledge. Van Driel *et al.* (1998) also found that conceptions of chemical reactions can affect students’ understanding in the dynamic nature of chemical equilibrium.

3.3 Language Difficulties

One source of alternative conceptions in chemical equilibrium might be the language problem. The differences between the meaning of words in everyday usage and scientific usage could generate students’ alternative conceptions. Gussarsky and Gorodetsky (1990) found that students’ alternative conceptions associated with the dynamic nature of chemical equilibrium via the transfer of static attributes from equilibrium to dynamic chemical equilibrium resulted from merging of the different meanings of the word “equilibrium” between everyday life and scientific meaning.

Similarly, Bergquist and Heikkinen (1990) suggest that the differences between the technical use of certain words in science and everyday usage of the same terms must have been aware because common everyday terms such as “shift, equal, stress, or balanced” occurring in statements of chemical equilibrium conception can generate very different “visual images” depending on personal experiences.

Language used in textbooks may reinforce students’ alternative conceptions in chemical equilibrium (Pedrasa and Dias, 2000). They found some direct relationship between the language used in textbooks and some of students’ alternative conceptions in chemical equilibrium. For example, the word “system” in textbooks is one of a major problem, some loose and ambiguous usage in everyday language, which appears to be source of difficulty for students.

3.4 Rote Learning

Rote learning is one source of students’ alternative conceptions in chemical equilibrium. Nakhleh (1992) reports that students applied an algorithm memorized through rote learning, resulting in successful in solving computational problems even though lack of conceptual understanding in chemical equilibrium conception is evident. Later, work by Quilez-Pardo and Solaz-Portoles (1995) show the similar findings that students’ alternative conceptions in chemical equilibrium merged through use of rote-learning recall and algorithmic procedures and difficulty in transferring such of Le Châtelier’s principle to a new situation.

In summary, previous research studies suggested that students might face with various obstacles to understand chemical equilibrium concepts in which alternative conceptions might be generated from these. Throughout the literature, it was found that there are four reasons concerning with difficulties for understanding chemical equilibrium concepts. These are abstract nature of chemical equilibrium content, high degree of linkage with other conceptions, language difficulty, and rote learning. Because of difficulties of understanding chemical equilibrium concepts, effective

teaching strategies for this concept are introduced to enhance scientific understanding. Examples of teaching strategies are presented in the next section.

4. Teaching Strategies Used in Chemical equilibrium concepts

Hence, the literature suggests that chemistry is one of the most difficult concepts at the secondary and tertiary levels. Causes of learning difficulties of chemistry have been summarized by Driver and Scott (1996). These difficulties are generated from deficiencies or inadequacies in students' knowledge structure; the demand and complexity of learning tasks in terms of information processing compared with students' information handling capacity; the use of analogies, scientific languages, and related communication problems in science education; and information overload. To enhance students' understandings about chemistry, Taber and Watts (1997) suggest that students' cognitive structure has to be developed in at least three ways: the range of their concepts will increase; the level of sophistication of their concepts will deepen; and their concepts will become better integrated with each other.

This section, therefore, focuses on some teaching strategies in chemical equilibrium concepts suggested by research studies in many countries. The aim of providing some examples of teaching strategies is to avoid or overcome the learning difficulties described in the previous section.

4.1 Teaching as Conceptual Change

The learning of science involves conceptual change that has generated in the work of a number of science educators, who studied areas of alternative conceptions about science learning (Vosniadou, 2001). A view of learning within a conceptual change model is that learning involves the reconstruction of existing ideas, rather than replacement by new experiences (Duit and Treagust, 1998). The precursor for conceptual change thus is dissatisfaction between the existing concept and new

situation, means that a new conception is accepted when only it is intelligible, plausible, and fruitful (Posner *et al.*, 1982).

Conceptual change also can be viewed as a teaching approach embedded in constructivist-based perspectives (Duit, 1999). Driver and Scott (1996) suggest that conceptual change teaching usually is embedded in conditions that support conceptual change. Students are thus given many opportunities to match their own experiences and to construct their own meaning of phenomena observed. Cognitive conflict, an important role, is embedded in the process of gradual processing reinterpretation of students' existing ideas toward scientific ideas.

Within the topics of chemical equilibrium, conceptual change approaches are widely employed for helping students understand in the concepts. These approaches could be seen as important aspect to support reconstruction of science subject matter structures (Duit, 1999). Chui, Chou, and Liu (2002), for example, using conceptual change approaches to promote student conception in chemical equilibrium, found that conceptual change could help student better understand the concept. Change occurred through a construction process to promote self-generated during work in small groups. However, they suggest that not all of topic in chemical equilibrium concepts could be changed. In this using, some are easy to change but other is not. The most difficult topic is the dynamic nature of equilibrium at both microscopic and macroscopic level.

The conceptual change approach also can be applied to technology teaching to enhance student understanding chemical equilibrium concepts. Hameed, Hackling, and Garnett (1993) employed Computer Assisted Instruction (CAI) strategies based on a conceptual change model to create cognitive conflict in students, and promote accommodation of their new conceptions. The CAI package consists of eleven modules; completion reactions; reversible reactions; equilibrium constant; equilibrium concentrations; equilibrium rates; effect of catalyst on rates; Le Châtelier's principle (LCP) and concentration; LCP and volume; LCP and

temperature; and changing equilibrium constant. Since this CAI package placed considerable emphasis on remediation of chemical equilibrium alternative conceptions, relationship between concentration of reactions and products at equilibrium are emphasized by providing dynamic graphs and interaction opportunities for students to generate cognitive conflict and facilitate conceptual change.

4.2 Analogies, Metaphors and Simulations

An analogy is a relation between parts of the structures of two domain; analog domain referring to everyday objects or events; and target domain (Duit, 1991). Using an analogy is essentially a two way process involving developing both analog and target (Duit, 1991). An analogy lies on 2 major backgrounds, the view of metaphorical aspects of analogies and the constructivist-based view of learning (Duit, 1999). In the latter view, learning fundamentally has to do with constructing similarities between the new and the already know.

Research suggests that the use of a teaching strategy for the presentation of models, metaphors and analogies will enhance student understanding and reduce misconceptions. Duit (1991), for example, found that many analogies facilitate a visualization of the abstract target domain. Hence, it is not surprising that analogies are used in textbooks and in the classroom. Duit (1999) argues that analogies are powerful tools to facilitate the learners' construction process, on the grounds of concepts that are already available. The advantage of analogies is due to their significance within a constructivist-based perspective of learning. However, Duit (1991) suggests that using analogies can be 'double-edged swords'. By this, he means that analogies cannot link to all of target domain. There may be some features between analog and target domain missing a misleading. Therefore, when the analogies are used to describe or explain scientific concepts, it is important that the teacher and the students share the scientific view intended by the analogies.

Within the topics of chemical equilibrium, a well known analogy on dynamic equilibrium is comparison chemical equilibrium situation in a shop where a queue is waiting to be served at a counter. Since the number of people who have been served, and who leave the queue, is compensated for by the number of people who newly join the queue, over a certain period of time, the range of the queue remains constant (Olney, 1988). Harrison and Ono De Jung (2005) used such analogies to enhance student understandings in reversible reactions, reaction rate, and dynamic equilibrium. These analogy models are summarized in Table 2.1

Table 2.1 Analogical models for teaching and learning about chemical equilibrium

Analog (Familiar Situation)	Target (Scientific Concepts)
School dance	Conditions for chemical equilibrium
Up- and down skier	Activated energy, energy in before energy out
Air flight including route details	Reaction mechanism, many steps produce the overall effect
Assembling a model aircraft	Reaction mechanism, many steps, some parallel like assembling two identical wings
Being normal and insane	Physical equilibrium is like being mentally stable
Busy highway	Dynamic nature of equilibrium; rate cars entering equals rate of cars leaving, collision rate is important
Balancing on a see-saw	Physical equilibrium; force multiply by distance balanced on each side

Table 2.1 (Continued)

Analog (Familiar Situation)	Target (Scientific Concepts)
Excess sugar in a teacup	Dynamic nature of equilibrium; cup sealed, rate dissolving equals rate precipitating; process continuous, temperature dependent
Pot of curry (lid in place)	Dynamic nature of equilibrium; amount of water evaporating equals amount condensing; continuous while simmering; sealed pot

Source: Harrison and Ono De Jung (2005: 4)

4.3 Laboratories and Demonstrations

The laboratory-based component is one of crucial characteristic features of many science courses (Altay and Edwards, 1993). Tobin and Garnett (1993) suggest that especially in high school chemistry teaching, demonstration and laboratory work can be effective methods to teach chemistry in meaningful ways, because students have a chance to explain or justify their thinking during learning.

To illustrate the topics of chemical equilibrium, to address the reversibility of chemical reactions, simple chemical experiments may demonstrate that the direction of chemical conversion may be reverse, such as adding on products to a reaction mixture or changing condition of reaction (van Driel, De Vos, Verloop, and Dekkers, 1998). A classical experiment dealing with reversible reactions concern with the system of cobalt (II) tetrachloro and cobalt (II) hexahydrate complexes in isopropanol solution. In this experiment, a cold solution is pink while a warm solution is deep blue (Spears and Spears, 1984). Students can see what happen in the test tube when temperature is changed. Another classical experiment is the reaction of iron (III) thiocyanate complex (Sandell, 1959 cited in van Driel *et al.*, 1998). Many

students appear to be puzzled by the change of reaction condition results in observable change (van Driel *et al.*, 1998). At the same time, asking questions to put forward explanation of results from experiments is important to reach scientific concepts. The type of questions should be involved corpuscular notions. Thus students may accept the notion of incompleteness of chemical reactions as an empirical fact.

5. Summary of Learning and Teaching Chemistry: Relevance to This Study

From the research studies, chemical equilibrium is reported to be a difficult conception for students, at both secondary level and higher level, and for chemistry teachers. They hold widely differing alternative conceptions. The literature review shows that students from different parts of the world seem to hold similar alternative conceptions about chemical equilibrium. However, there is little current information about Thai Grade-11 students' alternative conception related to chemical equilibrium although chemical equilibrium is one of the important concepts in chemistry. Therefore, in particular the study investigates student learning outcomes of chemical equilibrium in Thai Grade-11 in the current educational situation to find out preliminary data for improving teaching and learning about chemical equilibrium concepts. The literature suggests there are teaching strategies for chemical equilibrium concepts which seem to be successful in overcoming students' learning difficult. Those teaching strategies mostly rely on constructivist-based perspectives of teaching and learning, for example, teaching as conceptual change, using analogy or metaphor, or engaging with laboratories or demonstrations as described earlier. Referring back to the National Science Curriculum Standard of Thailand, constructivist-based perspectives of teaching and learning are consistent with the characteristics of learning activities employed in the exemplary learning unit of IPST. It might be implied that constructivist-based perspectives of teaching and learning might be effective in teaching and learning about chemical equilibrium for Thai educational context. However, because of uniqueness of Thai culture which differs from foreign countries, it is of interest to know how to be successful teaching and

learning about chemical equilibrium concepts using a constructivist-based approach would be in Thai educational context. The research questions generated to clarify this argument are as follows.

1. What are Thai high school students' learning outcomes for the topic of chemical equilibrium in the current educational situation in Thai high schools?

1.1 What are Thai high school students' conceptions about chemical equilibrium?

1.2 What are Thai high school students' capabilities of science process skills?

1.3 What are Thai high school students' attitudes toward chemical equilibrium concepts and teaching and learning?

2. How do Thai chemistry teachers implement a constructivist-based learning unit of chemical equilibrium into their classrooms?

3. How do Thai Grade-11 students learn chemical equilibrium concepts during the implementation of this constructivist-based learning unit?

4. What are the Thai Grade-11 student learning outcomes of chemical equilibrium after a constructivist-based learning unit?

4.1 What are Thai Grade-11 students' conceptions about chemical equilibrium?

4.2 What are Thai Grade-11 students' capabilities of science process skills?

4.3 What are Thai Grade-11 students' attitudes toward chemical equilibrium concepts and teaching and learning?

Next chapter, Chapter III, provides the methodology to find out data required for answering those research questions.

CHAPTER III

METHODOLOGY

Overview of the Chapter

Chapter II reports on literature about teaching and learning relying on constructivist-based approaches, especially for chemical equilibrium concepts. Research questions are generated to improve teaching and learning about chemical equilibrium concepts for Thai Grade-11 students. From this broad topic, this research involves two phases of study: an exploratory phase, and the development and the implementation phase.

This chapter describes the research methodology underlying this research study. The study's research methodology is first outlined in terms of philosophical assumptions guiding the research study. This study uses an interpretivist or qualitative approach to inform the design methods. Also described are various methods of data collection and analysis, along with discussion issues of validity and reliability. An overview of the research design relating to the study of teaching and learning chemical equilibrium is then described. Finally, ensuring trustworthiness of data generation, collection, and data analysis for this research study is addressed.

Introduction

In the field of science education research, research studies have moved into new phases which reflect researchers' awareness of the complexity of interactions occurring in teaching and learning (Kelly and Lesh, 2000; White, 2001). These new phases are generally consistent with constructivist-based perspectives, which provide a useful basis for describing the nature of teaching and learning in a given social context. Some questions related to the new cycles of research studies suggested by

White (2001) investigated in the late 1990s and the early 2000s, question what science content a teacher teaches, how classrooms are organized, and how students learn. Consequently, science education research has come to recognize the sociocultural, historical, systematic, cognitive, affective and physiological aspects of teaching and learning, rather than wishing to answer rather simplistic questions such as “Which instructional approach leads to the greatest growth in learning under controlled conditions[?]” (Kelly and Lesh, 2000: 36).

However, considerations about how to research not only depend on trends of doing research, but are also framed by research methodology. Research methodology is the theory of knowledge that provides the underlying thinking behind research methods (Lincoln and Guba, 1985). The aim of methodology is to help a researcher to understand the process of inquiry (Cohen and Manion, 1994). Research methodology also provides the reasons and methods for conducting the research and makes explicit the researcher’s theoretical views and assumptions (Bell, 1993).

Philosophical Assumptions Guiding the Research Methodology

The word research can be defined as “a cumulative endeavor by which bricks of empirical evidence are laid one on top of the other to form a building of knowledge” (Mestre, 2000: 151). Doing research can be said to be a part of an inquiry to study social reality (Cohen, Manion, and Morrison, 2000). One of the purposes of research is to answer the questions using an underpinning theory as a guide for the collection, and subsequent analysis, of data (Bryman, 2001). The way in which research is conducted may be conceived of in terms of the research philosophy or research paradigm (Creswell, 1998).

Paradigms are belief systems based on a set of views or assumptions that guide a process of inquiry. These assumptions are related to the nature of reality (the ontological assumption); the relationship of the researcher to that being researched (the epistemological assumption); and the process of research (the methodological

assumption) (Cohen and Manion, 1994; Lincoln and Guba, 1985). Debate concerning alternative paradigms continues, (Lincoln and Guba, 2000) and in order to unpack the complexity of research paradigms, the basic philosophical assumptions are now described briefly.

Ontological issues concern views of the nature of reality. A traditional ontological belief, known as *objectivism*, is that belief about social reality exists and its reality is knowable as it really is (Bryman, 2001; Cohen and Manion, 1994). In contrast, *subjectivism* asserts that social reality does exist, but different people construct it in various ways (Cohen *et al.*, 2000). Reality, from the latter point of view, is seen as relying on an individual interpretation (Creswell, 1998).

For the epistemological issue, the question is concerned with what should be regarded as acceptable knowledge in a discipline (Bryman, 2001). These concerns are based on the nature and form of knowledge; how it can be acquired, and how it can be communicated to other human beings (Cohen *et al.*, 2000). The relationship between the researcher and situations being researched is thus the question of epistemology. The epistemological of *positivism* affirms the importance of imitating the sciences, in which the methods of natural science are applied to the study of social reality (Bryman, 2001). Alternatively, an approach such as the *anti-positivist, naturalistic approach*, or *interpretivist approach* interprets the social reality in terms of subjective meanings which an individual places upon their action, rather than with the forces that are deemed to act on it (Cohen *et al.*, 2000). Bryman (2001) suggests that taking this approach might lead the researcher to some surprising findings within the particular social context being studied.

In educational research studies, positivism seems to be less favored nowadays because the research studies usually take place in the contexts of classroom and school (Cohen *et al.*, 2000; Kelly and Lesh, 2000). A positivist approach would inevitably ignore the complexity of classroom contexts in terms of the teaching and learning process or human interaction in which the researcher could be challenged.

While an interpretivist approach tends to be idiosyncratic, related to the individual learners, it is useful in the studies of a complex phenomenon such as learning and teaching of science (Tobin, 2000). The next section provides details of an interpretivist-based research approach.

Interpretivist Research and Qualitative Research Approach

Interpretivist research is seen as an umbrella term to describe “the study that endeavors to understand a community in terms of actions and interactions of participants, from their own perspectives” (Tobin, 2000: 487). Interpretivist research shares a constructivist ontology and epistemology. Generally, the construction of knowledge is seen as a social reality, but is seen as actively constructed, rather than built up piece by piece (Bryman, 2001). Interpretivist study concerning social reality requires procedures to make sense how different people interpret the world where they live (Cohen and Manion, 1994). These procedures could be seen as a process of deliberate inquiry to understand a complex, holistic picture in a natural setting (Cohen and Manion, 1994; Creswell, 1998).

Comparing interpretivist research and qualitative research, Denzin and Lincoln (1994) comment that qualitative research is typically multi-method in focus, involving an interpretive, naturalistic approach to its subject matter. This means that the qualitative researcher studies things in their naturally setting; attempting to make sense in terms of how each person understands nature in the world. Qualitative research is thus a fundamentally interpretive process, in which a researcher makes an interpretation of data (Creswell, 1998).

As mentioned above, interpretivist research and qualitative research share some ideas in terms of attempting to understand the world, and rely on interpretive methods of inquiry. In the rest of this chapter, the term interpretivist research and qualitative research are used interchangeably, in that both these terms refer to an

inquiry process of understanding relevance of interpretation through looking closely at interactions in a natural setting and sharing holistic views (see also Merriam, 1998).

A qualitative-based research approach employs an inductive process in the building of data into broad themes to a generalized model or theory (Bryman, 2001; Creswell, 2003). Within an inductive stance, theory is the outcome of research studies. This characteristic of inductive theory is associated with a qualitative approach (Bryman, 2001). However, qualitative studies not only generate theory, but also use theory at the beginning of the studies as a background of investigation. In this way, the theory may appear at the beginning, and be modified or adjusted based on participants' views (Creswell, 2003). Bryman (2001) identifies the process in which a theory will and will not hold as *iterative*, which “involves a weaving back and forth between data and theory” (p. 10). Subsequently, the research process is flexible and perhaps lacks structure, since data gathering and analyzing are ongoing process. The research design associated with a qualitative research approach is considered in the next section.

Research Design Associated with a Qualitative Research Approach

Within a broad qualitative research approach, there are five research designs reported: biography, phenomenological study, grounded theory study, ethnography, and case study (Creswell, 1998). All seem to share similar procedures, in which interpretation and thick descriptive data are involved (Merriam, 1998). However, Creswell (2003) suggests that each design has a diversity of strategies of inquiry, and unique steps in data analysis. Merriam (1998) suggests that each particular research design should be appropriate to the research problem.

In education research, case study is a particularly appealing qualitative design appropriate because of its particular strengths (Merriam, 1998). Research studies in science education especially, employ the case study to investigate particular situations (e.g. Haefner and Altoona, 2004; Taber, 2001; Wallace and Kang, 2004). For example, Taber (2000) suggests that a case study is an appropriate research design to

study teaching and learning science which involves a complex situation, so an in-depth examination is useful for understanding individual learners. Consequently, case study is one research design which will be emphasized in this research study, and this is now described.

1. Case Study: Research Design

1.1 Definitions and Types of Case Study

A case is defined as a bounded system which is a specific, a complex, functioning thing (Stake, 1995). A case study is seen in terms of the process of deliberately carrying out the investigation within a bounded system by focusing an in-depth study of the system, involving multiple sources of information rich in context, relying on a diversity of data collecting methods, and set within a context of a system or natural setting (Creswell, 1998; Merriam, 1998). Thus, a case study is an intensive, holistic description and analysis of a single entity, phenomenon, or social unit (Merriam, 1998). The aim of a case study is to probe deeply, and to analyze intensively (Cohen and Manion, 1994). Indeed, a case study can provide a relationship between ideas and abstract principles to enable the readers to understand how they can fit those things together (Cohen *et al.*, 2000; Denscombe, 1998).

Although a case study can utilize both quantitative and qualitative research designs, there are three major differences between the case study and conventional quantitative research: the distinction between explanation and understanding as the purpose of inquiry; the distinction between a personal and impersonal role for the researcher; and, the distinction between knowledge discovered and knowledge constructed (Stake, 1995). Generally, a case study is considered to be a qualitative research approach, but it can combine a wide range of methods, including quantitative techniques (Bell, 1993). Stake (1995) divides a case study into two areas: intrinsic, and instrumental. Each area focuses on different aspects. The former focuses on a particular case in terms of an intrinsic interest, for example, a

researcher is curious to know what happens when a particular teacher works with a student having learning difficulties. In contrast, the latter focuses on more specific than intrinsic interest, for example, an emphasis on the effect of marking on student learning difficulties. A researcher might investigate how the teacher marks student work and whether or not it affects learning difficulties. However, the distinction between intrinsic and instrumental case study is not used to sort each study into those categories, but an understanding between those is used for choosing methods of data collection and analysis (Merriam, 1998; Stake, 1995).

1.2 Selection of Cases

A case study is a broad term, which has been used for guiding research methods (Bell, 1993). The strategies to conduct case study research depend upon the nature of the research problem or the questions being asked, the willingness to understand a process rather than an outcome, and the emphasis on uniqueness (Merriam, 1998). Research questions, or at least intellectual curiosities, are considered to be the starting point for making decisions about what methods should be employed for gathering, analyzing, and interpreting information (Janesick, 2003). Typically, the type of research question concerning ‘what’, ‘why’, and ‘how’ are seen as having a distinct advantage within a case study research (Yin, 1994).

In conducting case study research, Creswell (1998) recommends that investigators first consider what type of case study is most promising and useful. The selection of a case is important because a case study focuses on a few instances of particular phenomena with a view to providing an in-depth account of events, relationships, experiences or processes occurring in that particular instance (Denscombe, 1998). In choosing what case to study, purposeful sampling is appropriate (Bell, 1993; Merriam, 1998; Stake, 1995). The characteristics of a selected case should be familiar to a researcher and information rich in nature (Creswell, 1998).

1.3 Strengths and Limitations of Case Study

The great strength of the case study method is that it allows the researcher to concentrate on a specific instance or situation and to identify the various interactive processes at work (Bell, 1993). Case study is the best plan for answering the research questions because it offers a means of investigating complex social units consisting of multiple variables of potential importance in understanding the phenomenon (Merriam, 1998). It provides a unique example of real people in real situations, enabling readers to understand ideas more clearly than simply by presenting them with abstract theories or principles (Cohen *et al.*, 2000). Anchored in real-life situations, a case study provides a rich and holistic account of a phenomenon. It offers insights and illuminates meanings that expand its reader's experiences. These insights can be constructed as tentative hypotheses that help structure future research (Merriam, 1998).

One of the limitations of a case study is the generally weak basis for generalization, also referred to as external validity. Stake (1995) claims that the results from a single case cannot reasonably be generalized to the wider population. To address this limitation, multi-case studies and in-depth description should be employed. Merriam (1998) suggests that the case selected could be more than one case also called a collective case study or multi-case study (see also Stake, 1995). Coll and Chapman (2000) also suggest that the so-called 'thick description' which describes the context of the study should be provided for the reader to decide if the findings are suitable with their own situation or not (see also Merriam, 1998).

2. Strategies for Collecting Data of a Qualitative Research Approach

Appropriate methods for the collection of data are selected when they provide the data required to solve the research problem or answer the research question (Bell, 1993). The data collection in qualitative research approach is extensive, drawing on multiple sources of information such as observations, interviews, and documents

(Creswell, 1998). As mentioned above, although case study is considered to be a qualitative research approach, it sometimes uses quantitative techniques such as questionnaires to collect the data (Bell, 1993). This section briefly describes techniques for data collection in terms of interviews, observations, and documents.

2.1 Interviews

The main purpose of an interviewing is to obtain special kinds of information in someone else's mind (Merriam, 1998; Patton, 1990). Gathering information includes obtaining feelings, individuals' interpretation of the world and of interesting past events which are impossible to replicate (Merriam, 1998). Interviewing is considered to be one of the best techniques for conducting intensive case studies of a few selected individuals (Cohen *et al.*, 2000; Merriam, 1998). The interview technique allows the researcher to gather greater in-depth data than most other methods of data collection (Lincoln and Guba, 1985). This technique enables participants to describe their interpretations of the world around them, and express their ideas from their point of view (Cohen *et al.*, 2000). The most common form of interviewing is the conversation, the person-to-person encounter, with the purpose to elicit and record information (Lincoln and Guba, 1985; Merriam, 1998).

In a qualitative research approach, the interview types range on a continuum that is based on the structure of an interview: from highly structured to unstructured (Merriam, 1998). There are three most common approaches: the standardized or structured interview; the general interview guide approach or semi-structured interview; and the informal conversational or unstructured interview (Erickson, 1998; Merriam, 1998; Patton, 1990).

The standardized or structured interview consists of a set of question which like is an oral form of a written questionnaire (Merriam, 1998; Patton, 1990). The questions being asked are carefully worded. All respondents are asked the same questions with essentially the same words, and in the same sequence (Patton, 1990).

Thus, variation from employment of several interviewers is minimized (Coll and Chapman, 2000). Since the structured interview is highly focused, time also is minimized. Thus, the structured interview is particularly appropriate when a large number of respondents are interviewed about the same topics (Patton, 1990). In a qualitative research approach, structured interview is employed when researchers aim to gather a particular state or a particular concept or term such as incomes, history of employment, level of education, and so on (Merriam, 1998).

The other type of an interview, the general interview guide approach or semi-structured interview, is more flexible in wording. This kind of interview mixes more and less structured questions together (Merriam, 1998). The semi-structured interviews consist of an outline of a set of issues being explored. The outline contains a question, but is more flexible than the structured interview. The interviewer, thus, needs to use their skills to adapt both wording and sequence of questions to be appropriate for the context of the actual interview (Patton, 1990). The interviewer uses the interview guide as a checklist to ensure that all of the questions being asked cover all topics of interests. Guba and Lincoln (1981) suggest that an interview technique in qualitative research approach should be more open-ended and less structured than structured interview, semi-structured interview seems to be an appropriate technique because it allows the researcher to participate in the interview situation, to respond to the emerging worldview of the responder, and to new ideas on the topic (See also, Merriam, 1998).

The informal conversational or unstructured interview is the most flexible in which the generation questions are raised from the natural flow of interaction (Coll and Chapman, 2000). It is not necessary that all participants are asked the same questions and in the same sequence. The interview questions could be changed or built up at any time depending on the conversational flow (Patton, 1990). Thus, the researcher needs to be skillful to drive naturally flowing conversation during the interview. This kind of interview is particularly useful when the researcher does not know enough about a phenomenon to ask relevant questions (Merriam, 1998).The

unstructured interview is commonly used in combination with participant observations in the early stages of a case study (Lincoln and Guba, 1985; Merriam, 1998). The main advantage of unstructured interview is the gathering of in-depth data (Lincoln and Guba, 1985). However, personal bias, subjectivity, and time, are issues that the researcher needs to address (Cohen *et al.*, 2000).

In a qualitative research approach, interviewing is often the major technique for gathering in-depth data. Thus, questions being asked are regarded as the heart of the interview (Merriam, 1998). The questions must be good questions, easily understandable, familiar to the responder, open-ended, and singular (Patton, 1990). The semi-structured interview is probably the most common technique used in qualitative research (Merriam, 1998). Follow-up and probing questions are an important part of interviewing process. The best way to increase skills of asking probing questions is practice. The more the researcher conducts interviews, the better the researcher can pursue potentially fruitful lines of inquiry (Merriam, 1998).

2.2 Observations

Observations are another major means of collecting data in a qualitative research approach (Merriam, 1998). The purpose of observation is to describe the activities that took place in the situation being studied (Patton, 1990). It is impossible for an observer to collect everything happening in a situation being studied (Merriam, 1998). What is appropriate to be observed depends on several factors, in which the most important determining factor is the research purposes which have been generated before going to the situation.

The differences between observation and interview are twofold. Firstly, observation takes place in the natural field setting instead of a location designated for the purpose of interviewing. Secondly, data from observation is seen as a firsthand encounter of the phenomena of interest, while that from interviews is seen as a secondhand account of the world (Merriam, 1998). Thus, observational data from

what people do may be more reliable than what people say in the interviews (see detail below) (Bell, 1993).

Although observations are a major means of collecting data in qualitative research (Merriam, 1998), there are some limitations in using the technique. Patton (1990) notes that observational data are limited, that they focus only on external behavior. The observer cannot see what is happening 'inside' participants. Another limitation of observations is bias, especially during participant observation (Bell, 1993).

Doing observation as research technique is not easy (Bell, 1993). Research observation differs to everyday observation, which is unconscious and non-systematic. Research observation requires formulation of research purposes: deliberate planning; systematic recording; and, checking and controlling validity and reliability (Merriam, 1998). Observation is criticized as being subjective and biased since it directly depends on an interpretation of an observer (Bell, 1993; Stake, 1995). Whatever happens in the same situations, different people may interpret it in various ways. Subsequently, research observation methods require disciplined training and rigorous preparation (Patton, 1990). Training includes learning how to write descriptively; practicing the disciplined recording of field notes; knowing how to separate detail from trivia; and the use of rigorous methods to validate observations. The role of researcher during observation is to be as unobtrusive as possible, so that observed behavior is as close to being natural as possible (Bell, 1993).

Observation can be employed in both quantitative and qualitative research approaches (Stake, 1995). Quantitative research seeks to develop aggregation of coded data leading to substantiated co-variation, while qualitative research with episodes of unique relationships seeks to fashion a story or unique description of the natural situation. The quantitative approach involves many repeated observations of situations for a representative coverage of the relationships for this particular situation, while the qualitative approach involves finding good 'moments' to reveal

the unique complexity of the situation (Stake, 1995). Most observations in a qualitative research approach are unstructured. The researchers observe events, situations, and behaviors without precise aims or checklists or charts, and then they write up their observations as soon as possible (Bell, 1993). In the case study especially, the researcher tries to keep good records of events, focused on categories or key events, and attentive to background conditions (Stake, 1995).

In a qualitative research approach, methods of an observation represent a continuum: from participant to non-participant observation (Bell, 1993; Lincoln and Guba, 1985). In participant, the observer is fully engaged in the situation being investigated. The researcher is a member of a group, and tries to really understand the insider's views of what is happening in that situation (Patton, 1990). In non-participant or complete observation, in contrast, the role of researcher is perhaps the case of the researcher sitting at the back of the classroom, recording the verbal exchanges between the teacher and students (Cohen *et al.*, 2000).

The process of collecting data from observations can be distinguished into three stages: entry, data collection, and exit (Merriam, 1998). To enter on to a site, the researcher has to ask permission from gatekeepers. Establishing rapport with the situation being investigated is the next step of entry (Merriam, 1998). Serious data collection starts after the researcher's becoming familiar with participants and situation.

Data obtained from observations can include both oral and visual data (Cohen *et al.*, 2000). Techniques employed in observations involve the use of videotape, audiotape, and field notes (Cohen *et al.*, 2000; Merriam, 1998). Audio-visual data collection can record both oral and visual data. It has a capacity for completeness of analysis and comprehensiveness of materials (Cohen *et al.*, 2000). Field notes are raw written data. To allow the researcher to find the desired information easily, whatever is being written down needs to be in a format, which has

many forms but at the least includes descriptions, direct quotations, and observer commentary (Merriam, 1998).

2.3 Documents

Document review is another unobtrusive method of data collection used in a qualitative research (Lincoln and Guba, 1985; Marshall and Rossman, 1995). It can be conducted without disturbing the natural setting (Marshall and Rossman, 1995). The term 'document' is an umbrella term referring to a variety of written, visual, and physical material used to develop understanding of the situation being studied (Merriam, 1998). Documents can be divided into three major types: public records, personal documents, and physical materials (Merriam, 1998).

Documentary data is a stable source of information (Lincoln and Guba, 1985), and Merriam (1998) suggests that this kind of data is particularly appropriate in case study research. The data accurately reflects some situations that have occurred in the past. Such data represent the situations at that time, and do not change, thus, it can ground an investigation in the context of the problems being studied.

However, some problems of using documentary data are concerned with determination of data authenticity and accuracy (Merriam, 1998; Patton, 1990). Documents are not produced for research purposes, and some information contained in them might not be in a form that is useful or understandable to the researcher. They also may be incomplete or inaccurate. Consequently, Lincoln and Guba (1985) suggest that the researcher should carefully choose documents to be used as a source of data. The selection of each document is generated from the determination by the researcher whether or not those documents contain information relevant to the research questions. Generally, documents beneficial to qualitative classroom instructional research are documents such as teacher's lesson plans, students assignments, objects in the classroom, official grade reports and school records, teacher evaluations, and so on (Merriam, 1998).

3. Data Analysis for a Qualitative Research Approach

Qualitative data analysis cannot be excluded from the qualitative research process as a whole, with its assumptions about the nature of reality, knowledge, methods, and social and education life. The beginning of data analysis starts as one is negotiating entry to the field of study. It often continues in re-study after supposedly 'final' reports are written (Erickson, 1998). Generally, the process of data collection and analysis is a simultaneous process in qualitative research (Miles and Huberman, 1994). The qualitative research approach is not only concerned with the qualitative data (field notes, or documents), but, on some occasions, it also involves quantitative data (Schensul, Schensul, and LeCompte, 1999). Thus, in this section, two kinds of analysis data in a qualitative research approach; quantitative and qualitative, are described.

3.1 Analysis of Quantitative Data

Quantitative data might be generated from using surveys or questionnaires as an instrument for gathering data (Schensul *et al.*, 1999). The strategy of quantitative data analysis is more systematic than that of qualitative data analysis. The quantitative data analysis follows the guidelines set by the formative theoretical model and the conceptual taxonomy of domains, factors, and variables. Schensul *et al.* (1999) suggests that the first step requires the production of frequencies for each of the variables in the study. Some computer programs such as SPSS or SAS may be employed to help the researcher in the process of analysis. Qualitative data already collected could be employed to help the researcher to interpret the meaning of those variables in the final step.

3.2 Analysis of Qualitative Data

By using multiple sources of information, interviews, observations, and documents, the researcher is faced with a huge array of texts from field notes,

recordings, and documents. Each source of data has strengths and weaknesses. Viewing data in the context and emphasis on relationship of an interdependence of data is important rather than isolating variables (Patton, 1990). The forms of data are usually words and sometimes visual representations rather than numbers. An analysis of data generated in a qualitative research approach is to understand the qualities or essences of a phenomenon by focusing on the meanings of events and phenomena and the social events that transform these meanings (Behrens and Smith, 1996). For example, case study research is an intensive, holistic description and analysis of a single, bounded system. The goal of data analysis in a case study then is to link the empirical data to the fact that has been derived from interviews, observations, and documents (Merriam, 1998).

Data analysis consists of three concurrent flows of activity: data reduction, data display, and conclusion drawing/verification (Miles and Huberman, 1994). Data reduction refers to the process of selecting, focusing, simplifying, abstracting, and transforming the data that appear in written-up field notes or transcriptions. Information from the original data is discarded in the process of foregrounding the features of interest (Lemke, 1998). There are many ways to reduce and transform qualitative data such as through selection, through summary or paraphrase, through being subsumed in a larger pattern. Miles and Huberman (1994) advise that a good analytical strategy should keep the numbers and the words that the researcher used to derive the numbers together. It is also important to keep the data within the context being studied.

Data display involves selection of techniques used to present the story to a reader. The techniques of data display may be: extended text, using matrices, graphs, charts, or networks (Miles and Huberman, 1994). The most useful technique depends on the decision of the analyst, whether they can see what is happening and if they can draw justified conclusions. Data display then serves the purpose of presentation and interpretation (Miles and Huberman, 1994).

4. Establishing the Trustworthiness of a Qualitative Research Approach

The basic issue which directly relates to the trustworthiness of a qualitative research study is emphasis on the quality of a qualitative inquiry. As Lincoln and Guba (1985) state: “The basic issue in relation to trustworthiness is simple: How can an inquirer persuade his or her audiences that the findings of an inquiry are worth paying attention to, worth taking account of?” (p. 290). Lincoln and Guba (1985) suggest adopting criteria for determining a trustworthiness of qualitative research containing four aspects: credibility, transferability, dependability, and confirmability.

4.1 Credibility or Internal Validity

Credibility is compared to the positivist term *internal validity* which is used to describe a quality of a research study (Lincoln and Guba, 1985; Moschkovich and Brenner, 2000). Credibility addresses the question: “How can one establish confidence in the ‘truth’ of the findings of a particular inquiry for the subjects (respondents) with which and the context in which inquiry was carried out?” (Lincoln and Guba, 1985: 290).

4.2 Transferability or External Validity

Transferability is like *external validity* within a positivist paradigm (Lincoln and Guba, 1985; Moschkovich and Brenner, 2000). The purpose of external validity is that the findings of one study could be able to be applied to another situation, in which case it is termed generalizability (Lemke, 1998). However, within qualitative research study, the term transferability is more appropriate than generalization because there is a weakness of generalizing qualitative findings to other populations, settings, or situations (Marshall and Rossman, 1995). Generalization can in principle at least apply to all contexts within the same population, while an application of transferability depends on the degree of similarity between the context of research study and the context of audiences (Lincoln and Guba, 1985).

4.3 Dependability or Reliability

The third construct is *dependability*, similar to the positivist term *reliability*, which is concerned with the stability, consistency, and predictability of findings (Lincoln and Guba, 1985). Referring back to the belief of the nature of reality, within positivist research study in which reality is seen as ‘tangible’ and unchanged, reliability is typically demonstrated by replication within similar inquiry processes and under similar conditions. However, interpretivist research recognizes the “ephemeral and changing” nature of education research (Lincoln and Guba, 1985: 299). Dependability, thus means taking into account the changing conditions in the phenomenon chosen for study as well as changes in the design created by increasingly refined understanding of the setting (Marshall and Rossman, 1995).

4.3 Confirmability or Objectivity

Finally, *confirmability* is similar to the positivist notion of *objectivity*, which exists when a result of a study and reality are isomorphic; an appropriate methodology is employed; and, a process of inquiry is value-free (Lincoln and Guba, 1985). What is seen as objectivity emphasizes a characteristic of a researcher, while confirmability has moved to be concerned with the data themselves (Lincoln and Guba, 1985; Marshall and Rossman, 1995). Thus, the criterion of confirmability addresses the question: “Do the data help confirm the general findings and lead to the implications?” (Marshall and Rossman, 1995: 145). The aim of confirmability is to ensure that the findings are not influenced by the researcher’s bias, when they attempt to immerse themselves in a field of a study (Moschkovich and Brenner, 2000).

Several techniques are employed to establish trustworthiness in qualitative studies. These involve using multi-methods of data collection and member-checking for establishing credibility; describing in-depth and using multi-cases for establishing transferability; building an audit trail and keeping a reflective journal for establishing

dependability confirmability (Lincoln and Guba, 1985; Merriam, 1998; Moschkovich and Brenner, 2000; Patton, 1990). All of their ideas are embedded in the use of the following techniques: prolonged engagement and persistent observation, triangulation, member-checking, in-depth description, peer review and debriefing, and external audits.

Prolonged engagement and persistent observation are regarded as techniques to enhance credibility (Lincoln and Guba, 1985). Prolonged engagement is concerned with an investment of enough time to reach certain purposes. Persistent observation is concerned with an identification of relevant events in the situation being studied, and a focus on those in detail. They relate to building trust with participants, learning the culture, and checking for misinformation that stems from distortions in which the investigator spends enough time in the context to eliminate or control distortions in the data that might occur because of unusual or atypical events, including the presence of the investigator (Creswell, 1998; Lincoln and Guba, 1985).

Triangulation is “one important way to strengthen a study design” (Patton, 1990: 187). Triangulation involves a combination of methods of data gathering from a different source of information to study some aspect of human beings (Cohen *et al.*, 2000; Coll and Chapman, 2000). Patton (1990) suggests that in triangulation, the researchers use multiple and different sources, methods, investigators, and theories including both quantitative and qualitative approaches. Triangulation could be considered to be a technique for enhancing credibility in terms of convergence of themes, patterns and ideas from variety of data sources (Lincoln and Guba, 1985; Patton, 1990).

Member checking is considered to be “the most crucial technique for enhancing credibility” (Lincoln and Guba, 1985: 314). The process of member checking involves taking raw, analyzed, or interpretive data back to the participants and asking whether an accurate description of their views has been written in order to provide the participants a chance to check the accuracy of findings (Creswell, 1998).

To enhance credibility of research findings, participants' feedback should be emphasized (Cohen *et al.*, 2000). Especially in case study research, as Stake (1995) suggests, participants should "play a major role directing as well as acting in case study" (p. 115). They should be asked to check rough drafts of the researcher's writing to provide their agreement about those data.

An in-depth description is a technique to enhance transferability (Lincoln and Guba, 1985). This technique is a strength of the qualitative research study because it provides an interaction with the complexities of events in a situation being studied (Bryman, 2001; Marshall and Rossman, 1995). Thick and in-depth description allows an audience to make a decision about transferability (Coll and Chapman, 2000). As Merriam (1998) suggests, rich and thick description provides enough explanation of a situation so that an audience could be able to compare the degree of similarity between a research study situation and their own situation, to determine whether the research findings could be transferred.

Multi-case study is another technique used to enhance transferability within case study research (Denscombe, 1998; Merriam, 1998). This type of study involves collecting and analyzing data from several cases and can be distinguished from the single case study that may have sub-units or sub-cases embedded within, such as students within a school (Merriam, 1998). The selected cases should show different perspectives on problems, processes, or events in which those cases might be relying on ordinary, accessible, or unusual cases (Creswell, 1998). The more cases included in a study, and the greater the variation across the cases, the more compelling the interpretation is likely to be (Merriam, 1998).

Peer review and debriefing is a technique useful in enhancing creditability in which an external check of the research process is provided, quite similar to reliability in quantitative research (Creswell, 1998). Lincoln and Guba (1985) define the role of the peer debriefer as a devil's advocate, an individual who keeps the researcher honest; asks difficult questions about methodological design; and provides the

researcher with opportunities for catharsis by listening to the researcher's feelings or assisting to devise coping strategies. The task of the debriefer is to be confident that the researcher is as fully aware of their inquiry process as possible.

The audit process is considered as enhancing confirmability, dependability, and providing credibility in terms of external checking on each step of an inquiry (Coll and Chapman, 2000; Lincoln and Guba, 1985). This process includes internal and external audits (Lincoln and Guba, 1985). An internal audit involves the researcher's explanation of methods of data collection and analysis, and assumptions and theory underpinning the research study (Merriam, 1998). An external audit allows an external person, such as a consultant or an auditor, to assess both process and product of inquiry (Creswell, 1998).

Methodology and Research Design for This Study

The methodology of this research is an interpretivist-based research approach, in which the researcher would like to understand an existing situation in order to develop, in specific detail and in depth, a learning unit for teaching and learning chemical equilibrium in Thai Grade 11 classrooms. Then, this research study is divided into two phases: an exploratory phase, and the development and implementation of learning unit phase (Figure 3.1). The foundation of interpretivist-based approach for this study is the case study approach with an emphasis on qualitiveness, subjectivity, and a variety of data gathering techniques. The interpretation of the researcher is important in this study. In order to understand the situation more clearly, a multi-case study has been employed.

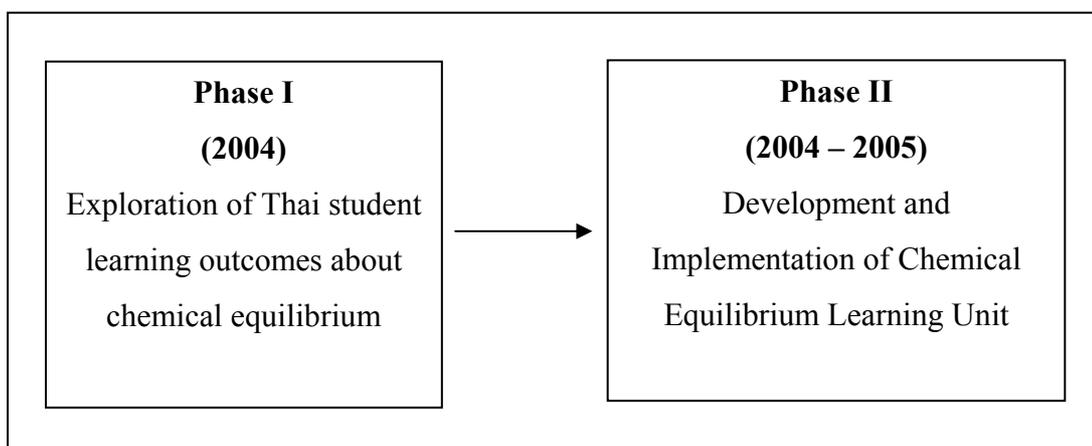


Figure 3.1 Research Phase Diagram

Phase I: An Exploratory Phase

1. Research Design

The first phase sought to identify Thai student learning outcomes in terms of understanding conceptions, science process skills, and attitudes toward chemical equilibrium concepts and teaching and learning. It was undertaken in February 2005 (Thai 2004 academic year), three chemistry teachers from three schools who teach chemical equilibrium concepts in high school level and 125 high school students from three schools in the Chanthaburi Province participated in this study. Then, in February 2005, 125 high school students who learnt chemical equilibrium concepts with those teachers were asked to complete a Chemical equilibrium concepts and Science Process Skills Survey and Questionnaire on Students' Attitudes toward Chemical Equilibrium Concepts and Teaching and Learning. At the same time, a literature review of teaching and learning about chemical equilibrium concepts and related concept was conducted in order to formulate guiding principles for the development of the Chemical Equilibrium Learning Unit (CELU). Informal interviews between each teacher and the researcher about their teaching of chemical equilibrium concepts in Thai 2004 academic year were afterward conducted for gathering data about

teaching and learning in the current situation to become fundamental data for developing the CELU.

2. Participants

In the first phase, 125 upper secondary students (93 girls and 32 boys) from three schools were involved in the administration of the Chemical Equilibrium Concepts and Science Process Skills Survey and Questionnaire on Students' Attitude toward Chemical Equilibrium Concepts and Teaching and Learning. All the students were selected because they had learnt the chemical equilibrium concepts with the teachers who volunteered for the research study. Table 3.1 shows the details of the students in each school.

Table 3.1 The students' information in Thai 2004 Academic Year

School	Year Level	Number of Students (Gender Numbers*)	Grade Interval (Average GPA)	Age Intervals
School A	Grade 12	46 (43F*, 3M*)	2.00 – 4.00 (2.83)	17 - 18
School B	Grade 12	44 (26F*, 18M*)	2.73 – 4.00 (3.60)	17 - 18
School C	Grade 11	35 (24F*, 11M*)	1.90 – 4.00 (2.82)	16 - 17

* F = Female, M = Male

3. Research Instrument

The aim of an exploratory phase was to identify Thai high school students learning outcomes in terms of understanding conceptions, science process skills, and attitude toward chemical equilibrium concepts and teaching and learning about chemical equilibrium. Data were gathered through using Chemical Equilibrium

Concepts and Science Process Skills Survey, the Questionnaire on Students' Attitude toward Chemical Equilibrium Concepts and Teaching and Learning.

3.1 Chemical Equilibrium Concepts and Science Process Skills Survey

Chemical Equilibrium Concepts and Science Process Skills Survey is a diagnostic test consisting of seventeen opened-ended questions. This survey is divided into two parts: chemical equilibrium concepts, and science process skills. The questions asked in the first part are related to the five main topics of chemical equilibrium: changes to achieve equilibrium, equilibrium in chemical reaction, equilibrium constant, factors affecting equilibrium condition and Le Châtelier's principle, and chemical equilibrium in living things and in industrial application.

In the second part, the questions asked were related to science process skills: identifying and controlling variables; interpreting data; formulating hypotheses; investigating and measuring operational definitions; and experimenting. Identification and control of variables is a skill which involves the use of experimental and control circumstances, standardizing procedures and repeating measurements. Interpretation of data refers to the intrinsic ability to recognize patterns and associations within bodies of data. Communication is a basic process required to interpret data. The nature of formulating hypothesis is to recognize that objectively gathered observations are justified into an explanation as a result of having an operational worldview. Hypotheses are seen to be current explanations based on linking of observations. An investigation and measurement of operational definitions is one that is made in measurable or observable terms. The meaning of the defined terms must be explicit, and limited to the parameters established for the definition. Experimentation is a systematic approach to solve a problem. Usually experimenting consists of five basic steps of the scientific process: identify problem; generate hypothesis or prediction; design the method to test hypothesis and collect data; analysis of data; conclusion and communication.

The steps of development the Chemical Equilibrium Concepts and Science Process Skills Survey were:

1. Analysis of learning outcomes of chemical equilibrium concepts from the IPST Science Curriculum Standards;
2. Study of related research in chemical equilibrium concepts and other literature used for developing survey items;
3. Consultation with four science educators (two from the Department of Education, Faculty of Education, Kasetsart University, two from CSTER, the University of Waikato, NZ) and one chemistry teacher at the Department of Chemistry, Faculty of Science, Kasetsart University;
4. Revision of the survey items after receiving feedback and suggestions;
5. Checking the validity of the survey by two experts (one from the Faculty of Science, Mahidol University, and one from Kasetsart University Laboratory School);
6. Second revision of survey items and piloting of the survey with high school students to establish face validity of the survey and to make sure that the survey would be sufficient and appropriate in terms of number of items and time needed for survey completion.

3.2 Questionnaire on Students' Attitudes toward Chemical Equilibrium Concepts and Teaching and Learning

The Questionnaire on Students' Attitudes toward Chemical Equilibrium Concepts and Teaching and Learning contains two main parts: responder's information, and rating scales for 30 items. It was modified from questionnaires from the literature relating to the study of attitude toward science, for example, the Questionnaire on Chemistry-Related Attitudes (QOCRA) (Wong, Young, and Fraser, 1997), the Attitude toward Science Scale (Francis and Greer, 1999), the Attitude toward Chemistry Questionnaire (Salta and Tzougraki, 2004). The modification of each item sometimes consisted of the replacement of the word 'science' or 'chemistry' with 'chemical equilibrium'.

In this study, the term attitudes toward chemical equilibrium concepts and teaching and learning refers to the concept which represents the emotional orientation of students to make evaluative judgments about the chemical equilibrium concepts and their chemical equilibrium course. In particular, it was intended to investigate student attitudes regarding difficulty of chemical equilibrium concepts, usefulness of chemical equilibrium concepts, interest in learning chemical equilibrium concepts, and preference of teaching chemical equilibrium concepts.

The questionnaire was developed by the following steps:

1. Define students' attitude toward chemical equilibrium concepts and teaching and learning;
2. Develop rating scales items aligned with definitions from the literature;

3. Consult science educators to discover validity and reliability of the questionnaire items;
4. Revise rating scale items to be consistent with science educators' feedback and suggestions;
5. Pilot constructed questionnaire to check the time taken to complete the questionnaire, and to check the appropriateness of each question.

4. Strategies for Collecting Data

One hundred and twenty high school students from three schools were asked to complete the Chemical Equilibrium Concepts and Science Process Skills, and Questionnaire on Students' Attitude toward Chemical Equilibrium Concepts and Teaching and Learning after completing teaching and learning chemical equilibrium concepts in their schools. The participating teacher from each school informed students to prepare themselves for two weeks before administering the survey and the questionnaire.

5. Data Analysis

The students' answers from the Chemical Equilibrium Concepts and Science Process Skills Survey were analyzed in both quantitative and qualitative terms. Quantitative data analysis involved using frequencies to present students' understanding in each topic of chemical equilibrium and students' science process skills. For qualitative data analysis, the researcher had read through students' answers in the survey. Then, students' answers were interpreted and categorized into each scheme. Before conducting the categorization of student answers, the researcher pre-analyzed answers from one school. Validity of the coding was done by the panel of science educators and a chemistry expert as described above.

5.1 Students' Conceptions about Chemical Equilibrium

In terms of students' conception about chemical equilibrium, coding items were designed to diagnose and to categorize students' conceptions in terms of the degree of understanding: sound understanding, partial understanding, partial understanding with specific misconception, specific misconception, and no understanding (Haidar, 1997). The details of each type of conception are shown below.

Sound understanding (SU) means that the student's answer includes all components of the valid answer which are consistent with scientific conception.

Partial understanding (PU) means that the student's answer indicates that there is at least one component consistent with scientific conception.

Partial understanding with specific misconception (PU and MU) means that student shows understanding of the concept, but also makes a statement which demonstrates a misunderstanding;

Specific misconception (MU) means that the student's answer is not consistent with scientific conceptions.

No understanding (NU) means that the student does not write any answer or student repeats the question, or gives irrelevant or unclear answers.

5.2 Students' Capabilities of Science Process Skills

In terms of student capabilities of science process skills, student answers were placed into five categories: Type A, Type B, Type C, Type D, and Type E (Germann, Aram, and Burke, 1996).

Type A means responses are consistent with the expected response.

Type B means incomplete responses that imply the correct response.

Type C means responses that give no specific detail. These responses might be generalized, incomplete, vague, or ambiguous.

Type D means that responses make no mention of the desired answer.

Type E means that student does not answer at all.

These types of student answer were transformed by grouping Type A and Type B together as successful, and grouping Type C, Type D, and Type E as unsuccessful attempts (Germann, Aram, and Burke, 1996).

5.3 Students' Attitudes toward Chemical Equilibrium Concepts and Teaching and Learning

The data from the Questionnaire on Students' Attitudes toward Chemical Equilibrium Concepts and Teaching and Learning was analyzed following a Likert-Scale rating scale, consisting of five scores. Descriptive statistics means were employed to help the researcher describe the variables and interpret the meaning of variables presented in numerical data. Students' scores were categorized into five levels as described below.

High positive attitude means that student scores range from 4.50 to 5.00.

Positive attitude means that student scores range from 3.50 to 4.49.

Moderate means that student scores range from 2.50 to 3.49.

Negative attitude means that student scores range from 1.50 to 2.49

High negative attitude means that student scores range from 1.00 – 1.49.

Phase II: Development and Implementation of the Learning Unit Phase

1. Research Design

The second phase sought to develop learning units for chemical equilibrium, using a constructivist-based teaching approach to enhance students' understanding of the concept of chemical equilibrium and subsequently to study the effects of the unit on students' learning outcomes. It was undertaken during the 2004-2005 Thai academic year with three teachers from three schools in Chanthaburi Province. The process of the development of the chemical equilibrium learning units was undertaken after February 2005. Before implementing the learning unit, an initial workshop for the researcher, supervisors, and participating teachers was set to arrive at a consensus for implementing the learning unit. Then, the learning unit was implemented by those three teachers between December 2005 and February 2006. During implementation, semi-structured interviews, meetings, and classroom observations were employed to gather data. As in the first phase, 148 students were asked to complete the Chemical Equilibrium Concepts and Science Process Skills Survey and Questionnaire on Students' Attitudes toward Chemical Equilibrium Concepts and Teaching and Learning by the end of February 2006, both of which were purpose-designed for this inquiry (see below).

2. Participants

Phase II employed a purposeful sampling strategy to select the cases being studied. The basis for case selection was that the selected cases are information rich, and familiar to the researcher. The contexts of the cases also emphasized understanding of the uniqueness of each case. Within this research study, the key players in each case were the teacher, the students, and the researcher. The nature of the sampling process is discussed below.

2.1 The Teachers

Three chemistry teachers who teach chemical equilibrium concepts at Grade 11 from three schools in Chanthaburi Province were involved in the second phase of this study. One of them, Miss Patcharee, also has a responsibility in chemistry and science in lower secondary level. She also had responsibility involving working for school academic affairs. The other two, Mrs. Malinee and Miss Waleerat, also have responsibility for teaching science at lower secondary level. All three teachers have many years experience teaching chemistry. Table 3.2 shows details of the background experience of each teacher.

Table 3.2 Teacher background and experience

Teacher*	Academic Background	Teaching Experience	Teaching Responsibility 2005 Academic Year
Mrs. Malinee	Bachelor Degree in Secondary Education (chemistry)	14 years	Teaching Science at Grade 8, and Chemistry at Grade 11
Miss Waleerat	Master Degree in Education (science teaching)	8 years	Teaching Science at Grade 7, and Chemistry at Grade 11
Miss Patcharee	Bachelor Degree in Education (chemistry)	9 years	Teaching Science at Grade 7 and Grade 9, and Chemistry at Grade 11

Teacher* – pseudonym of each teacher

2.2 The Students

In the second phase, 148 students from the three schools in Chanthaburi Province were involved in the research. Two schools which are School A and C participated continuously in the study. School B was not able to participate in the research study because chemical equilibrium concepts was taught at a different time from the other schools. Another school started to participate in the study only in the second phase. The students from three schools were observed during teaching and learning chemical equilibrium concepts from December 2005 to February 2006. Then, at the end of February 2006, all of the students were involved in the administration of the Chemical Equilibrium Concepts and Science Process Skills Survey and Questionnaire on Students' Attitude toward Chemical Equilibrium Concepts and Teaching and Learning. Student information is detailed in Table 3.3.

Table 3.3 The participating students' information in Thai 2005 Academic Year

School	Year Level	Number of Students (Gender Numbers*)	Grade Interval	Ages Intervals 28/02/2006
School A	Grade 11	48 (48F*)	3.89 – 4.00	15 - 17
School B**	Grade 11	45 (32F*, 15M*)	2.23 – 4.00	15 – 17
School C	Grade 11	55 (32F*, 23M*)	1.73 – 3.96	15 - 17

* F = Female, M = Male

** School B in the second phase was not the same school as the first phase

2.3 The Role of Researcher

Since qualitative research is interpretative research, it is important for the researcher to identify their biases, values, and personal interests about the research topic and process (Creswell, 2003). In this section, the beliefs and views of the researcher are described.

The researcher believes that chemical equilibrium concepts are important for secondary school students. They also are a fundamental for further the study of chemistry at the tertiary level. The researcher has been involved in teaching and learning chemical equilibrium since the 2002 academic year. The researcher had a chance to observe one classroom in Kasertsart University Laboratory. Then, in the 2003 academic year, the researcher observed the teaching and learning chemical equilibrium in another three schools in Chanthaburi Province. These experiences assisted the researcher to employ observation techniques with credibility and confidence.

3. Research Instruments

There were three types of research instrument in Phase II. These were Chemical Equilibrium Learning Unit (CELU) which was an intervention for teaching and learning about chemical equilibrium; initial workshop and teacher meetings; and survey and questionnaire instruments to find out students' learning outcomes. Details of those research instruments were described below.

3.1 Chemical Equilibrium Learning Unit (CELU)

Chemical Equilibrium Learning Unit (CELU) is an intervention for teaching and learning to promote student learning outcomes for chemical equilibrium. It is a package of lesson plans, teacher manual, student workbook, and learning materials. The CELU is designed for Thai eleventh graders who were science students to learn scientific conceptions about five topics of chemical equilibrium concepts which were changes to achieve equilibrium, equilibrium in chemical reaction, equilibrium constant, factors affecting equilibrium conditions and Le Châtelier's principle, and chemical equilibrium in living things and in industrial applications. Integrated science process skills and attitudes also are emphasized as being expected learning outcomes about chemical equilibrium. The CELU consists of eleven lessons

within five topics of chemical equilibrium concepts. It is planned to take about eighteen periods for implementation in a classroom (about 50 minutes per period). The process of developing the CELU will be detailed in Chapter V: The Development of the Chemical Equilibrium Learning Unit.

3.2 Initial Workshop and Teacher Meetings

The initial workshop and teacher meetings are one of the important process in the development of the CELU. Three chemistry teachers from three schools were asked to attend the initial workshop before implementing the CELU into their classrooms. The initial workshop was planned for a full day meeting of the researcher, three chemistry teachers, and science educators. The initial workshop was set to encourage the teachers to realize the importance of improving teaching and learning about chemical equilibrium in the current Thai situation by revealing the findings from the first phase. Research study was introduced to the teachers briefly. Guiding principles, processes of the development of the CELU, and details of the CELU were then presented to the teachers. The teachers were asked to give suggestions for improving the CELU to become most effective in their classroom context. Those suggestions were used to revise the CELU before implementation in the classroom.

Teacher meetings are set for the chemistry teachers to reflect on their opinions, problems, or suggestions about the implementation of the CELU into their classroom. The meetings are planned for three times (about 2 hours per time) during the implementation of the CELU.

3.3 Survey and Questionnaire

The survey and questionnaire used in the Phase II are Chemical Equilibrium Concepts and Science Process Skills Survey and Questionnaire on Students' Attitude toward Chemical Equilibrium Concepts and Teaching and Learning the same as in Phase I. The details and processes of developing these instruments have been described earlier.

4. Strategies for Data Collection

The aim of the development and implementation phase was to develop the learning unit for chemical equilibrium by using a constructivist-based teaching approach to enhance students understanding of concepts of chemical equilibrium and to study the effects of the unit on students' learning outcomes. Data were gathered throughout the implementation of the Chemical Equilibrium Learning Unit (CELU) by using classroom observations, semi-structured interviews, document examination, Chemical Equilibrium Concepts and Science Process Skills Survey, and the Questionnaire on Students' Attitude toward Chemical Equilibrium Concepts and Teaching and Learning.

Classroom observations were made during teaching and learning chemical equilibrium concepts from December 2005 to February 2006. The role of researcher in observations was as non-participant observer. Before collecting data, the researcher went into the classroom in order to ensure that those students were familiar with being observed. The teacher introduced the researcher to students, and explained to the class that they were participating in the research study. During non-participant observations, the researcher usually sat in a vacant seat at the back of the classroom. Sometimes, with the teacher's permission, the researcher walked around the classroom and asked students questions while students were doing laboratory work.

Techniques employed in classroom observations include videotaping and taking field notes. They were used extensively throughout classroom observation to collect data from a variety of situations and students. Field notes were written during observations and further notes were made as soon as possible after each observation. The pattern of field notes consisted of two columns: descriptive and reflective notes. The empirical data gathered as classroom observation was written in the descriptive notes. Reflections, interests, and conclusions made by the researcher were written as reflective notes.

Semi-structured interviews were employed to interview both teachers and students. For the teacher, the interviews were conducted after they had completed the implementation of each topic. The researcher began with open discussion, assisting teachers to feel comfortable in the interview situation. During interviews, the researcher took notes as much as possible and tape recording was used to help the researcher collect comprehensive data. The recording was transcribed verbatim and written up using a pattern similar to field note observations. The conversations between the teacher and the researcher were written as descriptive notes, while reflections and conclusions were written as reflective notes. In terms of the student interviews, students were selected to be interviewed by the consensus between the teacher and the researcher. Students were selected by considering their behavior in the classroom while engaging with learning activities.

Documents were collected during the implementation of the learning unit. In this research study, the documents consisted of student thinking books or journals, worksheets, and laboratory reports. Students' tasks and reports were collected and interpreted in order to ascertain their learning.

5. Data Analysis

The triangulation of multiple data collecting generated a thick description of data. To analyze those data, various methods were undertaken as described below.

5.1 Analysis of Data from Classroom Observations

Classroom observation field notes, qualitative data, were transcribed and stored as text. Field notes and videotape recordings were the data collecting instrument for classroom observation. Field notes were taken to confirm accurate recording data and to enhance the researcher's understanding of the context of the study and investigate how teachers taught. Videotape recordings were transcribed and written as text. The researcher read all of transcription and interpreted those

characteristic of evidences occurring in the classroom in terms of interaction between students and students and between students and the teacher. The researcher decided to use both field notes and videotape for recording data to enhance validity.

5.2 Analysis of Data from Semi-Structured Interviews

To analyze data from semi-structured interviews, both the teacher and student interviews, transcriptions from tape recordings were read through by the researcher. Then, data from interviews was interpreted and categorized to each theme, for example, how the teacher teaches and how the student learns, for answering the research questions.

5.3 Analysis of Data from Students' Thinking Books

Students' thinking books were analyzed by categorizing in terms of students' understanding, and students' attitudes toward chemical equilibrium concepts and teaching and learning.

5.4 Analysis of Data from Survey and Questionnaire

The Chemical Equilibrium Concepts and Science Process Skills Survey and Questionnaire on Students' Attitudes toward Chemical Equilibrium Concepts and Teaching and Learning were completed after implementation of the CELU. The data from the survey and the questionnaire were analyzed as described in the first phase.

Ensuring Trustworthiness of Data Generation, Collection, and Data Analysis for this Research Study

Trustworthiness for this study was ensured by the use of triangulation and member checking. Data collection methods employed in this research study involved several techniques including interviews, classroom observations, and document

collection. The researcher used evidence from various sources of data to confirm the validity of data, for example, using both questionnaires and students' thinking books to develop an understanding of student's attitudes towards chemistry. During the process of data collection and analysis, the researcher employed the member checking technique to enhance credibility of data. The participants were asked to recheck their answers after interviews or observations.

Enhancing transferability by in-depth description and use of multi-case study, thick description was used in the research study to explain the context of the situation and the findings. The researcher described the context of the situation being studied in detail to provide an opportunity for the others to make the decision whether or not it is consistent with their situation. Multiple case studies were also employed to enhance the transferability of the research study. The research used three cases. Each of them is in a different context. Briefly, one is a well known girls' high school in Chanthaburi Province. It is a large government school in which there are more than 3000 students. The other two schools are medium government schools in different districts of Chanthaburi Province. There were both male and female students in both schools. The analysis of each case and cross-case analysis provided detailed descriptions of the enhanced understanding of the current situation of teaching and learning chemical equilibrium in each context.

Working with a supervisory team facilitated the dependability and confirmability of the data collection and analysis as an ongoing process. The supervisory team also acts as an external audit to check each step of the inquiry process. The team gave feedback on ideas, fostered insights, adding to the study's credibility.

Summary of the Chapter

This chapter presents research methodology relating to teaching and learning about chemical equilibrium within constructivist-based perspectives. To improve teaching and learning about chemical equilibrium concepts for Thai eleventh graders using constructivist-based perspectives, the research study consists of two phases; exploratory phase, and development and implementation of the Chemical Equilibrium Learning Unit phase.

To answer the research questions, interpretive research study was employed to study students' learning outcomes for chemical equilibrium in the Thai 2004 academic year and to study teaching and learning about chemical equilibrium throughout the implementation of the CELU. The research study started with an exploratory phase to find out students' learning about chemical equilibrium concepts. Then, these findings were used as one of the guiding principles in the process of the development of the CELU. During implementation of the CELU in classrooms, various methods for collecting data which were classroom observations, semi-structured interviews, and students' worksheets and thinking books were employed in this study. Those methods generated a thick descriptive data which was analyzed by finding theme of the data. Ethics were also taken into consideration during the study. Triangulation was employed to enhance the trustworthiness of the research study. Findings in each phase were presented in the next chapter. Chapter VI presents the findings about students' learning outcomes from Thai 2004 academic year.

CHAPTER IV

STUDENTS' LEARNING OUTCOMES ABOUT CHEMICAL EQUILIBRIUM CONCEPTS: FINDINGS FROM 2004 ACADEMIC YEAR

Overview of the Chapter

Chapter IV presents the findings from the exploration of Thai high school students' learning outcomes about chemical equilibrium concepts from Thai 2004 academic year. To find out students' learning outcomes about chemical equilibrium concepts, one hundred and twenty five students from three schools in Chanthaburi Province were asked to complete Chemical Equilibrium Concepts and Science Process Skills Survey and Questionnaire on Students' Attitudes toward Chemical Equilibrium and Teaching and Learning. Then, data gathered from those students were analyzed. In this chapter, Thai upper secondary students' learning outcomes about chemical equilibrium concepts are presented in terms of students' conceptions about chemical equilibrium, students' capabilities in science process skills, and students' attitudes toward teaching and learning about chemical equilibrium.

Students' Conceptions about Chemical Equilibrium

Chemical equilibrium concepts taught in Thai upper secondary level consists of five topics: changes to achieve equilibrium, equilibrium in chemical reaction, equilibrium constant, factors affecting equilibrium conditions and Le Châtelier's principle, and equilibrium in living things and industrial applications. Students' answers from Chemical Equilibrium Concepts and Science Process Skills Survey were analyzed and categorized in terms of the degree of understanding. Then, types of students' conceptions about chemical equilibrium were presented via the degree of understanding which consists of five levels: sound understanding (SU), partial

understanding (PU), partial understanding with specific misconception (PU and MU), misconception, (MU), and no understanding (NU). They are presented in each topic of chemical equilibrium concepts as mentioned above.

Table 4.1 Distribution of high school students' conceptions about chemical equilibrium in Thai Academic Year 2004 (N=125)

Concepts	No. of students (percentage)				
	SU*	PU*	PU and MU*	MU*	NU*
Changes to achieve equilibrium	19 (15.2)	19 (15.2)	<u>51</u> <u>(40.8)</u>	36 (28.8)	-
Equilibrium in chemical reaction	1 (0.8)	12 (9.6)	<u>86</u> <u>(68.8)</u>	26 (20.8)	-
Equilibrium constant	13 (10.4)	30 (24.6)	16 (12.8)	12 (9.6)	<u>54</u> <u>(43.2)</u>
Factors affecting equilibrium condition and Le Châtelier's principle					
• Disturbing equilibrium condition by changing concentration	-	<u>96</u> <u>(76.8)</u>	2 (1.6)	27 (21.6)	-
• Disturbing equilibrium condition by changing pressure	46 (36.8)	<u>53</u> <u>(42.4)</u>	3 (2.4)	4 (3.2)	19 (15.2)
• Disturbing equilibrium condition by changing temperature	-	<u>96</u> <u>(76.8)</u>	-	29 (23.2)	-
Chemical equilibrium in living things and in industrial applications	13 (10.4)	22 (17.6)	-	3 (2.4)	<u>87</u> <u>(69.6)</u>

*SU = Sound understanding, PU = Partial understanding, PU and MU = Partial understanding with specific misconception, MU = Misconception, NU = No understanding

The results in Table 4.1 show that most of the students held partial understanding with specific misconception in the topic of changes to achieve equilibrium and equilibrium in chemical reaction. For the topic of chemical equilibrium in living things and in industrial applications and equilibrium constant, most of the students had no understanding. However, most of the students showed that they almost understand chemical equilibrium concepts in the topic of factors affecting equilibrium condition and Le Châtelier's principle, especially disturbing equilibrium condition by changing pressure. It was found that both partial understanding and sound understanding were found in the topic of disturbing equilibrium condition by changing pressure. While for the other two topics, disturbing equilibrium condition by changing concentration and temperature, it was found that most of students held partial understanding. No one had a sound understanding of those two topics. The details of students' conceptions about chemical equilibrium in each topic are described below.

1. Changes to achieve Equilibrium

To demonstrate sound understanding of changes to achieve equilibrium, a response should show that the reaction is in equilibrium if each substance's concentration in the reaction is constant which can be observed from graph between concentration of substances in the reaction and time. As listed in Table 4.1, most of students (41%) held partial understanding with specific misconception. These students thought that changes to achieve equilibrium can be observed from the graph but the slope of the graph presenting equilibrium is constant because there is no reaction occurring, resulting in the straight line of the graph. Misconceptions concerning changes to achieve equilibrium were held by 29 percent of the students. The most common misconception of these students was "the reaction reaches equilibrium when the lines of the graph are parallel because it is in the equilibrium, then each substance is equal". It seems that subject's misconceptions of changes to achieve equilibrium are because they might not understand the dynamic nature of equilibrium. Indeed, at equilibrium, both forward and reverse still take place in the same rate. This causes the

concentration of each substance in the reaction to be constant which could be observed from the graph as mentioned above. However, the findings showed that the same number of students (15%) held partial understanding and sound understanding of this topic so it could be assumed that those students could understand the topic of changes to achieve equilibrium.

2. Equilibrium in Chemical Reaction

Students' responses were classified as sound understanding if they indicated that "at the equilibrium, there are all of reactants and products in the reaction and the concentration of each substance occurred at the equilibrium directly relating to the equilibrium constant". Given the ammonia production situation using Haber process with equilibrium constant equals one, the students were asked to select a diagram that could be a representative of the ammonia production reaction at the equilibrium.

As listed in Table 4.1, in the topic of equilibrium in chemical reaction, the majority of students (69%) held partial understanding with specific misconception. Most of them believed that at the equilibrium, there will be all of substances in the reaction and the amount of each substance must be equal. The others believed that at the equilibrium, there will be all of substances in the reaction and the amount of each substance must be as same as the coefficient which is in the chemical equation of ammonia production process. Then, they understood that there were two molecules of nitrogen gas, two molecules of ammonia gas, and three molecules of hydrogen gas at equilibrium.

Some students showed that they had misconception about chemical equilibrium in the topic of equilibrium in chemical reaction. The results in the Table 4.1 show that misconceptions concerning equilibrium in chemical reaction were held by 21 percent of the students. Most of them chose the diagram that presents the equal amount of molecules of nitrogen gas, ammonia gas, and hydrogen gas because they

believed that at the equilibrium, the amount of reactants must be equal to the amount of products. The other students who held misconceptions chose the diagram that presents only the molecule of ammonia gas because they believed that, at the equilibrium, there are only products because the reactants are used up. Finally, some students who had misconceptions chose the diagram that presents the molecules of nitrogen gas and ammonia gas because they believed that, at the equilibrium, there are both products and reactants but one reactant must be used up depending on the chemical equation, then the reaction stops.

It could be said that the major student misconceptions might be generated from learning by memorization. The results from the survey showed that the students attempted to use the word “equal” to explain the characteristic of equilibrium but they had no understanding what equilibrium actually is. They only remembered that something must be equal if it is in equilibrium. Then, if they were asked to choose the diagram that could be a representative of equilibrium of the ammonia production process, they chose the diagram in which the amount of each substance is equal. The other students’ belief that there are only products at the equilibrium might be generated from a lack of understanding about chemical reaction. They believed that chemical reaction can be only a forward reaction, from reactants to products, and it could not be reverse. Thus, they explained the characteristic of the equilibrium as the condition in which there are only products due to the reactants being used up. The characteristic of students’ misconceptions concerning equilibrium in chemical reaction from this finding is similar to the finding from the study of Garnett *et al.* (1995) and van Driel *et al.* (1998) which revealed that most students believed that the reactants are totally converse to the products if the chemical reaction takes place. Then, after the chemical reaction takes place, there are only products remaining.

The results also showed that some students understood chemical equilibrium concepts in the topic of equilibrium in chemical reaction. Ten percent of the students showed that they held partial understanding. These students believed that at

equilibrium, there are all of substances in the reaction but they did not provide any reason. However, a few students (1%) showed that they held sound understanding about chemical equilibrium concepts. They could choose the correct diagram and provide correct reasons to describe why the diagram should be like that. These findings suggest the teachers to investigate why a few students only understood chemical equilibrium concepts as scientific conceptions.

3. Equilibrium Constant

Students' responses were classified as sound understanding if they indicated that the major substances of the reaction in which the equilibrium constant is more than 1 will be products while, the major substance of the reaction in which the equilibrium is less than 1 will be reactants because the equilibrium constant is related to the concentration of each substance in the reaction. The students' answers were categorized as shown in Table 4.1.

Most students (43%) had no understanding about equilibrium constant topic. Most of them did not answer the question, while the other provided irrelevant answers to the question.

The findings showed that only ten percent of the students had sound understanding about chemical equilibrium topic and 24 percent of the students had partial understanding. The students who had partial understanding believed that if the equilibrium constant is more than 1, the major substances in the reaction will be products and if the equilibrium constant is less than 1, the major substances in the reactions will be reactants. However, they did not provide any reason to explain their answer.

Misconceptions concerning equilibrium constant were held by ten percent of the students. They believed that the equilibrium constant is minus when the major

substances in the reaction are reactants. In fact, equilibrium constant could not be minus. These student's answers suggested that learning by memorization might be used for understanding equilibrium constant. The subjects did not really understand what equilibrium constant is but they had memorized the value of the constant and applied it to answer the question. This finding is similar to the study of Nakhleh (1992) which reported that the some students had difficulty in understanding equilibrium constant. They applied an algorithm memorized through rote learning, resulting in success in solving computational problems even though they showed lack of conceptual understanding of equilibrium constant.

4. Factors Affecting Equilibrium Condition and Le Châtelier's Principle

Factors affecting equilibrium condition and Le Châtelier's principle are one of the most important topics in chemical equilibrium. It consists of three aspects of the concepts: disturbing equilibrium condition by changing concentration; disturbing equilibrium condition by changing pressure; and disturbing equilibrium condition by changing temperature.

4.1 Disturbing Equilibrium Condition by Changing Concentration

In the aspects of disturbing equilibrium condition by changing concentration, the findings showed that no subject had sound understanding. However, about 77 percent of the students had partial understanding. These students believed that adding more reactants into the equilibrium reaction results in an increase of concentration of products compared with the early equilibrium.

Misconceptions concerning disturbing equilibrium condition by changing concentration were held by 22 percent of the students. Students' misconceptions of the disturbing equilibrium condition by changing concentration can be described in three aspects. First, they believed that adding more reactants into the equilibrium results in

the decrease of the products in order to reach a new equilibrium. These students showed that they could not really understand the changes of equilibrium condition if it was disturbed. It seemed that those students did not predict the changes of equilibrium if it is disturbed by changing concentration using Le Châtelier's principle. This finding is similar to the study of Furio *et al.* (2000), which revealed that some students could not apply Le Châtelier's principle in a new situation. Second, the students believed that adding more the reactants into the equilibrium results in the decrease of the products' concentration because of dilution. These students did not describe how equilibrium shifted or changed if the equilibrium condition was disturbed but they brought the concept of solution and solubility to explain that situation. They described that adding more reactants into the equilibrium resulted in an increase of volume. Thus, they thought that the concentration of product should decrease. Thus it could be assumed that these students believed that nothing happens if more reactant is added into the equilibrium. Third, the students described that the concentration of product should be constant compared to the early equilibrium. These students believed that there no change occurred even though more reactants are added into the equilibrium because the reaction is in equilibrium. It could be assumed that students might not understand dynamic equilibrium. Then, they could not explain what happens when disturbing the equilibrium condition.

4.2 Disturbing Equilibrium Condition by Changing Pressure

In aspects of disturbing equilibrium condition by changing pressure, the findings showed most of the students could almost understand this topic. As listed in Table 4.1, 43 percent of the students had partial understanding. Interestingly, students had sound understanding about this topic with the highest percent compared to the other topics of chemical equilibrium.

However, the findings revealed that fifteen percent of the students had no understanding about this topic. These students could not answer what happens if the

pressure of equilibrium of ammonia production process changes. Moreover, three percent of the students held misconceptions concerning disturbing equilibrium condition by changing pressure. Some of them believed that an increase of pressure results in a decrease of the product's concentration because the reverse reaction will take place. The other students who held misconceptions believed that the concentration of products could not be predicted because an increase of pressure of ammonia production process results in an increase of each substance's concentration. Then, there is a change at the equilibrium but this could not be explained. They also thought that equilibrium is a reversible reaction which continuously takes place, therefore, they could not predict that whether the product's concentration would increase or decrease. These students might not understand the characteristic of reversible reaction or could not apply Le Châtelier's principle to a new situation.

4.3 Disturbing Equilibrium Condition by Changing Temperature

In aspects of disturbing equilibrium condition by changing temperature, the findings showed that no subjects had sound understanding, but 77 percent of the students had partial understanding. These students understood that an increase of temperature of the ammonia production results in a decrease of the product's concentration but they did not provide any reason to explain their answer.

Misconceptions concerning disturbing equilibrium condition by changing temperature were held by 23 percent of the students. These students believed that an increase of temperature of the ammonia production results in the increase of product's concentration because of the increasing rate of the reaction. They believed that if the temperature of a reaction is increased, then the rate of the reaction will increase. Thus, the concentration of products should increase because of an increase of rate of the reaction of forward reaction. From these characteristic of misconceptions it could be assumed that the students might have no understanding about rate of reaction.

In conclusion, the characteristics of students' misconceptions about chemical equilibrium in the factors affecting equilibrium condition and Le Châtelier's principle might be generated from two problems. First, students might not understand Le Châtelier's principle. Then, they could not use the principle to explain any change if the equilibrium condition is disturbed. Another problem concerns basic concepts for learning chemical equilibrium concepts. Some students had no understanding about important basic concepts, for example, concept about concentration, concept about equilibrium in chemical reaction, or concept about rate of reaction. These problems might be obstacles to understanding the concept of chemical equilibrium in the topic of factors affecting equilibrium condition and Le Châtelier's principle.

5. Chemical Equilibrium in Living Things and in Industrial Applications

The students were asked to explain how to rescue a person who was poisoned by carbon monoxide. Interestingly, the findings showed that 70 percent of the students had no understanding about this topic. Some of them did not answer the question. The others tried to describe how to rescue a person who was poisoned by carbon monoxide gas but their answers were irrelevant to chemical equilibrium concepts. For example, some students suggested that the person should be rescued by making him become sensible all time or that person should be brought to the hospital immediately. However, as listed in Table 1, there were students who understood the concept of chemical equilibrium in the topic of chemical equilibrium in living things and in industrial application. Eighteen percent of the students had partial understanding about this topic. These students described that the strategy to rescue the person who was poisoned by carbon monoxide gas might be an inhalation of a high concentration of oxygen gas but they did not explain any reason.

Besides, the findings showed that two percent of the students held misconceptions about chemical equilibrium in the topic of chemical equilibrium in living things and in industrial applications. These students suggested that a person

should be rescued by injecting oxygen gas into a blood vessel. They also explained that the amount of oxygen gas which will be injected should be equal to the amount of carbon monoxide gas. The findings suggest that the students who held misconceptions might have no understanding about changes to be equilibrium or might not apply Le Châtelier's principle to this situation. Then, they could not apply this principle to explain how to rescue the poisoned person by using chemical equilibrium concepts.

Students' Capabilities in Science Process Skills

Students' capabilities in science process skills refer to integrated science process skills which consist of five processes: identifying and controlling variables; interpreting data; formulating hypotheses; defining operational definition; and, experimenting. Students' answers from Chemical Equilibrium Concepts and Science Process Skills Survey were analyzed and categorized. For each process skill, student responses were placed into five possible categories which are detailed in Table 4.2.

Table 4.2 Five categories of students' capabilities in science process skills

Category	Descriptions
Type A	Responses are consistent with the expected answer
Type B	Incomplete responses that imply the correct answer
Type C	Responses give no specific information, are generalized, incomplete, vague, or ambiguous
Type D	Responses are irrelevant to the expected answer
Type E	No answer at all

Each category of student response could be transformed by grouping Types A and B together as successful and grouping Types C, D, and E together as unsuccessful capabilities in science process skills. After analyzing and categorizing student responses from Chemical Equilibrium Concepts and Science Process Skills Survey,

the overall results of students' capabilities in science process skills are presented in Table 4.3.

Table 4.3 Distribution of high school students' capabilities in science process skills in Thai 2004 Academic Year (N=125)

Integrated science process skills	No. of students (percentage)						
	A	B	Total ^a	C	D	E	Total ^b
Identifying and controlling variables	12 (9.6)	-	12 (9.6)	17 (13.6)	83 (66.4)	13 (10.4)	113 (90.4)
Interpreting data	2 (1.6)	51 (40.8)	53 (42.4)	-	15 (12)	57 (45.6)	72 (57.6)
Formulating hypotheses	39 (31.2)	47 (37.6)	86 (68.8)	23 (18.4)	16 (12.8)	-	39 31.2)
Defining operational definition	12 (9.6)	4 (3.2)	16 (12.8)	36 (28.8)	24 (19.2)	49 (39.2)	109 (87.2)
Experimenting							
• Collecting data	2 (1.6)	41 (32.4)	43 (34.4)	-	25 (20.0)	57 (45.6)	82 (65.6)
• Making conclusion	2 (1.6)	33 (26.4)	35 (28.0)	20 (16.0)	13 (10.4)	57 (45.6)	90 (72.0)

^a Classified as successful categories which include Types A and B.

^b Classified as unsuccessful categories which include Types C, D, and E.

Table 4.3 presents the results from the survey of 125 Thai upper secondary students for their capabilities in five science process skills. Results of this analysis indicated that those students who were classified as being successful ranged from 69 percent for formulating hypotheses to 10 percent for identifying and controlling variables. The findings showed that formulating hypotheses was only skill in which most of the students (69%) were successful. Interestingly, a number of students who were unsuccessful in capabilities in science process skills ranged from 58% to 90%. Students' capabilities in science process skills which were categorized as being unsuccessful were identifying and controlling variables, defining operational definitions, experimenting (making conclusions), experimenting (collecting data), and interpreting data. The characteristics of students' capabilities in each science process skill are detailed below.

1. Identifying and Controlling Variables

In this study, student's capability in the science process skill related to identifying and controlling variables was analyzed in terms of independent variable, dependent variable, and variables to be held constant. Students were asked to specify those variables from the experiment for investigating whether an equilibrium process of a reduction reaction of dangerous pollutants, which are nitrogen monoxide gas and carbon monoxide gas from automobiles, is an exothermic reaction. Interestingly, as listed in Table 4.3, identifying and controlling variables were the skills that a number of students (90%) were unable to demonstrate correctly. Only 10 percent of students could specify the variables of the expected answer.

For students who were unsuccessful in identifying and controlling variables, most of students' responses were categorized to be Type D, Type C, and Type E. It could be seen that most students in Type D less able to specify variables to be held constant and dependent variables, more than independent variables. Examples of students' responses in Type D which related to variables to be held constant were included as the following; concentration of reactants, the amount of substances used,

concentration of each substance in the system, container, pressure, reaction's direction, or rate of the reaction. Additionally, examples of students' responses in Type D which related to dependent variables were energy, exothermic reaction, concentration of reactants, or reduction of temperature. On the other hand, many students in Type D showed that they could specify independent variables of the given experiment as the same as the expected answer, which was temperature. However, those students who showed an inability in specify dependent variables and variables to be held constant were categorized as being unsuccessful in identifying and controlling variables.

2. Interpreting Data

Students who were classified as being successful if they were able to interpret results which might be shown in terms of graph or numerical data and to explain those data to others for leading them to understand results of an investigation. Given the experiment of steam and coals to study the effect of temperature on equilibrium constant, concentration of each substance in the equilibrium at different temperature of this reaction were provided as numerical value to the students. Students were asked to describe the given numerical data in terms of how those data relate to an exothermic or endothermic reaction. More than a half of the students (58%) were classified as being unsuccessful. A large number of student responses (46%) were in Type E, while fifteen students (12%) explained that an increase of temperature causes the reaction to move better. Then, this reaction was exothermic reaction which could be observed from an increase of product concentration if the temperature was increased. This student response suggested that those students had struggled to describe how an increase of temperature relates to the type of the reaction. Their response showed that those students had a misunderstanding about exothermic reaction and rate of the reaction.

However, the results showed that 53 students (42%) were classified as being successful. Although students were expected to organize the given numerical data in

terms of equilibrium constant, only two students (2%) did that process. Those students also explained that if the temperature of the reaction is increased, equilibrium constant will increase, thus, the reaction could be concluded to be an endothermic reaction. An even larger number of students (41%) interpreted the given numerical data in terms of product concentration rather than equilibrium constant. Those students explained that because product concentration increases when the temperature of the reaction is increased, this reaction is an endothermic reaction. This response was categorized as Type B.

3. Formulating Hypotheses

Given the experiment of the reduction of the dangerous pollutants (nitrogen monoxide gas and carbon monoxide gas) in the exhaust from automobiles, the students were asked to write down their own hypotheses for this experiment. As listed in Table 4.3, the results showed that most of the students (69%) were classified as being successful whereas the others (31%) were unsuccessful.

Successful student answers were found in Type B more than in Type A. For successful students, about 38 percent stated that when the temperature of the reaction increases, concentration of nitrogen gas and carbonmonoxide gas [products] should increase if this reaction is an endothermic reaction, while about 31 percent of students specifically stated that the reaction should be an endothermic reaction if the equilibrium constant increases when temperature of the reaction is increased.

There were about 31% unsuccessful students. The characteristic of student's answers in the unsuccessful group could be categorized to be Type C and Type D. About 18% of students ambiguously formulated hypothesis of the given reaction that the reaction should be an endothermic reaction because of the change in the substance's concentration. About 13% of students did not answer the question.

4. Defining Operational Definition

The science process skills of defining operational definition was the most unsuccessful skills. About 87% of students were unsuccessful in defining the equilibrium constant of the reaction between steam and coal, while there were about 13% of students who were successful.

The unsuccessful students' answers could be categorized into three groups: Type E, Type C, and Type D. Students who answered as Type C indicated equilibrium constant is the value that indicates directions of the reversible reaction. It could be measured from concentration of products and concentration of reactant. For Type D answer, students answered that equilibrium constant is a constant value of the equilibrium state. From these answers it could be implied that these students did not have the science process skill of defining operational definition. Successful students' answers were Type A more than Type B. Students who answered as Type B did not specify how to measure equilibrium constant of the given reaction. They only provided the meaning of equilibrium constant.

5. Experimenting

This study aimed to find out students' capabilities of experimenting in three aspects: collecting data, analyzing data, and drawing conclusions. The majority of students were unsuccessful in experimenting in those three aspects. Details of each aspect of experimenting are described below.

5.1 Collecting data

Students were asked to design a table for recording experimental data from the study of the reaction between coals and steam. It was found that most of students (about 66%) were unsuccessful in collecting data. Their answers were categorized into two types: Type E and Type D. However, about 34% of students

were successful. Their answers were categorized as being Type B more than Type A. About 32% of students could arrange data from the experiment into their table correctly, but they did not design a special column for equilibrium constant. However, these students could find out the relationship between product concentration and temperature. Consequently, their table of collecting is usable, but not complete. For Type A answer, there were about 2% of students. These students arranged data from the experiment into their table, they also designed a special column to present equilibrium constant in order to find out a relationship between equilibrium constant which is a dependent variable and temperature which is an independent variable.

5.2 Drawing conclusions

In aspect of drawing conclusions, the findings showed that about 72% of students were unsuccessful while about 28% of students were successful. This could imply that there might be some point that students might be confused about in drawing conclusions.

For unsuccessful students, the answers could be separated into three types, Type E, Type C, and Type D. About 46% of students did not answer the question. About 16% of students presented a general and unclear conclusion for this experiment. For example, some students only concluded that concentration of products varies from temperature, or concentration of products increases because of an increase of temperature. About 10% of students provided an irrelevant conclusion.

For successful students, only about 2 percent of student answers were categorized as being Type A, while about 26 percent were Type B. Students who answered as Type B only concluded that the reaction between steam and coal is an endothermic reaction which could be observed from an increase of forward reaction. These students could conclude the type of the reaction using data from the experiment, but they provided incomplete reasoning to support their conclusion.

Students' Attitudes toward Chemical Equilibrium Concepts and Teaching and Learning

This section aims to describe students' attitudes toward chemical equilibrium concepts and teaching and learning which consists of four topics: difficulty of chemical equilibrium concepts, usefulness of chemical equilibrium concepts, interest in learning chemical equilibrium concepts, and preference of teaching chemical equilibrium concepts. Data from the Questionnaire on Students' Attitudes toward Chemical Equilibrium Concepts and Teaching and Learning were scored, and then students' scores were categorized into five levels: high positive attitude (range from 4.50 to 5.00), positive (range from 3.50 to 4.49), moderate (range from 2.50 to 3.49), negative attitude (range from 1.50 to 2.49), and high negative attitude (range from 1.00 – 1.49). Students' attitudes for each topic were presented in terms of mean score and standard deviation for each topic as shown in Table 4.4.

Table 4.4 Mean scores and standard deviations of high school students' attitudes toward chemical equilibrium concepts and teaching and learning in Thai 2004 Academic Year (N=125)

Topics	Sub-topic	Scores of Students' Attitudes*	
		Mean Score	SD
Complexity of Chemical Equilibrium concepts	Difficult when dealing with exercises.	3.03	0.95
	Difficult to understand.	3.15	1.03
	Difficult when dealing numerical value and mathematic calculation.	2.97	0.89
	<i>Average Mean Score</i>	<i>3.05</i>	<i>0.96</i>
Usefulness of Chemical Equilibrium concepts	Usefulness in daily life	2.86	0.89
	Usefulness in the future career	2.69	0.83
	Usefulness in developing the country	2.84	0.85
	<i>Average Mean Score</i>	<i>2.79</i>	<i>0.86</i>

*Scores of students' attitudes are high positive (4.49 -5.00), positive (3.49 – 4.50), moderate (2.49 – 3.50), negative (1.50 – 2.49), and high negative (1.00 – 1.49)

Table 4.4 (Continued)

Topics	Sub-topic	Scores of Students' Attitudes*	
		Mean Score	SD
Interest in Chemical Equilibrium concepts	Want to learn more about the chemical equilibrium concepts	2.78	0.87
	Concept is interesting	2.63	1.03
	Interested in chemical equilibrium concepts because of doing laboratory	2.39	0.95
	<i>Average Mean Score</i>	<i>2.60</i>	<i>0.95</i>
Preference of Teaching and Learning about Chemical Equilibrium	Study in small group is better than by individuals	3.07	0.87
	Discussion could enhance understanding about chemical equilibrium concepts	2.96	0.95
	Doing exercises could enhance understanding about chemical equilibrium concepts	3.29	0.83
	Learning from doing activities is better than lecturing	3.18	0.97
	<i>Average Mean Score</i>	<i>3.13</i>	<i>0.91</i>
Overall Average Mean Score		2.89	0.92

*Scores of students' attitudes are high positive (4.49 -5.00), positive (3.49 – 4.50), moderate (2.49 – 3.50), negative (1.50 – 2.49), and high negative (1.00 – 1.49)

As seen in Table 4.4, mean score of the overall students' attitude was about 2.89 (SD = 0.92). This meant that students held a moderate attitude toward chemical equilibrium concepts and teaching and learning. The findings showed that students held moderate attitudes towards all four topics which ranged from the highest mean score to the lowest mean score as follows: preferences of teaching and leaning about chemical equilibrium, complexity of chemical equilibrium concepts, usefulness of chemical equilibrium concepts, and interest in chemical equilibrium concepts.

In the topic of preference of teaching and learning, the findings showed that students held moderate attitudes with the highest mean score (3.13). Students' attitude's scores of each statement ranged from the highest to the lowest as follows: doing exercises could enhance understanding about chemical equilibrium; learning from doing activities is better than from lecturing; study in small group is better than by individuals; and discussion could enhance understanding about chemical equilibrium concepts.

The lowest student attitude mean score was attitude toward interest in chemical equilibrium concepts. The findings showed that the mean score was only 2.60 which meant that those students held moderate attitudes toward this topic. Within students' attitude toward interest in chemical equilibrium concepts, it was found that positive attitude toward each sub-topic could be ranged in this order: interested in chemical equilibrium concepts because of doing laboratory, concept is interesting, and want to learn more about chemical equilibrium concepts.

Summary of Students' Learning Outcomes about Chemical Equilibrium Concepts: Findings from Thai 2004 Academic Year

The findings from the Chemical Equilibrium Concepts and Science Process Skills Survey revealed that Thai high school students had difficulties in understanding chemical equilibrium concepts. The findings revealed that Thai high school students faced obstacles to understanding all concepts of chemical equilibrium. It was found

that the majority of students held partial understanding with specific misconceptions about the topics of changes to achieve equilibrium, equilibrium in chemical reaction, no understanding about the topics of equilibrium constant and chemical equilibrium in living things and in industrial applications, and partial understanding of the topic of factors affecting equilibrium conditions and Le Châtelier's principle. Especially, in the topic of changes to be equilibrium and equilibrium in chemical reaction, it was found that most of students held misconceptions which were concerned with dynamic equilibrium and reversible chemical reaction. A few of these students had sound understanding about chemical equilibrium. These findings were consistent with the overseas research study which revealed that chemical equilibrium is one of the difficulty concepts for studying chemistry (Garnett *et al.*, 1995). It was found that Thai high school students held various characteristic conceptions or alternative conceptions, similar to those identified in the literature (e.g. Benerjee, 1991; Huddle and Pillay, 1996).

In aspect of students' capabilities in the five science process skills: identifying and controlling variables, interpreting data, formulating hypotheses, defining operational definition, and experiment, the findings revealed that most of the students were only successful in formulating hypotheses. Students' capabilities in science process skills in which most of Thai high school students were categorized to be unsuccessful involved the process skills of identifying and controlling variables, defining operational definition, experimenting, and interpreting data. One source of difficulties might be generated from a lack of understanding in chemical equilibrium concepts. It was found that Thai high school students rarely held sound understanding about chemical equilibrium concepts. This lack might influence students' capabilities in science process skills. As Harlen (1999) suggested, science process skills should be studied in relation to specific science content since any task involving the skills will be influenced by the nature of the subject content as well as the ability to use the skills.

The last aspect of students' learning outcomes about chemical equilibrium is students' attitude toward chemical equilibrium concepts and teaching and learning. It was found that Thai high school students held moderate attitudes towards all four topics: preference of teaching chemical equilibrium concepts, complexity of chemical equilibrium concepts, usefulness of chemical equilibrium concepts, and interest in learning chemical equilibrium concepts.

Implications for Further Teaching

The findings from Thai 2004 academic year revealed that students had difficulty in understanding scientific conceptions of all concepts of chemical equilibrium. The difficult concepts found in Thai high school students were concerned with dynamic equilibrium, reversible reaction, and factors affecting equilibrium condition and Le Châtelier's principle. It seemed that they employed memorization to study chemical equilibrium concepts, for example, students explained dynamic equilibrium using the word "equal" without really understanding as described in the earlier section: students' conception of changes to achieve equilibrium. These might result in a lack of an ability to link each concept of chemical equilibrium together. It was also found that most of these students were unsuccessful in capabilities of science process skills in terms of identifying and controlling variables, defining operational definition, experimenting, and interpreting data. For the last aspect of learning outcomes, students' attitudes toward chemical equilibrium concepts and teaching and learning were moderate in all topics. These findings suggested that students' conceptions about chemical equilibrium and students' capabilities of science process skills of Thai high school students should be concentrated on so as to achieve success in teaching and learning about chemical equilibrium. It could be said that Thai high school students seemed to be far from acquiring meaningful learning about chemical equilibrium concepts. Therefore more effective teaching strategies need to be developed for enhancing students' learning outcomes about chemical equilibrium concepts.

The next chapter presents the guiding principles used in developing the Chemical Equilibrium Learning Unit (CELU). One of guiding principles relates to findings from the exploratory phase. Details of the development of the CELU also are briefly described in the next chapter.

CHAPTER V

THE DEVELOPMENT OF THE CHEMICAL EQUILIBRIUM LEARNING UNIT (CELU)

Overview of the Chapter

This chapter details the development of the Chemical Equilibrium Learning Unit (CELU) and presents the guiding principles used in developing the CELU for Thai high school students and the characteristic of the Unit. The aim of the CELU is to improve teaching and learning about chemical equilibrium at the high school level in order to promote student learning outcomes about chemical equilibrium concepts. This chapter begins by describing the framework underpinning the development of the CELU. The framework is first outlined in terms of constructivism – the learning theory guiding the development. This is followed by a description of visions of science learning as the framework for the CELU, and a recommendation for teaching and learning about chemical equilibrium concept from literature respectively. Then, six guiding principles are generated for design the CELU. The process of designing and developing the CELU is described in the next section followed by a description of the CELU is introduced in terms of content, activity, and time for each lesson of the CELU. In the last section, summary of the chapter is presented.

Framework Underpinning the Development of the Chemical Equilibrium Learning Unit (CELU)

The aim of developing the Chemical Equilibrium Learning Unit (CELU) is to improve teaching and learning about chemical equilibrium for Thai Grade-11 science students for enhancing students' learning outcomes to be consistent with the National Science Curriculum Standard (IPST, 2003). There are three important frameworks related to this development. These are the constructivism, visions of learning science,

and recommendation of teaching and learning chemical equilibrium concept from literature.

1. Constructivism as Theory Underpinning in the CELU

The theory of learning underpinning the development of the CELU is constructivism which here includes individual and social constructivist-based perspectives (see details in Chapter II). The process of learning, from a constructivist-based perspective, involves interaction between a learner's existing ideas and new learning experiences (Asoko, Leach, and Scott, 1995; Fensham, Gunstone, and White, 1994). Within a constructivist-based perspective, it is acknowledged that learning results from the addition of new elements of knowledge to pre-existing knowledge structures, and from the re-organization of prior structures to accommodate new elements. Constructivist-based perspectives of teaching and learning emphasize the engagement of the student in the learning process, and the importance of prior knowledge or conceptualizations for new learning. In such a model, the teacher becomes a facilitator and coach rather than knowledge dispenser (Yager, 1991). Constructivist-based perspectives of teaching and learning also use students thinking, experiences, and interests to drive lessons. Cooperative learning strategies that emphasize collaboration also are one of successful strategies for improving teaching and learning (Yager, 1991). Consequently, most of the activities designed for the CELU aim to encourage students to accomplish learning outcomes for chemical equilibrium concept by considering the importance of the followings: learner's existing ideas, opportunities for doing activities, social processes, and assessment strategies.

2. Visions of Science Learning as Framework for the CELU

Three aspects of 'visions of science learning' within the National Science Curriculum Standards (IPST, 2001) used in this development of the learning unit are stated as follows.

- Learning science should be a developmental process so that the learner acquires proper knowledge, process, and attitude;
- Learning science should be life long process so that one will be able to make use of what one learns in science for one's daily and professional life continuously because our natural world changes constantly and science also grow with it;
- Basic science learning is for greater understanding, better appreciation of nature and the environment. This viewpoint should help the learners integrate various and diverse disciplines leading to creativity in the development of an quality of life. It should also enhance our ability to collaborate to manage the natural world more sustainably.

Expected learning outcomes for the CELU strived to be consistent with these visions of science learning detailed in the National Science Curriculum Standards (IPST, 2001). The students were expected to understand chemical equilibrium concepts, to develop capabilities in science process skills for chemical equilibrium, and to develop a positive attitude towards chemical equilibrium concepts and teaching and learning. They also were expected to learn how to integrate knowledge about chemical equilibrium with other concepts to explain, for example, natural phenomena, or processes in living things, or to apply in industrial processes. Additionally, the students were challenged by encounters with new learning situations intended to encourage the students to be able to use knowledge about chemical equilibrium and related concepts to explain things from those situations.

3. Recommendation of Teaching and Learning Chemical Equilibrium Concept from Literature

As literature suggests, there are teaching approach which seem to be successful in overcoming students' learning difficulties in chemical equilibrium

concept. Those teaching strategies mostly rely on constructivist-based perspectives of teaching and learning, for example, teaching as conceptual, using analogy or metaphor, or engaging with laboratories or demonstrations as described in Chapter II: Literature Review. Research studies related to the development of the CELU are categorized into two aspects: literature relating to the teaching and learning chemical equilibrium concepts, and findings from an exploratory study of students' learning outcomes about chemical equilibrium from Thai academic year 2004.

Guiding Principles for Developing the Chemical Equilibrium Learning Unit (CELU)

The guiding principles of the development of the Chemical Equilibrium Learning Unit (CELU) for Thai Grade-11 science students are impacted from those three frameworks which are constructivism, visions of learning science, and recommendation of teaching and learning chemical equilibrium concept from literature as described in the previous section. Guiding principles for developing the CELU consist of the followings.

1. Thai High School Students' Learning Outcomes about Chemical Equilibrium from Thai Academic Year 2004 Suggests the Design of Learning Activities

Students' learning outcomes for chemical equilibrium in the 2004 academic year were reviewed and analyzed for the purposes of planning the CELU. The results from the survey of students' conceptions and integrated science process skills about chemical equilibrium in the 2004 academic year revealed that students had difficulty in learning chemical equilibrium (see details in Chapter IV). In terms of students' conceptions, they held alternative conceptions for each topic of chemical equilibrium, and these were used when designing learning activities for each lesson of the CELU. For example, the findings from the survey suggested that most students held alternative conceptions about the dynamic nature of equilibrium. The notion of the dynamic nature of equilibrium concept is fairly abstract, since students have to

imagine in microscopic level and cannot observe such things. Hence, help student to overcome the alternative conception about the dynamic nature of equilibrium, the *Small Beads Relay Race Game* was adapted from the *School Dance Analogy* reported by Harrison (2003) and introduced into a lesson dynamic equilibrium. Using this strategy, the students were asked to compare and contrast characteristics of *Small Beads Relay Race Game* with the characteristic of dynamic equilibrium to reach the scientific view of dynamic equilibrium.

2. Eliciting Students' Existing Knowledge as an Important Process

The process of eliciting students' existing knowledge is the initial process of learning from constructivist-based perspectives (Asoko, Leach, and Scott, 1995). Hence, finding out student's existing ideas is seen as important process of learning for the CELU in which the learning process in each lesson of the CELU starts by trying to find out student's existing ideas for the concept under instruction. Examples of activities for seeking student's existing ideas employed in the CELU are: pen and paper test, observation of classroom activities, group and whole-class discussion, and students and teachers questions.

3. Successful Teaching Strategies should be Applied for the CELU

Successful teaching strategies for chemical equilibrium concept derived from the literature were reviewed in Chapter II. One of those teaching strategies is the use of laboratory activities, and this was applied in the CELU. For example, in the lesson about disturbing equilibrium condition by changing temperature, the classical laboratory experiment reported by Spears and Spears (1984) using tetrachlorocobalt (II) ion and tetrahydrate cobalt (II) ion system was used as the learning activity. In this experiment, students observed that the color of that solution changed when the temperature was changed – the cold solution being pink and the warm solution being deep blue. The students were challenged using questions and asked to put forward explanations for the results from the experiment.

4. Social Interaction in the Classroom Supports Learning Science

The activities employed in the CELU emphasized the importance of social process in learning and teaching. Classroom interactions between teacher and students or among students were established to help support the individual student's exploration and negotiations in reaching consensus ideas. Most activities in the CELU encouraged students to work collaboratively in a small group. In these groups, discourse opportunities for students arose allowing them to share ideas with their peers and trying to reach a consensus view. Additionally, the students also had opportunities to express their ideas in whole – class discussion. For example, when doing hands-on and minds-on laboratory work for some lessons in the CELU, the students were assigned to work in group of about 4 – 6 students and students in each group had to share responsibility for doing the laboratory work. After completing the laboratory work, students in each group were asked to discuss the findings and answer the questions provided in worksheets. All of students then were require discussing their findings in whole – class discussions and make conclusion about the findings and to reach the scientific conception for the topic. Activities employed in the CELU were considered to be suitable for Thai classroom context in terms of the amount of students in a classroom, the laboratory instrument available, and the physical environment of the classroom.

5. Various Methods for Assessing Students' Learning Outcomes should be used Through the Assessment Needs to Take Plan Teaching and Learning Process

The aims of the assessment for the CELU were to evaluate students' conceptual understanding, science process skills, and attitude toward chemical equilibrium concept and teaching and learning. The strategies for assessing students' learning outcomes in the CELU wee planned to be consistent with these learning outcomes and the learning activities and comprised both formative and summative assessment during and at the end of the Unit. The student in each group was assessed by their peers and the teacher using observation form which detailed student's

behaviors during the experiment. Students' laboratory reports also were examined as students' seeking information to evaluate the learning outcomes and to give students feedback about their development.

6. Learning Activities Need to Emphasize Conceptions, Science Process Skills, and Attitudes

Learning activities in the CELU mostly were activities which put emphasis on giving students opportunities to test, refine, or consolidate their understanding in new contexts. Teaching strategies which are consistent with constructivist-based perspectives of teaching and learning are applied for the CELU. For example, laboratory and demonstration which emphasize hands-on and minds-on activities are specially focused for supporting students' learning outcomes in terms of conceptions and science process skills. Various learning activities also employed in the CELU, for example games, and the use of analogy.

Finally, the relationship between frameworks underpinning the development of the CELU and guiding principles are summarized as shown in Figure 5.1

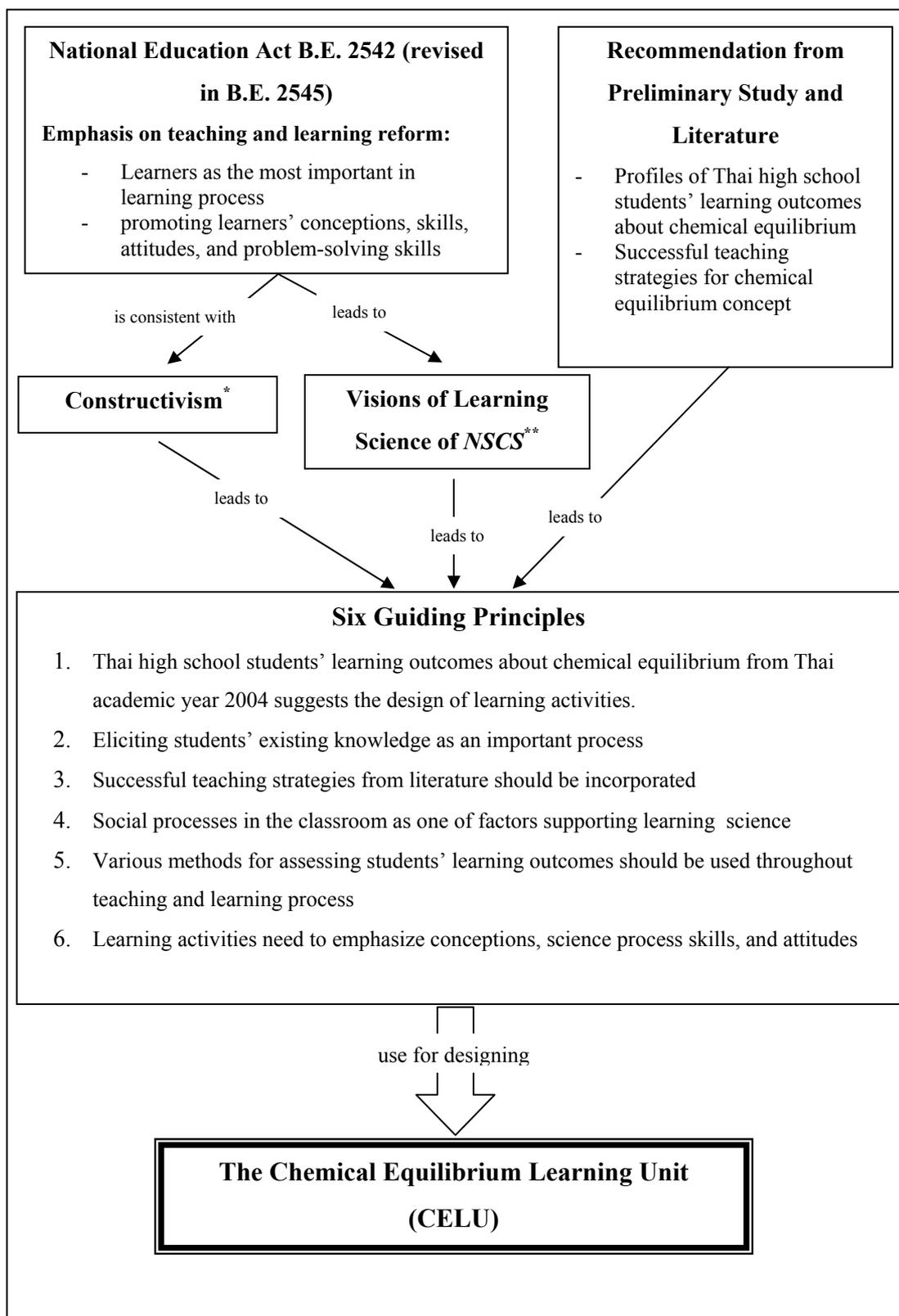


Figure 5.1 An Acquisition of Guiding Principles for the Development of the CELU

The Process of Developing the Chemical Equilibrium Learning Unit

The process of the development of the Chemical Equilibrium Learning Unit (CELU) employed following steps.

1. Exploring Students' Learning Outcomes about Chemical Equilibrium in Academic Year 2004

Student's learning outcomes for chemical equilibrium in 2004 academic year were explored, used when designing the CELU. The findings from this exploration of students' learning outcomes of chemical equilibrium suggested that reasons that why students struggle to understand the chemical equilibrium concept are general difficulty of the concepts, the fact that they are used to learning via memorization, and lack of basic concept knowledge for learning chemical equilibrium concept. These obstacles for learning about chemical equilibrium concepts were considered to be important when designing the learning activities for the CELU (see Section 3.2 – this Chapter).

2. Identifying Expected Learning Outcomes about Chemical Equilibrium

Expected learning outcomes for chemical equilibrium were set drawing on the framework of the *National Science Curriculum Standards* and it was considered that these should be consistent with the visions of science learning described in the previous section. The overall of expected learning outcomes for chemical equilibrium are shown in Figure 5.2

Expected Learning Outcomes about Chemical Equilibrium (For Thai Eleventh-Grade Science Students)

By the end of *Chemical Equilibrium Learning Unit (CELU)*, students are expected to be able to:

1. Identify a definition for reversible reaction, equilibrium state, phase equilibrium, solubility equilibrium, chemical equilibrium, and equilibrium constant.
2. Identify the conditions and the properties of a system at equilibrium state.
3. Write equation to express the relationship between concentration of reactants and of products at equilibrium state.
4. Calculate the equilibrium constant meaningfully, and concentration of the species presented at equilibrium state.
5. Identify the factors that can influence on equilibrium system and explain changes of the system when changes of external conditions occur.
6. Identify the factors that can influence on equilibrium constant and explain the reason.
7. Explain the movement of the position of chemical equilibrium using Le Châtelier's principle, and apply this principle in industrial applications.
8. Explain chemical equilibrium processes in living things, natural phenomena, and the environment.
9. Do experiments, collect data, interpret data, and make conclusion in the following laboratory experiments.
 - The reversible reaction using the reaction between CuSO_4 and HCl
 - The equilibrium in chemical reaction which consists of two experiments
 - Testing of Fe^{3+} , Fe^{2+} and I_2
 - Testing of equilibrium state of Fe^{2+} and Fe^{3+} reaction
 - The effect of changing concentration on equilibrium condition
 - The effect of changing pressure on equilibrium condition
 - The effect of changing temperature on equilibrium condition
10. Realize the importance of share responsibility in explaining, expressing opinions and concluding for scientifically correct presentation to the public.

Figure 5.2 Expected Learning Outcomes of the CELU

Source: IPST (2004)

3. Designing and Developing the Chemical Equilibrium Learning Unit

The Chemical Equilibrium Learning Unit (CELU) was designed and developed in terms of a series of lesson plans. The expected learning outcomes for chemical equilibrium, the content of the concepts, the lesson plan format, the suggested learning and assessment activities were derived from the literature and from the National Science Curriculum Standards in order to try to adapt the CELU for the Thai educational context. A draft of the CELU consisting of a teacher manual and student manual was first written. This draft was validated by four experts namely the advisory committee for the thesis. Three of these experts were science educators specialized in curriculum planning, and pedagogy: two from the Faculty of Education, Kasetsart University, Thailand; and one from the Center for Science Technology Education Research, of the University of Waikato, New Zealand. The other expert was a lecturer from the Faculty of Science, Kasetsart University who specialized in teaching concept for chemical equilibrium. Three of those experts were invited to be in meeting in October, 2004 and were asked to discuss the draft CELU. Research issues, guiding principles and content analysis, and organization of the CELU were introduced to the experts in turn. Then, the experts were asked to validate each lesson of the CELU and to give suggestions about the CELU in terms of expected learning outcomes, chemical equilibrium content, learning activities, and assessment for each lesson plan in the CELU.

4. Revising and Developing Instructional Materials of the Chemical Equilibrium Learning Unit

After receiving suggestions of the panel of experts from the meeting in October 2004, the researcher revised the CELU and subsequently developed instructional materials for each lesson plan for the CELU. Some instructional materials, *Small Beads* and *Chemical Equation Card*, were provided as part of the package for the lesson. However, for instructional materials involving chemical substances, were simply suggested, and details provided of how to calculate and

prepare those substances for each laboratory activity. The chemical apparatus was suggested as a 'laboratory basket' needed for each group of the students and this consists of basic necessary apparatus needed to do laboratory exercises such as test tubes, stirring rods, beakers, conical flasks, and so on.

The CELU package consisted of a teacher manual, student manual, and instructional materials. The package of the CELU were prepared and distributed to the teachers who participated in this study in November, 2004, to continue revising to be appropriate with their students, and then starting the process of implementing the CELU details of which are presented in Chapter VI.

5. Attending Initial Workshop with the Participating Teachers for Revising the CELU before Implementing

Before implementing the CELU in the classroom, the participating teachers were asked to attend the initial workshop. The workshop was programmed for a day. The initial workshop is set for encouraging the teachers to realize the importance of improving teaching and learning about chemical equilibrium in Thai current situation. Three teachers who taught chemical equilibrium concept in Thai academic year 2005 from three schools in Chanthaburi Province and the researcher's supervisors were invited to attend the workshop. The program of the workshop firstly started with the introduction about the rationale and benefit of the implementation of the CELU. Guiding principles underlying the CELU was briefly described. The overview of the CELU was outlined to make the teachers understand the whole CELU. Then, the CELU was introduced the teachers lesson by lesson in terms of expected learning outcomes, key concept, learning activities and instructional materials, and assessment of each lesson. At the end of each lesson, the teachers were given a chance to provide the researcher suggestions or comments about the CELU or to negotiate if they did not agree with the researcher. Feedbacks from those teachers were very important in which they were used for improving the CELU in order to make the CELU more effective especially in real classroom. This process could make the teachers feel as a

part of the development of the CELU and could make the CELU fit with the students and classroom context.

Comparison of Contents and Its Organizations of the Chemical Equilibrium Learning Unit (CELU) and IPST Textbook

Contents and its organizations of the Chemical Equilibrium Learning Unit (CELU) is similar to those outlined in CHEM III which is the IPST textbook for chemical equilibrium concepts. However, the CELU rearranged some topics outlined in CHEM III in which those are suggested by findings from exploratory phase. For example, the topic “dynamic equilibrium”, it was found that most of Thai high school students held misconceptions about dynamic equilibrium. Regard to contents and its organizations of the IPST textbook, dynamic equilibrium is put in the lesson of changes to be equilibrium state which consists of four concepts including dynamic equilibrium. These might be one reason that why Thai high school students held misconceptions. Then, the CELU put the topic of dynamic equilibrium in the second lesson before teaching and learning equilibrium in other conditions. The rearrangement of contents results an increase of the number of topics which called lesson in the CELU but reduces time for teaching of this concepts (as shown in Table 5.1).

Table 5.1 Comparison of the contents and its organization of the CHEM III textbook and the CELU

CHEM III textbook of IPST (Revised in 2001)	The Chemical Equilibrium Learning Unit (CELU)
Lesson 1: Reversible Reaction (1 period)	Lesson 1: Reversible Reaction (2 periods)

Table 5.1 (Continued)

CHEM III textbook of IPST (Revised in 2001)	The Chemical Equilibrium Learning Unit (CELU)
Lesson 2: Changes to be Equilibrium State	Lesson 2: Dynamic Equilibrium
<ul style="list-style-type: none"> • Equilibrium condition in changes of the state of matter • Equilibrium condition in saturated solutions • Equilibrium condition in chemical reactions • Dynamic equilibrium 	(2 periods)
	(4 periods)
Lesson 3: The Relationships between Concentration of Each Substances at the Equilibrium	Lesson 3: Equilibrium in Physical Changes
<ul style="list-style-type: none"> • Equilibrium constant and chemical equation • Calculation of equilibrium constant 	<ul style="list-style-type: none"> • Equilibrium condition in saturated solutions • Equilibrium conditions in the changes of the state of matter
	(1 period)
	(4 periods)
Lesson 4: Factors Affecting Equilibrium Conditions	Lesson 4: Equilibrium Condition in Chemical Reactions
<ul style="list-style-type: none"> • Changes of concentrations • Changes of pressure and temperature 	(3 periods)
	(5 periods)
Lesson 5: Le Châtelier's principle and Its Application for Industry	Lesson 5: Equilibrium Constant Equation
	(1 periods)
	(2 periods)

Table 5.1 (Continued)

CHEM III textbook of IPST (Revised in 2001)	The Chemical Equilibrium Learning Unit (CELU)
Lesson 6: Chemical Equilibrium in Living Things and Environment (4 periods)	Lesson 6: The Relationship between Equilibrium Constant and Chemical Equation (1 period)
Total 20 periods	Lesson 7: The Calculation of Equilibrium Constant (2 periods)
	Lesson 8: Disturbing Equilibrium Condition by Changing concentration (1 period)
	Lesson 9: Disturbing Equilibrium Condition by Changing Pressure (1 period)
	Lesson 10: Disturbing Equilibrium Condition by Changing Temperature (1 period)
	Lesson 11: Application of Chemical Equilibrium <ul style="list-style-type: none"> • Le Châtelier's principle • Chemical equilibrium in living things • Chemical equilibrium in industrial application (3 periods)
	Total 18 periods

Outline and Scope of the Chemical Equilibrium Learning Unit (CELU)

The Chemical Equilibrium Learning Unit (CELU) was designed for Thai Grade-11 students who were doing in science subject. The CELU consists of 11 lessons and takes 18 periods (about 50 minutes per period). The concept and learning activities in each lesson of the CELU are presented in outline in Table 5.2.

Table 5.2 Outline and scope of the Chemical Equilibrium Learning Unit (CELU)

Lesson and Concepts	Teaching Activities	Guiding Principles Used
Lesson 1: Reversible Reaction (2 periods)	<ul style="list-style-type: none">• Probe students' existing ideas about physical change, chemical change, and chemical reaction from the given situations• Discuss about those situation if those are reversible change or not• Ask students to define the reversible change• Do the experiment about chemical reaction which could be reversible in group (4 – 6 students for each group)• Make conclusion of the experiment• Define the reversible reaction, forward reaction, and reverse reaction• Identify reactants, products, forward reaction, and reverse reaction of the reversible reaction	Items 2, 4, , 5, and 6
Lesson 2: Dynamic Equilibrium (2 periods)	<ul style="list-style-type: none">• Probe students' existing ideas about equilibrium from given situation• Play <i>Small Beads Relay Race Game</i> to study about dynamic equilibrium• Compare and contrast the characteristic of <i>Small Beads Relay Race Game</i> to the characteristic of dynamic equilibrium• Identify the conditions of the reaction/change which could be in dynamic equilibrium	Items 1, 2, 3, and 4

Table 5.2 (Continued)

Lesson and Concepts	Teaching Activities	Guiding Principles Used
<p>Lesson 3:</p> <ul style="list-style-type: none"> • Equilibrium condition in the saturated solution • Equilibrium condition in the changes of the state of matter <p>(1 period)</p>	<ul style="list-style-type: none"> • Probe students' existing ideas about the system (closed system and open system) from the given situations • Ask students to define about closed system • Do the experiment to find out the condition of the change which could be equilibrium in group (4 – 6 students for each group) • Discuss and conclude about the results from the experiment • Describe the equilibrium condition in the saturated solution and the equilibrium condition in the changes of the state of matter • Identify the conditions which are needed for the changes to be equilibrium • Use the equilibrium condition in the saturated solution and in the changes of the state of matter to explain the changes of perfume in the closed bottle. 	<p>Items 2, 4, 5, and 6</p>

Table 5.2 (Continued)

Lesson and Concepts	Teaching Activities	Guiding Principles Used
Lesson 4: Equilibrium condition in the chemical reaction (reversible chemical reaction) (3 periods)	<ul style="list-style-type: none">• Ask students to exemplify the changes in their daily which could be in equilibrium• Ask students to divide into a group (4 – 6 students for each group)• Do experiment to remind how to test substances and ions (I_2, Fe^{3+}, and Fe^{2+})• Summarize how to test substances and ions• Use the knowledge about testing substances and ions, and conditions which could be in equilibrium to study equilibrium in chemical reaction by doing experiment• Compare and contrast equilibrium conditions in the chemical reaction to equilibrium conditions in the saturated solution and in the changes of the state of matter• Consider the graph presenting concentration of substances in the reaction versus time if that reaction is in equilibrium or not	Items 2, 4, 5, and 6

Table 5.2 (Continued)

Lesson and Concepts	Teaching Activities	Guiding Principles Used
<p>Lesson 5: Equilibrium constant equation (1 period)</p>	<ul style="list-style-type: none"> • Probe students' existing ideas about balancing chemical reaction, coefficient of mole • Find the algebra relationship among reactants, products, and coefficient of mole in the chemical equation from the given situation. • Conclude the algebra relationship which lead to numerical constant • Define equilibrium constant and express how to write equilibrium constant equation. • Express equilibrium constant equation of the given reactions 	<p>Items 1, 2, and 3</p>
<p>Lesson 6: The relationship between equilibrium constant and chemical equation (1 period)</p>	<ul style="list-style-type: none"> • Ask students to write equilibrium constant equation of each given reaction • Provide <i>Chemical Equation Cards</i> to the students in each group and ask students to group those cards depending on their relationship • Conclude the relationship between equilibrium constant and chemical equation 	<p>Items 1, 3, and 6</p>

Table 5.2 (Continued)

Lesson and Concepts	Teaching Activities	Guiding Principles Used
Lesson 7: The calculation of equilibrium constant (2 periods)	<ul style="list-style-type: none">• Probe students' existing ideas about the concentration and equilibrium constant equation• Present the strategies to calculate equilibrium constant and provide the meaning of equilibrium constant• Ask students to summarize how to calculate equilibrium constant• Assign students to calculate equilibrium constant in other reaction	Items 1, 2, 3, 4, and 6
Lesson 8: Disturbing equilibrium condition by changing concentration (1 period)	<ul style="list-style-type: none">• Demonstrate the chemical reaction between Fe^{2+} and Fe^{3+} which is in equilibrium• Challenge students to predict what happen if some chemical substances are added into the equilibrium• Do experiment and make conclusion to test the prediction• Provide experimental data done by scientist and ask student to consider if changing concentration of substance at the equilibrium affect the equilibrium constant or not	Items 1, 3, 4, and 6

Table 5.2 (Continued)

Lesson and Concepts	Teaching Activities	Guiding Principles Used
<p>Lesson 9: Disturbing equilibrium condition by changing pressure (1 period)</p>	<ul style="list-style-type: none"> • Give students an example of chemical equilibrium in soft drink, <i>Soda or Coke</i> • Discuss about that example in terms of what if the bottle of soft drink is shaken and what if that is opened • Demonstrate the reaction between NO_2 and N_2O_4 • Discuss and conclude about the demonstration • Assign students to study about the effect of changing pressure to the equilibrium constant 	<p>Items 1, 2, 3, 4, and 6</p>
<p>Lesson 10: Disturbing equilibrium condition by changing temperature (1 period)</p>	<ul style="list-style-type: none"> • Ask students to exemplify endothermic and exothermic reaction • Discuss about those examples and define endothermic and exothermic reaction • Do experiment in group about the effect of changing temperature to equilibrium condition of the reaction of $[\text{Co}(\text{H}_2\text{O})_4]^{2+}$ and HCl • Study in group about the effect of changing temperature to the equilibrium constant using the given experimental data • Discuss and conclude about the effect of changing temperature to the equilibrium conditions 	<p>Items 1, 3, 4, 5, and 6</p>

Table 5.2 (Continued)

Lesson and Concepts	Teaching Activities	Guiding Principles Used
<p>Lesson 11:</p> <ul style="list-style-type: none"> • Le Châtelier’s principle • Chemical equilibrium in living things and in industrial applications <p>(3 periods)</p>	<ul style="list-style-type: none"> • Probe students’ existing ideas about the concept of factors affecting equilibrium condition • Discuss about effect of changing concentration, pressure, and temperature to the equilibrium conditions in order to introduce Le Châtelier’s principle • Instruct about the scientist named Le Châtelier • Predict the changes of equilibrium condition in each situation by using Le Châtelier’s principle • Study in group about chemical equilibrium in living things and in industrial applications from the following topic: <ul style="list-style-type: none"> ○ Haber process ○ The synthesis of sulfur trioxide, and fosgene gas ○ The equilibrium condition of the respiration in the living things ○ The effect of climate to eggshell ○ Causes of Tooth decay from eating candy • Plan how to study those topics in terms of the investigated topic or questions, learning resources, and presentation • Present the results from the study to the other group • Assess students’ understanding of those topic and conclude the concept of chemical equilibrium in living things and industrial applications 	<p>Item, 1, 2, 3, 4, 5, and 6</p>

Summary of the Chapter

The aim of the CELU is to promote Thai eleventh-grade students' learning outcomes about chemical equilibrium. The CELU was developed for serving the science students who focus their emphasis on science content for their further study. This chapter discussed the development of the Chemical Equilibrium Learning Unit (CELU) in terms of framework underpinning the development of the CELU which are constructivism, the visions of learning science stated in the National Science Curriculum Standard, and recommendation from literature. These frameworks influence to guiding principles for developing the CELU. There are six guiding principle derived from those frameworks as shown as the following.

1. Eliciting students' existing knowledge as an important process
2. Providing learning activities to emphasize conceptions and science process skills
3. Social processes in the classroom as one of factors supporting learning science
4. Various methods for assessing students' learning outcomes should be used throughout teaching and learning process
5. Successful teaching strategies from literature should be applied for the CELU
6. Thai high school students' learning outcomes about chemical equilibrium from Thai academic year 2004 suggests promoting learning outcomes, especially conceptions and science process skills.

After receiving guiding principles, the development of the CELU starts by these processes.

1. Exploring Students' Learning Outcomes about Chemical Equilibrium in Academic Year 2004

2. Identifying Expected Learning Outcomes about Chemical Equilibrium

3. Designing and Developing the Chemical Equilibrium Learning Unit

4. Revising and Developing Instructional Materials of the Chemical Equilibrium

5. Attending Initial Workshop with the Participating teachers for Revising the CELU Before Implementing

Finally, the CELU consist of 11 lessons covering five concepts of chemical equilibrium. Series of lesson plans of the CELU are ranged as follows: reversible reaction, dynamic equilibrium, equilibrium condition in the situated solution and in the changes of the state of matter, equilibrium condition in chemical reaction, equilibrium constant equation, the relationship between equilibrium constant and chemical reaction, the calculation of equilibrium constant, disturbing equilibrium condition by changing concentration, disturbing equilibrium condition by changing pressure, disturbing equilibrium by changing temperature, and Le Châtelier's principle and chemical equilibrium in living things and in industrial applications. The overall of the CELU was briefly presented in Table 5.2.

Then, in next chapter, the process of implementation the CELU and effect of the CELU to students' learning outcomes were being presented and discussed.

CHAPTER VI

IMPLEMENTATION OF CHEMICAL EQUILIBRIUM LEARNING UNIT (CELU): FINDINGS FROM 2005 ACADEMIC YEAR

Overview of the Chapter

The previous chapter describes the process of the development of the Chemical Equilibrium Learning Unit (CELU). It focuses on the theory and principles underlying the development of the CELU rather than the strategy of the implementation. This chapter details the program for implementing the CELU which was set as the initial workshop and the meetings. This chapter presents data gathered in Phase II: Development and Implementation of the Chemical Equilibrium Learning Unit.

The case studies of three chemistry teachers have been described. The findings from this implementation during Thai 2005 academic year are described as an in-depth description of each case. The results from of each case are shown in terms of contexts of the study, how teacher implemented the CELU, how students learn during implementing the CELU, and students' learning outcomes for chemical equilibrium after implementing the CELU. Then, findings from three case studies are summarized and described. Each aspect involving the implementation of the CELU is described in the following sections.

Program for Implementing the Chemical Equilibrium Learning Unit (CELU)

The program for implementing the Chemical Equilibrium Learning Unit (CELU) could be liken to teacher conferences which consisting of the initial

workshop and three meetings. The outline of the program is shown in Figure 6.1. The details of the program are described.

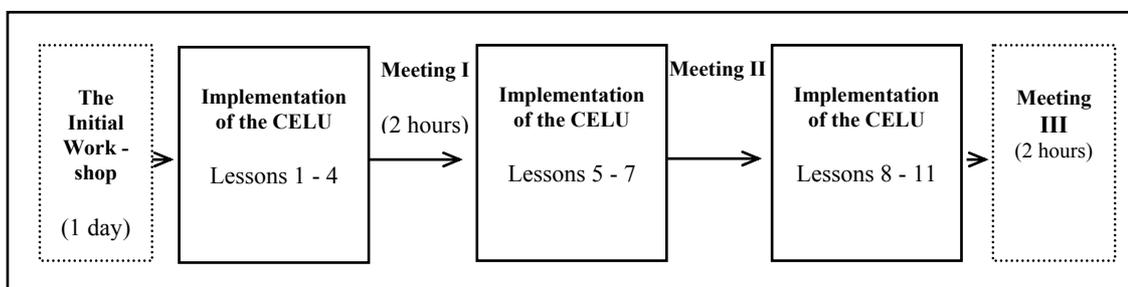


Figure 6.1 Outline of the Program for Implementing CELU

1. Initial Workshop

The workshop was programmed for one day. The aim of the workshop was to encourage the teachers who participated in this study to recognize the benefit of teaching chemical equilibrium concept by using the Chemical Equilibrium Learning Unit (CELU). Details of the initial workshop were described in the processes of developing the CELU in Chapter V.

2. Meetings

The three meetings between the researcher and three participating teachers were set during and after the implementation of the CELU. Meeting I and Meeting II were arranged during the implementation of the CELU. The aim of both meetings was to support the implementation of the CELU in the classroom to make it more effective. Both meetings were arranged on Friday afternoon during the implementation of the CELU (after completing lesson 4 and lesson 7). For each meeting, the teachers started with the reflection on their teaching discussing whether their teaching was consistent with the plan, students' responses to the CELU, and problems and limitations of the implementation of the CELU. Data from classroom observations also were presented to the teachers. Then, the teachers and the researcher

discussed those situations to reach the best solution to avoid obstacles to teaching and learning that might occur in the next lesson. Finally, the planning for further implementation of the CELU was introduced and an appointment for the next Meeting was scheduled.

The aim of Meeting III was similar to both previous meetings but it also aimed to ask the teachers to reflect on the overall implementation of the CELU and evaluation of the implementation of the CELU. Meeting III was arranged for two hours on Friday afternoon after completing the last lesson of the CELU. Each teacher was asked to describe her thoughts in terms of the advantages and limitations of the implementation of the CELU.

3. Summary of the Program for Implementing the CELU

The aim of the program for implementing the CELU is to give the teachers a chance to be involved in the development and implementation of the Chemical Equilibrium Learning Unit (CELU). It consisted of a workshop and meetings between the researcher and the teachers who volunteered to participate in the research. The teachers were asked to attend the program to help the teachers themselves to understand the constructivist-based perspectives and rationale of the implementation of the CELU. The workshop was carried out before the implementation of the CELU to give the teachers a chance to work collaboratively with the researcher in the process of the improving the CELU so it would be suitable in the real classroom situation and to persuade the teachers to recognize the benefit of the implementation of the CELU. Then, the CELU was implemented in the classroom and the meetings between the researcher and the teachers were carried out during and after the implementation. The overview of the program is summarized and shown in Table 6.1.

Table 6.1 Overview of program for implementing the CELU

Initial Workshop (21 Nov 2005)	Meeting I (20 Jan 2006)	Meeting II (17 Feb 2006)	Meeting III (20 Mar 2006)
<ul style="list-style-type: none"> • Overview of the research study and rationales for improving teaching and learning about chemical equilibrium • The guiding principles of developing the CELU • The content of the CELU (lesson plans 1 – 11, teacher manual, student manual, and teaching materials) • The role of the researcher and the teachers in the study and overview of the program of the meetings 	<ul style="list-style-type: none"> • Reflections on the implementation of the lessons 1 – 4 of the CELU in classrooms • Students’ responses to the teaching and learning via using the CELU • Problems concerning teaching and learning from each teacher and the strategies for improvement • Comments or suggestions from the researcher and teachers • Program of the next meeting 	<ul style="list-style-type: none"> • Reflections on the implementation of the lessons 5 – 7 of the CELU in classrooms • Students’ responses to the teaching and learning via using the CELU • Problems concerning teaching and learning from each teacher and the strategies for improvement • Comments or suggestions from the researcher and teachers • Program of the next meeting 	<ul style="list-style-type: none"> • Reflections on the implementation of the lessons 8 – 11 of the CELU in classrooms • Students’ responses to the teaching and learning via using the CELU • Problems concerning teaching and learning from each teacher • Evaluation of the overall implementation of the CELU

The next section describes the findings from the implementation of the Chemical Equilibrium Learning Unit (CELU) in terms of how each teacher implemented the CELU, how students learned chemical equilibrium concept, and students' learning outcomes for the chemical equilibrium concept. The findings are described as three case studies from School A, School B, and School C. For each case study, the context of each case is initially introduced to the reader. Then, the findings from the implementation of the CELU are presented.

Case Study One [School A]: Findings from the Implementation of Chemical Equilibrium Learning Unit (CELU)

1. Context of the Case Study One: School A

1.1 School Context

School A is a large government secondary school located in an urban area of Chanthaburi Province in the eastern part of Thailand. The total number of students in Thai 2005 academic year was about 4000 students of which there were about 2000 girl students in lower secondary level (Grade 7 to Grade 9) and there were about 1900 girl students and about 200 boy students in the upper secondary level (Grade 10 to Grade 12). The students came variously from low to high income families. There were 14 science teachers from a total of 123 teachers in the school. In the 2005 academic year, the ratio of science teachers to students was 1:33. There were 13 classrooms of Grade 11 level. Five of these classrooms were called *Science and Mathematics Program* classrooms. The science subjects of upper secondary level are Physics, Biology, and Chemistry. The students in the *Science and Mathematics Program* had to study science subjects for nine periods a week, three of which were Chemistry. Each period was about 50 minutes. In total, these students had to study Chemistry for 48 periods per semester. However, in the second semester of 2005 academic year, there were a number of public holidays and school activities, so there were only about 35 periods per semester for studying Chemistry. For Grade 11, the

students who were in the *Science and Mathematics Program* were to study chemical equilibrium concepts for 18 periods.

1.2 Classroom Context

The chemical equilibrium concept was taught in a chemistry laboratory room. There were four chemistry laboratory rooms in the school. Each room was decorated in the similar pattern. The teacher's desk, which was about 2.5 meters long, was placed in front of the laboratory room. Beside the teacher's desk was a television. There were many cupboards placed at the back and at one side of the room, near the wall. The scientific instruments were inside the cupboards. On one other side of the laboratory room, near the windows, there were eight sinks on the top of cupboards. There were twelve tables and about fifty chairs in the classroom. During study, the students were divided into ten groups and sat around a table as shown in Figure 6.2.

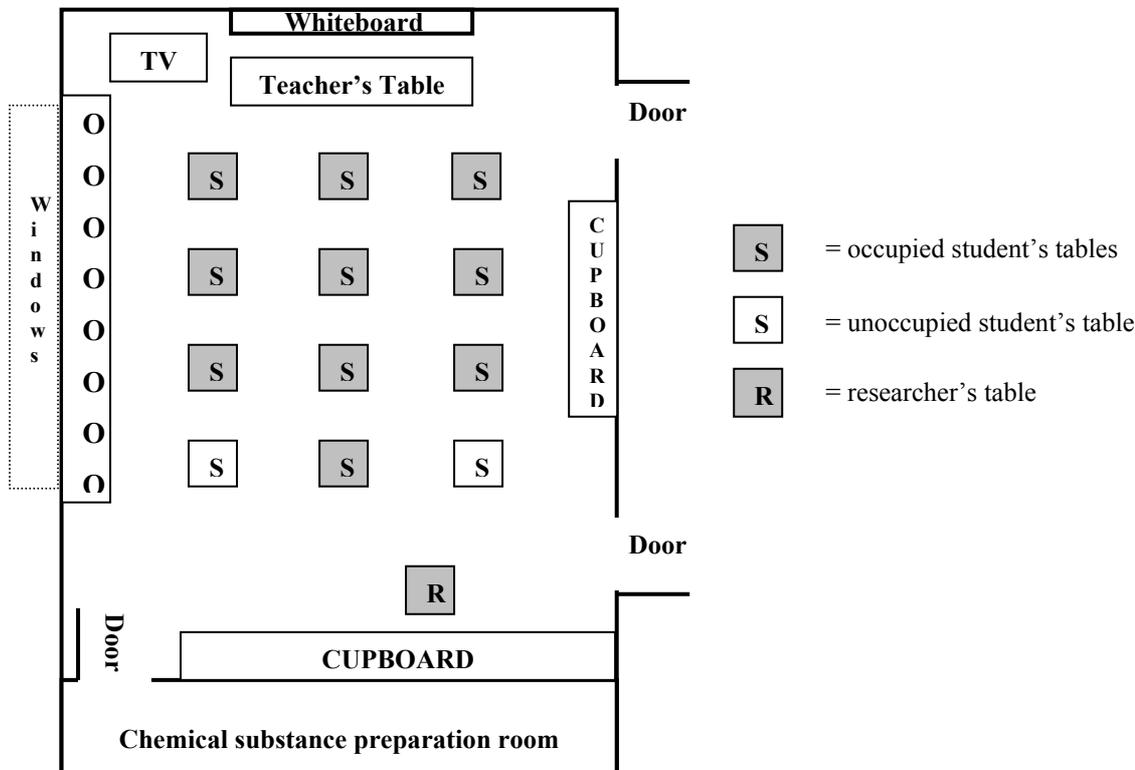


Figure 6.2 Classroom Context of School A

1.3 Teacher's Background

Mrs. Malinee was a 40-year-old teacher. Her formal qualification is a Bachelor degree in secondary education majoring in chemistry. She had fourteen year's experience in secondary science teaching both in lower and upper secondary levels. She was interested in improving her teaching. She once attended in professional development program set by IPST. She had normally taught at Grade 11 level but she had not taught the chemical equilibrium concept. Because of the education reform, teaching and learning about the chemical equilibrium concept had been moved from Grade 12 to Grade 11. So, it was the first time for her to teach the chemical equilibrium concept. She believed that she had no problem with the concept, but, she still felt uncomfortable to teach chemical equilibrium. She was interested in the implementation of the CELU and wanted to participate in the research study.

1.4 Students' Background

Forty eight girl students who were in Grade 11 and studied chemistry with Mrs. Malinee in the second semester of Thai 2005 academic year participated in this research study. Most students in this classroom had high competencies when compared to other students. In 2004 academic year, forty three of those students were ranged in top ten score of all students in the *Science and Mathematics Program*. The participating students aimed at entrance into a famous university of Thailand, especially in Faculty of Medicine, Engineering, Pharmacy, or Science. Consequently, they paid more attention in studying Science, Mathematics and English subjects.

2. Teacher's Implementation of the CELU in the Classroom

As mentioned above, the teachers who participated in this study had a chance to be a part of the process of developing the CELU. The initial workshop allowed the teachers to improve the CELU to be more effective. Before implementing the CELU in her classroom, Mrs. Malinee had about four weeks to prepare herself. She started to

implement the CELU by the last week of December, 2005 and finished by the third week of February, 2005. In total, she spent 18 periods for implementing the CELU. This section focuses on the way in which Mrs. Malinee had implemented the CELU in her classroom.

2.1 Teaching Preparation

Mrs. Malinee nicely prepared herself for the implementation of the CELU. Before implementing each lesson plan, she often asked the researcher to clarify some doubts she had in that lesson. At the beginning of the implementation, Mrs. Malinee was rather worried about the implementation of the CELU. By the end of each lesson plan, she often asked the researcher whether her teaching was nice or consistent with the plan. She wanted the researcher to reflect on her teaching. She said that she was not familiar with the teaching strategies and learning activities employed in the CELU and believed that reflection could help her improve her own teaching.

2.2 Teaching Practice

Mrs. Malinee's teaching process followed the teacher manual of the CELU. At the beginning of the implementation, Mrs. Malinee tended to be a traditional teacher who emphasized the transmission of knowledge. Although Mrs. Malinee often asked the questions, those questions did not aim to seek students' information but were usually aimed to assess in terms of what the teacher had already known. These strategies look like informing knowledge using questions to drive conversation. She believed that the students understood the concept that had been taught but they were not familiar with answering the questions. She said that she had to give students time for adaptation.

I thought that my students did not respond to the questions as much as I expected. But I believed that these students understood what had been taught. Maybe these students were not familiar with the way of learning in this style,

same as me. I thought that I should sometimes aid students to answer the questions. Then, I sometimes told student's the concept. It was easier and faster than this strategy [constructivist-based teaching]. I knew that it was not good but my students needed time to change their behavior during teaching and learning.

Mrs. Malinee, reflection on her first teaching

However, data from classroom observations showed that Mrs. Malinee had changed her teaching strategies noticeably. After the Meeting I, her teaching practice had approached constructivist-based teaching rather than having an emphasis on transmitting of knowledge from the teacher to students. The evidence which showed that Mrs. Malinee's teaching practice tended to be constructivist-based perspectives was the way of asking questions, the realization of students' prior knowledge, the teaching activities, and the strategies for assessment.

2.2.1 The Way of Asking Questions

Although the students rarely answered the questions, Mrs. Malinee still asked the questions for motivating student to think about what they had known. When she found that students did not answer the questions, she changed the words used in such question and asked students again. The findings showed that students were not able to completely answer the questions at the beginning of the implementation of the CELU. Students usually answered only key words, either individually or collectively. Mrs. Malinee attempted to complete students' answers by rearranging the answers or by repeating those answers to the whole class again. Here, students' contribution to conversations increased. Subsequently, conversations between the teacher and students in classroom were driven by students' explanations. For example, one student was concerned that cutting an apple into small pieces is chemical change.

- S11: From the definition of physical change, can cutting an apple into small pieces be a physical change because it is the changing in shape of the matter?
- Malinee: Students, could you help your friend to answer the question? Do you think cutting apple to be small pieces can be physical change?
- Students: Yes.
- S21: Can be both.
- Malinee: Why do think like that?
- S21: ...
- Malinee: How do you identify each type of the change?
- Students: Considered from new substances whether they have occurred or not.
- Malinee: Then, do you think cutting apple to be small pieces should be physical change or chemical change?
- S21: Could be both.
- Malinee: Why?
- S21: Apple changes to be small pieces and they become dark.
- Malinee: Then, if you would like to consider whether it is a physical change or chemical change, you have to observe what happens. You should draw a conclusion from your observations and provide the reason. Which type can cutting apple to be small pieces is?
- Students: Both.

As shown above, conversation between Mrs. Malinee and students first started from a student's ambiguity about the change of cutting apple into small pieces. The student acted as an important person who drove that conversation. Mrs. Malinee did not answer the students directly but asked the other students to think about that student's questions. She continuously asked the questions based on previous students' explanations or students' answers. This showed that Mrs. Malinee

realized the importance of students' answers and explanations. She believed that students understood the concept if they could explain the given situation reasonably. This meant that Mrs. Malinee evaluated students' understanding from their answers or from their questions.

2.2.2 Realization of Importance of Students' Prior Knowledge

Mrs. Malinee also realized the importance of students' prior knowledge. She believed that each student has different way of thinking. Before teaching a new concept, Mrs. Malinee usually spent ten minutes for each lesson to find out students' prior knowledge as suggested in the CELU. She normally asked the questions about necessary prior knowledge for learning new concept. Fortunately, students in Mrs. Malinee's students were high competency students. Those students could answer Mrs. Malinee's questions correctly. Data from observation showed that Mrs. Malinee not only used questions for finding out students' prior knowledge, she also asked students to give her examples and provide reasons. For example:

- Malinee: You have studied physical changes that could be equilibrium. Could you please tell me what they are?
- Students: Equilibrium in saturated solution and equilibrium of changing the state of matter.
- Malinee: Could you please give me some examples of that equilibrium.
- S11: Sublimation of Iodine.
- Malinee: Is that an example of equilibrium in a saturated solution or equilibrium of changing the state of matter?
- S11: Equilibrium of changing the state of matter.
- Malinee: What are conditions indicating that the example is equilibrium of changing the state of matter?
- S11, S12: Occurring in closed system/ Reversible reaction.
- Malinee: Very good. O.K. Anything else?

- S21: The rate of forward reaction must be equal to the rate of reverse reaction.
- Malinee: Well done. Could you please summarize the equilibrium of changing the state of matter?

Conversation between Mrs. Malinee and students is interesting. It appears to reflect that Mrs. Malinee attempted to probe students' understanding about equilibrium of physical change by asking students to provide example of that equilibrium rather than directly asking for meaning of that equilibrium. After providing some examples, Mrs. Malinee asked students to summarize the concept about the equilibrium of changing the state of matter before introducing new concept.

2.2.3 The Teaching Activities

Teaching activities which were employed in Mrs. Malinee's classroom were various. Mrs. Malinee tried to follow teaching activities as described in the CELU (teacher manual). She gave students opportunities to do hands-on experiments and to discuss with their friends in the group before sharing their ideas to the whole class in order to summarize the concept by themselves. This showed that Mrs. Malinee emphasized social process. She believed that giving opportunities students to discuss in groups could help students to understand the concept. However, during discussion within groups, Mrs. Malinee did not leave students by themselves completely. She usually walked around the classroom and discussed with students in each group by asking students some questions or answering students' questions. If she found that all students had completed the discussion, she went in front of the classroom and asking students to discuss within the whole class.

Interestingly, although Mrs. Malinee seemed to do not emphasize hands-on activities before the implementation the CELU, she slowly realized the importance of teaching by using hands-on activities. At the beginning of the implementation of the CELU, Mrs. Malinee asked the researcher to omit some

activities because she was worried about time limitations. After talking with the researcher, Mrs. Malinee had changed her mind. Only one activity, the experiment of an example of equilibrium in chemical reaction was adapted to suit her students. She gave the reason that this experiment was too difficult for students to do by themselves because it consisted of three sub-experiments which involved various chemical substances and it took a lot of time. However, she had realized that students could better understand if they had a chance to do experiment or to observe the results of the experiment. Then she made decision to demonstrate this experimentation. Mrs. Malinee asked students to observe and record the results of the experimentation by themselves. Mrs. Malinee followed other activities in the CELU as described in the teacher manual.

2.2.4 Strategies for Assessment

Mrs. Malinee employed various ways for assessing student learning, for example discussion (asking and answering questions), worksheet, presentation, or using test. Mrs. Malinee assessed student learning throughout the teaching and learning process, from the beginning to the end. She used students' answers to assess students' understanding of the concept. She believed that students understand the concept if they could answer the questions. She usually gave students feedback if students could answer her question correctly, for example 'Very good,' 'Well done' or 'O.K.' She normally explained or provided more information if she found that students did not answer her questions. This showed that Mrs. Malinee provided feedback on both students' strengths and weaknesses. It seems to show that Mrs. Malinee realized the importance of assessment which did not only grade students but also monitored students' progress in order to help students develop their understanding of the concept.

2.3 Summary of Teacher's Implementation of the CELU into the Classroom

In conclusion, Mrs. Malinee taught the chemical equilibrium concept following the instructions of the CELU. She tried to follow each step of teaching as detailed in teaching manual as much as possible. She understood about constructivist-based approach and employed that in her classroom by using various techniques in her teaching practice; the way of asking questions, the importance student's prior knowledge, various teaching activities, and the strategies for assessment. She accepted that the CELU is effective for her classroom. However, she argued that some learning activities might be adapted to suit her students. This showed that Mrs. Malinee emphasized students' abilities and she made decisions to select learning activities based on students' abilities. It could be seen that Mrs. Malinee noticeably changed from a traditional teacher who emphasized instructing knowledge to being a teacher who employed a constructivist-based approach.

3. Students' Learning about Chemical Equilibrium during the Implementation of the CELU

This section focuses on the way students' learned about chemical equilibrium during the implementation of the CELU. Data from various sources, for example, classroom observations, interviews, or student's worksheets, were used to describe how student learn about the chemical equilibrium concept. The factors involved in students' learning are discussed below.

3.1 Doing Hands-on and Mind-on Activities

The CELU emphasized the importance of hands-on and mind-on activities. Students were encouraged to be involved with such activities in every lesson plan. The findings revealed that hands-on and mind-on activities could help students to understand the chemical equilibrium concept. For example, instead of

teaching the concept of the dynamic equilibrium by lecturing, students were challenged to study this concept by using the *Small Bead Game*. The *Small Bead Game* was adapted based on the concept of “*School Dance Analogy*” (Harrison, 2003). The findings showed that this activity could enhance students’ understanding of dynamic equilibrium. Students could imagine what happened while reversible changes were in equilibrium. Students defined the dynamic equilibrium based on the data from *Small Bead Game*. For example:

At the [dynamic] equilibrium, something is constant because the rate of forward is equal to the rate of reverse reaction. But the amount [of substances] is not necessary to be equal. As seen from the game, the amount of small beads is constant but is not equal. The change is in equilibrium since there are both forward and reverse changes with the same rate and continuously occurring.

Montira’s (pseudonym) worksheet

As shown above, it seems to be that students imagined the characteristics of dynamic equilibrium by comparing them with the game. However, the findings suggested that for doing hands-on and mind-on activities, students should realize the aim of the activity. The results from the activities should be discussed either in groups or in the whole class to approach the concept. These could help the students to better understand the concept.

3.2 Classroom Interaction

Students in Mrs. Malinee’s classroom were challenged with a number of questions during teaching and learning about the chemical equilibrium concept in the CELU. Asking questions could encourage students to think about what they are learning and could help them understanding the concept, as detailed in section 2.2.1. At the beginning of the implementation, students answered Mrs. Malinee’s questions by using key words. Mrs. Malinee had to help them to rearrange their words. This

strategy was useful for students. After that, students noticeably changed the style of answering the questions from using key words to using sentences. It could be noted that there were two important factors that to be aware of during asking questions: (a) characteristics of the questions, and (b) teacher's feedback.

Findings from classroom observations suggested that the characteristics of questions were that they should be open-ended questions which challenged students to think about them, rather than Yes-No questions. The teacher could continuously bring student's answers or explanations to become the topic of ongoing conversations. Students might answer the questions either correctly or incompletely. Ongoing conversations between the teacher and students in Mrs. Malinee's classroom were mostly driven based on students' explanation. Besides, questions are not necessarily generated from a teacher. Students should be encouraged to generate questions. This showed that students were emphasized as being important persons of the ongoing conversation. It could be noted that students might develop their understanding about the chemical equilibrium concept from ongoing conversations, especially conversations between Mrs. Malinee and all the students in the classroom.

The teacher's feedback was another important factor that could drive conversations effectively. Mrs. Malinee usually gave students feedback to motivate students' answers and explanations. When students answered or explained some situation wrongly, Mrs. Malinee did not indicated that those answers were wrong. She usually asked other students to answer the question again or provided some explanations to students. Then, students were comfortable to answer the question or provide some explanation. As seen from classroom observation, after engaging teaching and learning process based on the CELU, students answered Mrs. Malinee's questions increasingly. Sometimes, students acted as curious people who generated the questions and contributed to conversations with the others. When students dared to share their ideas with the others, they could compare and assess their understanding about such concepts. Teacher's feedback was one of factors that could help students enhance their understanding of the concept they had learnt.

3.3 Working in Groups

In process of teaching and learning about chemical equilibrium by using the CELU, students were encouraged to work in groups. All students in Mrs. Malinee's classroom were high competency students, especially in Science and Mathematics subjects. Students divided into groups by themselves. Classroom observations of teaching and learning chemical equilibrium which were involved with doing laboratory indicated that students' understanding could be enhanced working in a group. After observing the findings from the laboratory, students usually spent a little time to discuss the findings and attempted to draw conclusions within their group. Then, they were asked to share their findings to the whole class. The interview with students also indicated that most of the students usually began to ask questions with their peers in the group. They discussed those questions before contributing those questions to the teacher. Sometimes, the puzzles were not posed to the teacher if there was someone in a group who could clarify them. This indicated that working in groups was one of the important factors that could help students to develop their understanding of the chemical equilibrium concept.

3.4 Self and Peer Assessment

Student self-assessment was focused on during the implementation of the CELU. There was more emphasis on encouraging students to reflect and to assess their own progress throughout the process, not just at the end of teaching and learning about the chemical equilibrium concept. Students could benefit from assessing themselves, especially writing in a student's thinking book. At the end of each lesson, students were asked to summarize and write the concept that they had learnt from the lesson, questions, curiosity about the concept, and suggestions for improving teaching and learning about chemical equilibrium concept. These meant that at least students were encouraged to prepare themselves before learning the next concept. As Mayuree (a student in Mrs. Malinee's classroom) described:

Student's thinking book looks like a tool which reminds me about what I have learnt in such lesson. Amm.... It is quite useful for me but I sometimes don't like to write things down in the book. But when I have to write, at least I have summarized my understanding, especially before learning the next topic.

In addition, each student was assessed by her peers during group work activities. This process could encourage students to work collaboratively with their friends. Here, students' responsibilities were realized as being important for teaching and learning about the chemical equilibrium concept. Data from classroom observations showed that students in each group clearly assigned duties for each person. However, they still worked or studied together. For example, in doing laboratory, each student knew her duty in such laboratory but she sometimes helped her friend, too.

3.5 Summary of Students' Learning about Chemical Equilibrium during the Implementation of the CELU

In conclusion, students in Mrs. Malinee's classroom were encouraged by the CELU to noticeably change from being passive students to being active students. Students engaged in doing hands-on and mind-on activities in the classroom rather than passively listening to information from the teacher. Then, ongoing conversations between the students and the teacher or among a group of students could be seen in the classroom. Normally, ongoing conversations were iterative. Students and the teacher had opportunities to share their ideas together. It could be noted that the types of questions and teacher's motivation were important factors in making the ongoing conversation effective. Working in groups or self and peer assessment also were important factors of students' learning about the chemical equilibrium concept. This could help students to develop their thinking ability and enhance their understanding of the concept.

4. Students' Learning Outcomes for Chemical Equilibrium after the Implementation of the CELU

To study the effect of the CELU on students' learning outcomes, the Chemical Equilibrium Concept and Integrated Science Process Skills Survey and Students' Attitudes Survey were administered to the students in Mrs. Malinee's classroom after completely implementing the CELU. This section focuses on students' learning outcomes for chemical equilibrium in terms of students' conceptions of chemical equilibrium, students' integrated science process skills for chemical equilibrium, and students' attitudes toward teaching and learning about chemical equilibrium. The details of each topic were described below.

4.1 Students' Conceptions of Chemical Equilibrium

Students' conceptions of chemical equilibrium were explored by using the Chemical Equilibrium Concept and Science Process Skills Survey after completing the CELU. The students' conceptions about chemical equilibrium which were sought consisted of five topics: changes to achieve equilibrium, equilibrium in chemical reaction, equilibrium constant, factors affecting equilibrium conditions and Le Châtelier's principle, and equilibrium in living things and in industrial applications. Students' responses to the survey were sorted into five categories: sound understanding (SU), partial understanding (PU), partial understanding with specific misconception (PU&MU), misconception (MU), and no understanding (NU) as detailed in Chapter III: Methodology. The results from survey are shown in Table 6.2

Table 6.2 Distribution of students' conceptions about chemical equilibrium: findings from School A (N = 48)

Topics	No. of students (percentage)				
	SU*	PU*	PU & MU*	MU*	NU*
Changes to achieve equilibrium	43 (89.6)	5 (10.4)	-	-	-
Equilibrium in chemical reaction					
• Reaction of hydrogen gas and iodine gas	34 (70.8)	8 (16.7)	6 (12.5)	-	-
• Ammonia production by Haber process	16 (33.3)	-	30 (62.5)	2 (4.2)	-
Equilibrium constant					
• Equilibrium expression	48 (100)	-	-	-	-
• Calculating equilibrium constant	45 (93.8)	3 (6.2)	-	-	-
• Interpreting equilibrium constant	48 (100)	-	-	-	-

*SU = Sound understanding, PU = Partial understanding, PU & MU = Partial understanding with specific misconception, MU = Misconception, NU = No understanding

Table 6.2 (Continued)

Topics	No. of students (percentage)				
	SU*	PU*	PU & MU*	MU*	NU*
Factors affecting equilibrium condition and Le Châtelier's principle					
• Disturbing equilibrium condition by changing concentration	37 (77.1)	11 (22.9)	-	-	-
• Disturbing equilibrium condition by changing pressure	38 (79.2)	2 (4.2)	5 (10.4)	3 (6.2)	-
• Disturbing equilibrium condition by changing temperature	46 (95.8)	1 (2.1)	-	-	1 (2.1)
Chemical equilibrium in living things and in industrial applications	34 (70.8)	14 (29.2)	-	-	-

*SU = Sound understanding, PU = Partial understanding, PU & MU = Partial understanding with specific misconception, MU = Misconception, NU = No understanding

4.1.1 Changes to achieve Equilibrium

Students' conceptions about changes to achieve equilibrium could be assessed by using information from a graph to identify equilibrium state. The findings from the Chemical Equilibrium Concept and Science Process Skills Survey indicated that the majority of the students' conceptions about changes to achieve equilibrium were categorized as sound understanding. As in Table 6.2, the results show that about 90 percent of students could identify the equilibrium state by using information from the graph. The graph of each substance's concentrations versus time was provided to students and they were asked to identify whether this change could be in equilibrium and to provide the reason to support their answers. These students could indicate that the change is in equilibrium because each substance's concentration in the change is constant. They gave as the reason that the slope of graph is constant from the sixth second because the rate of forward reaction equals the rate of reverse reaction. This meant that the concentration of each substance is constant. Furthermore, students also described that data from the graph showed that the change is a reversible change, and then it could be in equilibrium. While about 10 percent of students' conceptions were categorized to be partial understanding, these students could identify that the change could be in equilibrium from the sixth second. They only gave the reason that it could be seen from the graph.

Interestingly, the results showed that most of the students in Mrs. Malinee's classroom had sound understanding of changes to achieve equilibrium concept. Students could identify whether the change is in equilibrium or not by using these indicators; reversible reaction, constant concentration, and the rate of forward and reverse reaction. These might have resulted from students having opportunities to deal with a number of situations. Looking back to the classroom observation, Mrs. Malinee challenged students to plot a graph of the equilibrium condition by using information from the *Small Bead Game*. Then, a volunteer student was asked to explain her graph to the whole class. Mrs. Malinee also provided many examples of various changes to students. She asked students to predict whether the given change is

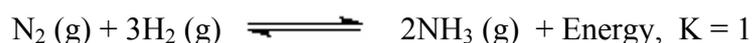
in equilibrium first, and then ongoing conversation about that change was generated. Finally, after discussing all examples, Mrs. Malinee asked students to conclude the conditions that indicated equilibrium. These confirmed the findings in section 3 that doing hands-on and mind-on activities and conversations could help students to understand the concept.

4.1.2 Equilibrium in Chemical Reaction

The reaction between hydrogen gas and iodine gas was given to students to find out students' conceptions about equilibrium in chemical reaction. The scientists found that reaction occurs after mixing both gases (equal molar amounts) into the vessel. Measurements were made on the second hour and again on the fourth hour: both showed that 2 mol of hydrogen gas, 2 mol of iodine gas, and a mol of hydrogen iodide gas were all present. Students were asked to explain the observation data from the experiment why it was like that. The results showed that about 71 percent of students could indicate that the given situation is in an equilibrium state because the given reaction is a reversible reaction. The amount of each substance in the reaction is constant because the rate of forward and reverse reaction is equal. About 17 percent of students had partial understanding. They could identify that the given situation is in equilibrium. However, they only gave the reason that it is in equilibrium because each substance's amounts is constant. The percentage of the category, partial understanding with specific misconception, is the least. These students believed that from the given situation, the reaction is in equilibrium because equilibrium constant is constant. This showed that these students might be confused between concentration and equilibrium constant.

Another situation also was given to students, ammonia production by the Haber process. Students were asked to choose a diagram which could be a snapshot of equilibrium conditions of the ammonia production process and to provide the reason. The findings showed that the majority of the students held partial understanding with specific misconception, as listed in Table 6.2. All of these

students understood that all substances occurred at equilibrium because of reversible reaction and the same rate, both forward and reverse reaction. However, these students believed that amounts of each substance which presented in the equilibrium are equal to the stoichiometric coefficient of each substance. They believed that at the equilibrium, there will be two molecules of nitrogen gas, two molecules of ammonia gas, and three molecules of hydrogen gas. About 33 percent of students' conceptions were categorized as being sound understanding. These students could indicate that at the equilibrium, all substances must have constant concentration because the rate of forward and reverse reaction is equal. They also could identify the amounts of each substance in the ammonia production process by linking with the given equilibrium constant. They chose a diagram which consisted of all substances and gave the reason that the amounts of each substance presenting in the equilibrium depends on equilibrium constant. They believed that such diagram could be appropriate to present a snapshot of the ammonia production process. Another category of students' conceptions about equilibrium in chemical reaction, misconception, was held by four percent of students. These students believed that there will be only nitrogen gas and ammonia gas at the equilibrium, while hydrogen gas is used up. They linked to chemical equation which is:



These students wrote that:

From chemical equation, the ratio between nitrogen gas and hydrogen gas is 1:3. When the reaction takes place, reactants [nitrogen gas and hydrogen gas] change to be product [ammonia]. But hydrogen gas is used up, there will be only nitrogen gas and ammonia gas at the equilibrium.

It could be noted that the students who held the misconception about equilibrium in chemical reaction were confused about reversible reaction. They might not understand that both reactants and products in reversible reaction could be

interchangeable. On the other hand, they might understand that chemical reaction occurred if reactants are changed to be products. This showed that those students failed to understand reversible chemical reaction which is prior knowledge of equilibrium in the chemical reaction concept. Looking through teaching practice in equilibrium in chemical reaction concept, Mrs. Malinee had decided to teach this concept by demonstration because of time limitations. Sharing ideas and discussing among students were done hastily. These might have generated the student difficulty in understanding this concept.

4.1.3 Equilibrium Constant

Students' conceptions of equilibrium constant can be separated into three topics; expression of equilibrium constant equation, calculation of equilibrium constant, and interpretation of equilibrium constant. The findings showed that majority of students held sound understanding of equilibrium constant in all three topics. All students, 100 percent, understood the concept equilibrium expression and interpretation of equilibrium constant. They could write the equation to express the relationship between equilibrium constant and concentrations of each substance in a chemical reaction. These students understood that equilibrium expression could be written as a mathematical formula which relates to chemical equation. They also interpreted the numerical value of equilibrium constant correctly. The equilibrium constant for a reaction tells the scientist whether the reaction favors the reactants or the products. These students understood that if the equilibrium constant is more than one, then the reaction favors products while a small K , less than one, indicates only a small proportion of product will be formed. When given a chemical equation and an equilibrium constant for that equation, all of the students could use the given information to indicate the major substances occurring at the equilibrium and provided the reason correctly.

For another topic, calculating equilibrium constant, the results showed that about 94 percent of students had a sound understanding while about 6

percent had partial understanding. Students' responses were classified as being sound understanding if they could express these correctly; equilibrium expression of the reaction between hydrogen gas and iodine gas, calculation, and numerical value of equilibrium constant or concentration of each substance. Most of the students could complete those tasks. However, about 6 percent of students could not. The findings revealed that these students could write equation expression of the given chemical reaction but they had obstacles with the calculation step. Then, they could not use the given numerical value of the equilibrium constant to find out iodine's concentration at the equilibrium. The findings showed that these students calculated the numerical value of iodine gas wrongly. However, this characteristic of students' conceptions is not categorized as being a misconception. These students might not be able to completely find out numerical value of iodine's concentration at the equilibrium because of their hastiness. This finding is consistent with Kousathana and Tsaparlis (2002) who suggested that students' error in numerical calculation of equilibrium constant might be generated from doing without thinking carefully, resulting in a wrong calculation. This kind of mistake is concerned with mathematical obstacles rather than misconception.

4.1.4 Factors Affecting Equilibrium Conditions and Le Châtelier's

Principle

Factors affecting equilibrium conditions and Le Châtelier's principle concept consist of three aspects; disturbing equilibrium condition by changing concentration, disturbing equilibrium condition by changing pressure, and disturbing equilibrium condition by changing temperature. The majority of students had sound understanding about three aspects of this concept, 77 percent, 79 percent and 96 percent, respectively. These students could describe the characteristic of new equilibrium condition and compare it to the old condition. They also explained the direction of change during an adaptation to achieve a new equilibrium. Interestingly, none of student's misconceptions were found in the topic of disturbing equilibrium condition by changing concentration and by changing temperature. For the topic of

disturbing equilibrium condition by changing pressure, it was found that about 10 percent and 6 percent had partial understanding with specific misconception and misconception, respectively. Students who had partial understanding with specific misconception could explain that a reaction of gas phase will shift to new equilibrium if a pressure of the reaction is changed. However, these students incorrectly described the amount of each substance present after reestablishment of equilibrium in the following system.



These students described that the equilibrium will shift to the side with fewer gas moles, then the amount of hydrogen gas and iodine gas will increase. Another group of students believed that if the pressure of this reaction is increased by a decrease in volume, the molecules of hydrogen gas and iodine gas will be closer. Then, at new equilibrium, there will be more hydrogen iodide gas.

4.1.5 Chemical Equilibrium in Living Things and in Industrial Applications

The majority of students, about 71 percent, had sound understanding of chemical equilibrium in living things and in industrial applications and about 29 percent of students had partial understanding of this concept. These students could explain the use of Le Châtelier's principle to apply in rescuing a carbonmonoxide poisoned person and in the ammonia production by the Haber process. Students who had partial understanding could explain how to rescue that person and how to increase the amount of ammonia correctly, but not all. The teaching and learning process in this concept was determined. Data from classroom observation showed that Mrs. Malinee assigned students to exhibit an example of chemical equilibrium in living things and in industrial applications. Students in each group had to discover information on the selected topic and present it to the whole class. They were assessed by their peers as to whether their presentation was valuable. In the same

time, presenters had to generate questions to ask their friends for discussion of their topic. These activities might help students to effectively develop their understanding of the concept.

4.2 Students' Capabilities in Science Process Skills

Students' capabilities in science process skills were the other aspects of students' learning which were assessed by Chemical Equilibrium Concept and Integrated Science Process Skills Survey. Five process skills were assessed: identifying and controlling variables; interpreting data; formulating hypotheses; defining operational definitions; and experimenting. Students were asked to complete the survey. Their responses, in the integrated science process skills survey part, were categorized into five types (detailed in Chapter Three: Methodology). Distribution of students' responses are presented in Table 6.3 and described below.

Table 6.3 Distribution of students' capabilities in integrated science process skills: findings from School A (N=48)

Integrated science process skills	No. of students (percentage)						
	A	B	Total ^a	C	D	E	Total ^b
Identifying and controlling variables	24 (50.0)	15 (31.2)	39 (81.2)	6 (12.5)	2 (4.2)	1 (2.1)	9 (18.8)
Interpreting data	25 (52.1)	20 (41.7)	45 (93.8)	3 (6.2)	-	-	3 (6.2)
Formulating hypotheses	10 (20.8)	26 (54.2)	36 (75.0)	12 (25.0)	-	-	12 (25.0)
Defining operational definitions	27 (56.2)	13 (27.1)	40 (83.3)	8 (16.7)	-	-	8 (16.7)
Experimenting							
• Collecting data	25 (52.1)	23 (47.9)	48 (100)	-	-	-	-
• Drawing conclusions	18 (37.5)	12 (25.0)	30 (62.5)	16 (33.3)	2 (4.2)	-	18 (37.5)

^a Classified as successful categories which include Types A and B.

^b Classified as unsuccessful categories which include Types C, D, and E.

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4.2.1 Identifying and Controlling Variables

The findings revealed that most of the students (81%) were successful in identifying and controlling variables which include independent variable[s], dependent variable[s], and variable[s] to be held constant. Most of these students successfully specified that the independent variable of this study should be temperature.

In the aspect of independent variable, students successfully identified the independent variable of the study of exothermic reaction of the given reaction. These students correctly identified that dependent variable of this study should be equilibrium constant or K . Another group of successful students thought that dependent variables of this study should be product's concentration which is concentration of nitrogen gas and carbonmonoxide gas. Finally, these students identified that variables to be held constant in the study of exothermic reaction from the reduction reaction of air dangerous pollutants might be time for measurement substance's concentration, reactants' concentration, or reactants' amount.

Another group of students, about 19 percent, were not successful in identifying and controlling variables. Unsuccessful students' answers could be found in Type C, Type D, and Type E.

4.2.2 Interpreting Data

There were about 94 percent of students successful in interpreting the given data of the experimentation between steam and coal and about 6 percent of students were not. About 52 percent of student answers were categorized to be Type A. These students interpreted the given data in terms of equilibrium constant first, then they explained those data by considering the relationship between equilibrium constant and temperature. They explained that when the temperature of the reaction increased, it was found that equilibrium constant increased, too, which meant that this

reaction is an endothermic reaction. About 42 percent of student answers were categorized as being Type B. These students explained the relationship between temperature and product's concentration rather than equilibrium. However, they could analyze the given data to determine type of the reaction and provide a reason correctly, although it might be not the same as the expected answer. For students who were unsuccessful, it was found that their answers were categorized into Type C which is general or ambiguous. These students explained that the change of temperature resulted in the change of both reactant's and product's concentration.

4.2.3 Formulation Hypotheses

There were about 75 percent of students successful in formulating the hypotheses of the reduction reaction of dangerous air pollutants, and about 25 percent were not. Successful student answers were found in Type B more than in Type A. For successful students, about 54 percent of students stated that when the temperature of the reaction increases, concentration of nitrogen gas and carbonmonoxide gas [products] should have increased if this reaction is an endothermic reaction, while about 21 percent of students specifically stated that the reaction should be an endothermic reaction if equilibrium constant increases when temperature of the reaction is increased. For unsuccessful students, they ambiguously formulated an hypothesis of the given reaction that the reaction should be an endothermic reaction because there is a change in the substance's concentration.

4.2.4 Defining Operational Definition

About 83 percent of students were successful in defining operational definition, which is the equilibrium constant of the reaction between steam and coal, while about 17 percent were unsuccessful. For successful students, it was found that their answers were Type A more than Type B. Students who answered as Type B did not specify how to measure equilibrium constant of the given reaction. They only provided the meaning of equilibrium constant. Unsuccessful students only answered

as Type C. These students indicated that equilibrium constant is a constant value of equilibrium state. These could imply that these students did not have the science process skill of defining operational definition.

4.2.5 Experimenting

For the science process skill of experimenting, students were assessed in the skills of collecting data and drawing a conclusion from the reaction between steam and coal. It was found that most students were successful in the skills of collecting data and drawing a conclusion. Interestingly, all of the students were successful in designing a table to collect data from the experiment; however, their tables were categorized as being Type A and Type B. About 52 percent of student answers were Type A. These students arranged data from the experiment into their table, they also designed a special column to present the equilibrium constant in order to find out a relationship between equilibrium constant which is a dependent variable and temperature which is an independent variable. Another group of students, about 48 percent, could arrange data from the experiment into their table correctly, but they did not design a special column for the equilibrium constant. However, these students could find out the relationship between products' concentration and temperature. Consequently, their table of data collected is usable, but not complete.

Although most students were successful in collecting data, in the aspect of drawing a conclusion, the findings showed that about 63 percent of students were successful while about 37 percent were not. This could imply that there might be some point that students might find confused about drawing a conclusion. Interestingly, for successful students, only about 38 percent of answers were categorized as being Type A, while Type B answer was about 25 percent. Students who answered as Type B only concluded that the reaction between steam and coal is an endothermic reaction which could be observed from an increase of forward reaction. These students could conclude the type of the reaction by using data from the experiment but they provided an incomplete reason to support their conclusion. For

unsuccessful students, the answers could be separated into two types of answer, Type C and Type D. About 33 percent of students presented general and unclear conclusions for this experiment. For example, some students only concluded that the concentration of products varies from temperature, or concentration of products increases because of an increase of temperature. About 4 percent of students provided an irrelevant conclusion. These students concluded that the reaction between steam and coal is disturbed by an increase of temperature, and then changes occur.

4.3 Students' Attitudes towards Chemical Equilibrium Concepts and Teaching and Learning

This section aims to describe students' attitudes toward teaching and learning about chemical equilibrium and consists of four topics: difficulty of the chemical equilibrium concept, usefulness of the chemical equilibrium concept, interest in learning the chemical equilibrium concept, and preference of teaching the chemical equilibrium concept. Data from the Questionnaire on Students' Attitudes toward Teaching and Learning about Chemical Equilibrium were scored, and then students' scores were categorized into five levels: high positive attitude (range from 4.50 to 5.00), positive (range from 3.50 to 4.49), moderate (range from 2.50 to 3.49), negative attitude (range from 1.50 to 2.49), and high negative attitude (range from 1.00 – 1.49). Students' attitudes are presented in terms of mean score and standard deviation for each topic as shown Table 6.4.

Table 6.4 Mean scores and standard deviations of students' attitudes toward chemical equilibrium concepts and teaching and learning: Findings from School A (N=48)

Topics	Sub-topic	Scores of Students' Attitudes*	
		Mean Score	SD
Complexity of Chemical Equilibrium Concept	Difficult when dealing with exercises.	3.20	0.85
	Difficult to understand.	3.35	0.89
	Difficult when dealing numerical values and mathematical calculations.	3.41	0.83
	<i>Average Mean Score</i>	3.32	0.86
Usefulness of Chemical Equilibrium Concept	Usefulness in daily life	3.76	0.80
	Usefulness in a future career	3.84	0.87
	Usefulness in developing the country	3.14	0.93
	<i>Average Mean Score</i>	3.57	0.93
Interest in Chemical Equilibrium Concept	Want to learn more about the chemical equilibrium concept	3.18	0.95
	Concept is interesting	3.50	0.85
	Interested in chemical equilibrium concept because of doing laboratory	3.20	1.03
	<i>Average Mean Score</i>	3.27	0.95
Preference of Teaching and Learning about Chemical Equilibrium	Study in small groups is better than by individuals	4.07	0.74
	Discussion could enhance understanding about chemical equilibrium concept	4.04	0.71
	Doing exercises could enhance understanding about chemical equilibrium concept	4.00	0.83
	Learning from doing activities is better than lecturing	4.01	0.61
	<i>Average Mean Score</i>	4.03	0.71
Overall		3.55	0.92

*Scores of students' attitudes are high positive (4.49 -5.00), positive (3.49 – 4.50), moderate (2.49 – 3.50), negative (1.50 – 2.49), and high negative (1.00 – 1.49)

As can be seen in Table 6.4, mean score of the overall students' attitude was about 3.55 (SD = 0.92). This meant that students in School A held positive attitude toward teaching and learning about chemical equilibrium. Topics that students held a positive attitude towards were preference of teaching and learning and usefulness of chemical equilibrium concept. In the other two topics, the complexity of chemical equilibrium concept and interest in the chemical equilibrium concept, it was found that those students held moderate attitudes. Details of students' attitudes about each topic are described below.

In the topic of preference of teaching and learning, the findings showed that students in School A held positive attitudes with the highest mean score (about 4.03). Students' attitude scores of each statement ranged from the most to the least as these: study in small groups is better than by individuals; discussion could enhance understanding of the chemical equilibrium concept; doing exercises could enhance understanding of chemical equilibrium; and learning from doing activities is better than from lecturing. The lowest of student attitude mean scores was attitude toward interest in the chemical equilibrium concept. The mean score was only 3.27 which meant that those students held moderate attitudes toward this topic.

4.4 Summary of Students' Learning Outcomes for Chemical Equilibrium

In conclusion, the findings revealed that most students held sound understanding of all topics in the chemical equilibrium concept, were successful in integrated science process skills, and had positive attitudes toward teaching and learning about chemical equilibrium. However, there was some points that need to be noted: for example, students' misconceptions still were found in the topic of equilibrium in chemical reaction and disturbing equilibrium by changing pressure. These showed that students' misconceptions might be influenced by their prior knowledge. For example, the students' misconception found in the topic of equilibrium in chemical reaction occurred due to some students lacking understanding of chemical reaction which is a basic concept of chemical equilibrium. Then, teacher

should realized the importance of linkage between each concept and prior knowledge. For students' capabilities of science process skills, most students were successful. However, there were some students, who were unsuccessful in some skills, especially formulating hypotheses and experiment (drawing a conclusion). It was found that more than one quarter of the students were unable to use those skills. If these findings are linked to classroom observation, it could be seen that some students were unsuccessful due to inadequate practice. Data from classroom observation showed that Mrs. Malinee usually emphasized identifying laboratory's objectives rather than formulating hypotheses. This might influence the students' capability in science process skills.

Case Study Two [School B]: Findings from the Implementation of the Chemical Equilibrium Learning Unit (CELU)

1. Context of the Case Study Two: School B

1.1 School Context

School B is a medium government secondary school, located in a rural area of Chanthaburi Province. The total number of students in the Thai 2005 academic year was about 1000, of which there were about 700 students in lower secondary level (Grade 7 to Grade 9) and there were about 300 students in the upper secondary level (Grade 10 to Grade 12). The students mostly came from average income families. There were seven science teachers from a total of fifty seven teachers in the school. In the 2005 academic year, the ratio between the science teacher and the students was 1:27. There were two classrooms of Grade 11 level. Both of them were called *Science and Mathematics Program* classrooms. The science subject of upper secondary level consists of Physics, Biology, and Chemistry. The students in the *Science and Mathematics Program* had to study science for nine periods a week in which three periods were Chemistry. Each period was about 50 minutes. In total, in the second semester of the 2005 academic year, there were about 32 periods per semester for

studying Chemistry. For Grade 11, the students who were in the *Science and Mathematics Program* were planned to be taught the chemical equilibrium concepts for 18 periods, similar to School A.

1.2 Classroom Context

The chemical equilibrium concept was taught in a chemistry laboratory room. There was only one chemistry laboratory room in School B. The room was decorated in a similar pattern to that of School A. The teacher's desk which was about 2.5 meters long was placed in front of the laboratory room. Beside the teacher's desk, there was a sink. There were three cupboards in the room, one placed at the back and the other two placed at one side of the laboratory room, near the wall. The scientific instruments were inside the cupboards. At the other side of the laboratory room, near the windows, there were four sinks on the top of cupboards. There were nine tables and about fifty chairs in the classroom. During study, the students were divided into nine groups and sat around tables as shown in Figure 6.3.

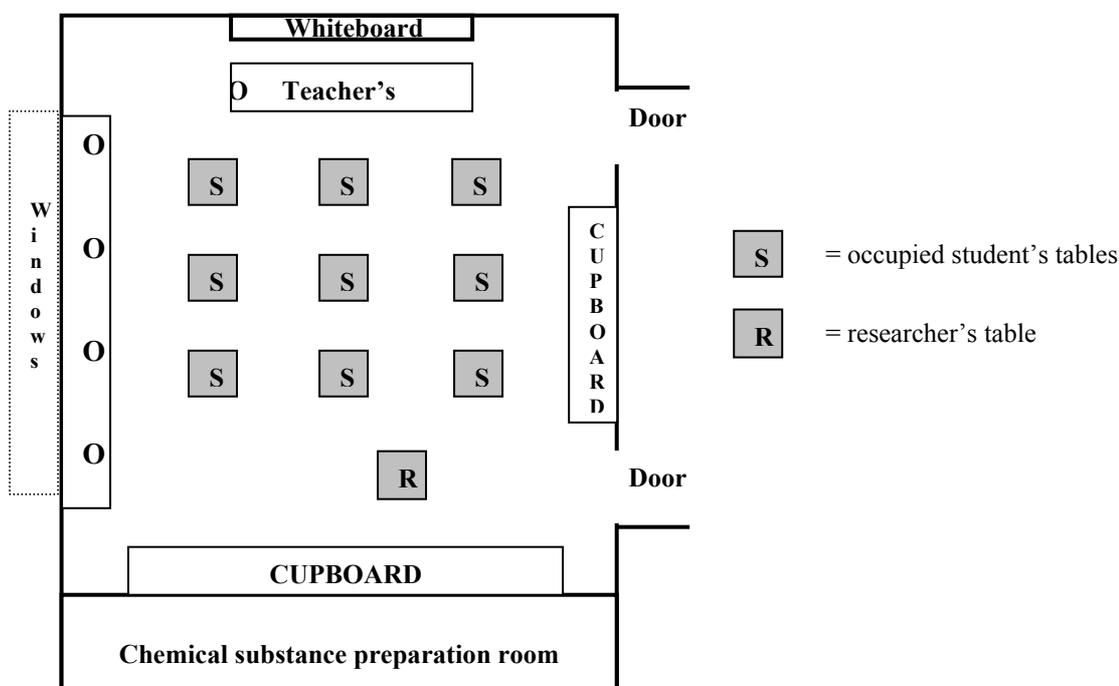


Figure 6.3 Classroom Context of School B

1.3 Teacher's Background

Miss Waleerat was a 33-year-old teacher. Her formal qualification is a Master degree in Education (science teaching). She had eight years experience in secondary science teaching both in lower and upper secondary level. Normally, she had taught at Grade 11 level. For School B, the chemical equilibrium concept had been taught regularly at Grade 11 so, Miss Waleerat was familiar with teaching the chemical equilibrium concept. She believed that she had no problem with chemical equilibrium concept. However, she was interested in the implementation of the CELU and would like to participate in the research study. She gave the reason that she would like to learn more about teaching and learning using constructivist-based perspectives.

1.4 Students' Background

In the secondary semester of the Thai 2005 academic year, forty five students were in Grade 11, fifteen male and thirty two female, and studied chemistry with Miss Waleerat and participated in this research study. The average student's G.P.A in this classroom is higher than other *Science and Mathematic Program* classrooms. However, these students had average competency in Science and Mathematics subject. About a half of the students in this classroom decided to study in the *Science and Mathematic Program* classroom because they would like to study at tertiary level, which may or may not involve science. So, they paid attention in studying all subjects. But some students had to be in the classroom because they had no choice for selection. They had no plan for their further study, so, they sometimes did not pay attention to study if they did not like a subject.

2. Teacher's Implementation of the CELU into the Classroom

Before implementing the CELU in her classroom, Miss Waleerat had only two weeks to prepare herself. She started to implement the CELU on the first week of December, 2005 and finished on the third week of February, 2005. Because of the

number of public holidays and school activities, Miss Waleerat had completely implemented the CELU at the time as School A. In total, Miss Waleerat spent about 25 periods for implementing the CELU which was more than the time planned. The following section describes the way in which Miss Waleerat implemented the CELU in her classroom.

2.1 Teaching Preparation

Miss Waleerat nicely prepared herself for teaching the chemical equilibrium concept during the implementation of the CELU. She had clearly read each lesson plan in the teacher manual of the CELU before implementing each lesson in her classroom. If there was a laboratory involved in the teaching and learning process, she usually completely prepared chemical substances and laboratory equipment in the morning before teaching. She did the experiment by herself in order to observe results before implementing the laboratory in the classroom. She said that this process could help her to be certain that the experiment would work. If she was doubtful about anything, she asked the researcher to clarify it before teaching. She usually spent about twenty minutes in the period before teaching in discussion with the researcher about the teaching and learning process of the CELU.

In the first period of the implementation, Miss Waleerat informed students that they were in the process of doing research. Then, she asked students to divide into new groups. She explained that each group had to consist of mixed ability, from high to low. There were five students in each group because the laboratory room was quite small and there were only nine tables in the room. Students were not free to form groups, these were chosen by Miss Waleerat. However, they were not serious about these. They were asked to sit in the same group throughout the implementation of the CELU.

2.2 Teaching Practice

Miss Waleerat's teaching process followed each step as described in the teacher manual of the CELU. However, she usually spent more teaching time than planned, especially at the beginning of the implementation. Miss Waleerat said that she could not finish each lesson in time because of the nature of students. She thought that students could understand the concept if there was enough time for them. She said that she had to provide time for students to think and discuss. Students also noticed that they had to change their behavior from listening to do more thinking. Although, students were not familiar with this strategy of teaching, they attempted to improve themselves due to Miss Waleerat's stimulation. The teaching and learning process approach used constructivist-based perspectives, and students were engaged in the process by discussion, doing activities. Characteristics of Miss Waleerat's teaching practice which could be representative of constructivist-base perspectives are described in the following sections.

2.2.1 The Way of Asking Questions

Miss Waleerat followed the steps of asking questions as described in the teacher manual of the CELU. When she found that students did not answer the questions, she usually asked students to discuss them in a group and answer the questions again. If students still could not answer questions completely, Miss Waleerat usually helped students by repeating student answers and asking further questions based on student's answers. Here, students' contribution to conversations increased. The findings showed that there were a few students who were able to answer the questions at the beginning of the implementation of the CELU. Miss Waleerat usually waited for other student answers, but not more than a minute except for questions involving mathematical calculation. Then, she repeated those student's answers again but key words were omitted. Subsequently, most of students answered that question again. For example,

Waleerat: Which reaction is the forward reaction? (points to the written reactions on the whiteboard)

S21: The first reaction.

Waleerat: First reaction is

Students: forward reaction.

Waleerat: Yes, first reaction is forward reaction. Why?

Students: ...

Waleerat: Forward reaction is the reaction which ... (points to the reactants). What is it called?

Students: Reactant.

Waleerat: Forward reaction is the reaction which reactants change to be ...

Students: Products.

Waleerat: Yes. Then, what is forward reaction?

Students: The reaction in which reactants change to be products.

Waleerat: And what is another reaction called? (points to another reaction on the whiteboard)

Students: Reverse reaction.

Waleerat: Why?

Students: ...

Waleerat: Reverse reaction is the reaction which products change to be ...

Students: Reactant.

Waleerat: Yes. Products react together, and then they change to be...

Students: Reactant.

Waleerat: Why do you say that reaction is reverse reaction?

S51: Because products could change to become reactant again.

Waleerat: Yes, very good.

It could be noted that the strategy that Miss Waleerat used for asking students started with a closed question, then she asked further questions based on students' answers. When she found that students kept quiet, she implied that students did not understand the concept, resulting in being unable to answer such question.

Miss Waleerat decided to help students answer the question by omitting key words. She rephrased those after receiving key words from students. Finally, Miss Waleerat tried to encourage students to summarize those answers again. This might enhance students' ability in thinking about and understanding the concept.

2.2.2 The Realization the Importance of Students' Prior Knowledge

Miss Waleerat strongly emphasized students' prior knowledge. She often spent more time to find out and clarify students' prior knowledge than planned. This resulted in going over time for the implementation of the CELU. For example, in the lesson of reversible reaction of chemical reaction, students had to understand about physical change and chemical change before studying this concept. Miss Waleerat asked students to identify whether the given situation is a physical change or a chemical change and provide the reason. She found that each student could not identify the given situation correctly because he/she lacked understanding of physical change and chemical change. Then, Miss Waleerat decided to spend time for discussing those changes. She provided other everyday life situations to challenge students to predict those changes. Finally, she asked students to sum up the definition of physical change and chemical change. In another lesson, Miss Waleerat found that most students held misconceptions about the calculation of concentration of substances in the reaction. These students had no understanding of concentration in the unit of mol/dm^3 . Miss Waleerat spent a period for explaining that concept before teaching the concept of calculation of equilibrium constant. However, Miss Waleerat did not explain the concept of concentration by herself. She found that a few students had a scientific understanding of that concept, so she asked one of those students to explain how to calculate concentration of substances to other students in the classroom. Finally, she asked all of the students to summarize the strategy to calculate concentration. These strategies showed that Miss Waleerat realized the importance of prior knowledge. She tried to encourage students to have scientific understanding as prior knowledge as much as possible before starting to teach new concept. Then, it

could be said that Miss Waleerat's teaching strategy approaches used constructivist-based perspectives.

2.2.3 The Teaching Activities

Miss Waleerat employed various teaching activities as suggested in a teacher manual of the CELU, for example, doing hands-on and mind-on laboratory, discussion, or doing exercises. For the lesson which dealt with laboratory, she gave students opportunities to do the experiment and discuss the results within a group. Then, all of the students were asked to present their collected data to the whole class. The collected data was collectively analyzed and summarized by all the students. All of the questions in the student worksheet were discussed and summarized, either by students or by the teacher. These showed that Miss Waleerat realized that learning is concerned with social process. She believed that students could better understand the concept if they have a chance to discuss their ideas, together. However, it sometimes took time, especially at the beginning of the implementation of the CELU because students were not familiar with this strategy.

In summary, Miss Waleerat taught the chemical equilibrium concept in the sequence as described in the teacher manual of the CELU, not skipping any topic or activity. Miss Waleerat also posed more questions to clarify some ambiguity about the concept. This showed that Miss Waleerat was able to adapt the CELU to be appropriate with the nature of her students in order to enhance the effectiveness of the CELU as much as possible.

2.2.4 The Strategies for Assessment

Miss Waleerat employed various techniques of assessment to evaluate student's learning. Miss Waleerat assessed students by taking into account discussions, classroom participations, and doing activities. She assessed students' learning throughout the teaching and learning process. During doing laboratory, Miss

Waleerat usually walked around the room and asked some students to assess what they are learning. She explained that those strategies could assist her to understand the students and to improve students' learning and her teaching to become more effective. She asked students to write a journal of each lesson and to send it back to her. She tried to read students' journals before teaching a new lesson. She would explain some student's misunderstanding to the whole class if she found that a number of students had the same pattern of misunderstanding. But if only a few students had a misunderstanding, she suggested those students ask their friend or ask her after finishing the lesson. These showed that Miss Waleerat used assessment to monitor the progress of students' learning in order to assist the students to understand the concept.

2.3 Summary of Teacher's Implementation of the CELU in the Classroom

In conclusion, Miss Waleerat taught the chemical equilibrium concept by following the steps as detailed in the teacher manual of the CELU. She quite understood about constructivist-based perspectives as informed by her implementation of the CELU. She employed various techniques of teaching practice in terms of the way of asking questions, the realization about the importance of student's prior knowledge, various teaching activities, and the strategies for assessment. Miss Waleerat was able to adapt the CELU to suit her students. Although, Miss Waleerat accepted that the CELU was effective in her classroom, she argued that it quite took a lot of time to implement. Then, she suggested that some activities in the CELU should be improved in order to enhance the effectiveness of the CELU.

3. Students' Learning about Chemical Equilibrium during the Implementation of the CELU

This section focuses on the way students' learned about chemical equilibrium during the implementation of the CELU. Data from various sources, for example classroom observations, interviews, or student's worksheets, were used to describe

how students learned about the chemical equilibrium concept. The factors involved in students' learning were discussed below.

3.1 Doing Hands-on and Mind-on Activities

The findings from student's interviews revealed that there were two learning activities that could promote student understanding of the chemical equilibrium concept; playing the *Small Bead Game* and doing exercises. For playing *Small Bead Game*, most of students confirmed that this game could help them to understand what dynamic equilibrium is. Data showed that most of students like learning by playing the game because it could lead them to understand dynamic concept easily. They also believed that this strategy is better than reading or listening from the teacher. As one of the students said:

Researcher: How do feel about learning dynamic equilibrium by playing a game?

S24: I like it very much because it helps me to understand the concept easily.

Researcher: How does the game help you to understand the concept?

S24: Umm... I thought that I pay more attention to learn than in the past because it is interesting.

Researcher: What else?

S24: I also thought that I really understand about dynamic equilibrium because of the game. If I did not have a chance to play it, I could not imagine that what happens at the equilibrium. It is very interesting and better than reading from a book.

Researcher: Why do you think teaching by using the game is better than reading from a book?

S24: Because it is not boring. Umm.. I thought that I have learnt by understanding rather than memorization. Then, it is fun.

As shown above, it seems to be that students understand the characteristics of dynamic equilibrium by comparison with the situation from the *Small Bead Game*. However, one of students suggested that although teaching by game could promote their understanding about the concept, it could be realized that a game should be easy, not too complex.

3.2 Classroom Interaction

Students revealed that during the implementation of the CELU, they had to be involved in discussion more than the past. They said that they like this strategy. Their thinking ability was improved because they had to think and to answer Miss Waleerat's questions. Asking questions could encourage students to think about what they are learning and could help them in understanding the concept. Students were encouraged to participate in discussion. At the beginning of the implementation of the CELU, only a few students who were high competency students participated in discussion. Miss Waleerat encouraged the other students to be in discussion by challenging students to discuss in small groups. After that, it was found that most of students dared to share their ideas to the whole class.

3.3 Working in Groups

In the process of teaching and learning about chemical equilibrium by using the CELU, students were encouraged to work in groups. Each group consists of mixed ability of students, from high to low achievement, and was determined by Miss Waleerat. Some students did not want to be in that group at the beginning. They wanted to sit with their close friend but they could not. However, most of students who were low competency thought that it could assist them to understand the concept

because they could ask their friend in the group when they were unsure. Data from students' interviews showed that each student had to take responsibility in their group, especially during doing laboratory in order to complete the task on time. During discussion about the results observed from the laboratory, each student had to pose an idea to the others in their group. Then, they summarized ideas together and individually wrote answers in their worksheet. If no one in the group could answer the question, they would ask the teacher. This indicated that working in a group was one of the important factors that could help students to develop their understanding of the chemical equilibrium concept.

3.4 Self and Peer Assessment

Students were encouraged to be involved in self assessment by writing a journal. They were asked to reflect on their understanding of the concept of each lesson, describe their ambiguous understanding, or suggest how to improve the teaching and learning process for each lesson to be more effective. This meant that students were engaged in summarizing what they have learnt by themselves. Although, most of students did not like to write a journal, they realized that it was important because it could help to remind them of the concept. They also asked some questions, and displays their thinking to the teacher. This could assist them to enhance their understanding about the concept. As Somchai said:

Although, I don't like to write a journal, I know that writing could assist me to learn. At least, writing a journal is a summary of the concept. I have to think what I have learnt and write it in a book. The teacher could know that whether I understand or not.

As Somchai described, it could be noted that writing a journal is valuable if the teacher has a chance to read it and gave students feedback. These could help students to reflect on their understanding and share it with the teacher. Then, the teacher could know what students already know and what students might not

understand. Then, writing a journal could promote a more effective teaching and learning process.

3.5 Summary of Students' Learning about Chemical Equilibrium during the Implementation of the CELU

In conclusion, students in Miss Waleerat's classroom were encouraged by the implementation of the CELU to noticeably change from being passive students to being active students. They engaged in learning activities, for example, discussion, answering questions, presentations. The characteristics of teaching and learning process occurring in Miss Waleerat's classroom emphasized doing hands-on and mind-on activities rather than transmission of knowledge from the teacher to students. The data from classroom observations showed that ongoing conversation between the students and the teacher or among students in small groups were dominant activity in the classroom. These conversations were iterative. Working in groups and assessment also were important factors that influenced students' learning about the chemical equilibrium concept. Those factors could help students to develop their thinking ability and enhance their understanding of the concept.

4. Students' Learning Outcomes about Chemical Equilibrium after the Implementation of the CELU

This section focuses on students' learning outcomes for chemical equilibrium in terms of students' conceptions of chemical equilibrium, students' integrated science process skills for chemical equilibrium, and students' attitudes toward teaching and learning about chemical equilibrium. The details of each topic are discussed below.

4.1 Students' Conceptions about Chemical Equilibrium

The students' conceptions of chemical equilibrium which were sought consisted of five topics: changes to achieve equilibrium, equilibrium in chemical

reaction, equilibrium constant, factors affecting equilibrium conditions and Le Châtelier's principle, and equilibrium in living things and in industrial applications. Then, students' responses on the survey were categorized into five categories as detailed in Chapter Three: Methodology. The results from the survey are shown in Table 6.5

Table 6.5 Distribution of students' conceptions about chemical equilibrium: findings from School B (N = 45)

Topics	No. of students (percentage)				
	SU*	PU*	PU & MU*	MU*	NU*
Changes to achieve equilibrium	20 (44.4)	13 (28.9)	7 (15.6)	-	5 (11.1)
Equilibrium in chemical reaction					
• Reaction of hydrogen gas and iodine gas	17 (37.8)	19 (42.2)	-	9 (20.0)	-
• Ammonia production by Haber process	-	-	41 (91.2)	4 (8.8)	-
Equilibrium constant					
• Equilibrium expression	45 (100)	-	-	-	-
• Calculating equilibrium constant	35 (77.8)	10 (22.2)	-	-	-
• Interpreting equilibrium constant	29 (64.4)	-	-	13 (28.9)	3 (6.7)

*SU = Sound understanding, PU = Partial understanding, PU & MU = Partial understanding with specific misconception, MU = Misconception, NU = No understanding

Table 6.5 (Continued)

Topics	No. of students (percentage)				
	SU*	PU*	PU & MU*	MU*	NU*
Factors affecting equilibrium condition and Le Châtelier's principle					
• Disturbing equilibrium condition by changing concentration	30 (66.7)	7 (15.6)	-	3 (6.7)	5 (11.0)
• Disturbing equilibrium condition by changing pressure	15 (33.3)	-	-	26 (57.8)	4 (8.9)
• Disturbing equilibrium condition by changing temperature	33 (73.4)	-	-	6 (13.3)	6 (13.3)
Chemical equilibrium in living things and in industrial applications	14 (31.1)	19 (42.2)	-	-	12 (26.7)

*SU = Sound understanding, PU = Partial understanding, PU & MU = Partial understanding with specific misconception, MU = Misconception, NU = No understanding

4.1.1 Changes to achieve Equilibrium

Students' conceptions about changes to achieve equilibrium could be assessed by using information from a graph to identify an equilibrium state. The findings indicated that the majority of the students' conceptions about changes to achieve equilibrium were categorized as being sound understanding. As listed in Table 6.5, the results showed that about 44 percent of students had a sound understanding. These students could indicate that the change is in equilibrium because each substance's concentration in the change is constant. They described that the slope of graph is constant from the sixth second because the rate of forward reaction equals the rate of reverse reaction. So, the concentration of each substance is constant. While about 29 percent of students' conceptions were categorized to be partial understanding, these students could identify that the change could be in equilibrium from the sixth second. They only gave the reason that it could be seen from the graph. It was also found that about 16 percent and 11 percent of students had partial understanding with specific misconceptions, and no understanding about changes to achieve equilibrium, respectively. Students who held partial understanding with specific misconceptions understood that the given reaction could be in equilibrium from the sixth second because no change occurred. This showed that these students held a misconception about the characteristics of dynamic equilibrium.

4.1.2 Equilibrium in Chemical Reaction

The reaction between hydrogen gas and iodine gas was given to students to find out students' conceptions about equilibrium in chemical reaction. Scientists found that reaction occurs after mixing both gases (equal molar amounts) into the vessel. Measurements were made on the second hour and again on the fourth hour: both showed that 2 mol of hydrogen gas, 2 mol of iodine gas, and a mol of hydrogen iodide gas were all present. Students were asked to explain why the observed data from the experiment it is like that. The results showed that the majority of students had partial understanding about equilibrium in a chemical reaction. About

42 percent of students described the given reaction as being in equilibrium because the concentration of each the substances in the reaction is constant. About 38 percent of students had sound understanding. These students could indicate that the given situation is in an equilibrium state because the given reaction is a reversible reaction. The amount of each substance in the reaction is constant because the rate of forward and reverse reactions is equal. There were about 20 percent of students with a misconception in this topic. These students described the concentration of each substances in the reaction as being constant because the reaction goes completely. Then, there is no change.

Another situation also was given to students, the ammonia production by the Haber process. Students were asked to choose a diagram which could be snapshot of equilibrium conditions of the ammonia production process and to provide the reason. The findings showed that the majority of the students had partial understanding with specific misconception, as listed in Table 6.5. About 92 percent of students understood that there all substances must be at equilibrium because of reversible reaction. However, these students believed that amounts of each substance which were present in the equilibrium are equal to the stoichiometric coefficient of each substance. Then, they believed that at the equilibrium, there will be two molecules of nitrogen gas, two molecules of ammonia gas, and three molecules of hydrogen gas. Another category of students' conceptions of equilibrium in chemical reaction, misconception, was held by about 8 percent of students. These students believed that at the equilibrium, the amount of all substances must be equal because of reversible reaction. Then, reactants could change to be products, at the same time, products could change to be reactants. These resulted in the same amount of all substances.

4.1.3 Equilibrium Constant

Students' conceptions of the equilibrium constant could be separated to be three topics; expression of equilibrium constant equation, calculation of

equilibrium constant, and interpretation of equilibrium constant. The findings showed that majority of students held sound understanding about equilibrium constant in all three topics. All students, 100 percent, understood the concept equilibrium expression and interpretation of equilibrium constant. They could write the equation to express the relationship between equilibrium constant and concentrations of each substance in a chemical reaction. These students understood that equilibrium expression could be written as a mathematical formula which relates to a chemical equation.

For topic of calculating equilibrium constant, the results showed that about 78 percent of students had a sound understanding while about 22 percent had a partial understanding. Students' responses were classified as being sound understanding if they could express these correctly; equilibrium expression of the reaction between hydrogen gas and iodine gas, calculation of numerical value of equilibrium constant or concentration of each substance. Most of the students could complete those tasks. However, about 22 percent of students could not. The findings revealed that these students could write the equation expression of the given chemical reaction but they had obstacles in the calculation step. Some of them did every step correctly but an incorrect mathematical calculation. Then, they could not find out iodine's concentration at the equilibrium. These only showed some mistakes concerned with mathematical obstacles rather than misconception.

In another topic, interpreting the equilibrium constant, the findings showed that students' conceptions of this topic were sound understanding, misconceptions, and no understanding. The equilibrium constant for a reaction tells the scientist whether the reaction favors the reactants or the products. About 64 percent of students understood that if the equilibrium constant is more than one, then the reaction favors products while a small K , less than one, indicates only a small proportion of product will be formed. These students could indicate the majority substances occurring at the equilibrium and provided reasons correctly. There were about 13 percent of students having a misconception of this concept. These students described that which substances should be major could not be identified, due to

reversible reaction. At the equilibrium, it is a reversible reaction. Then, all substances continuously change from reactants to products, and from products to reactants.

4.1.4 Factors Affecting Equilibrium Conditions and Le Châtelier's Principle

Factors affecting equilibrium conditions and Le Châtelier's principle concept consist of three aspects; disturbing equilibrium condition by changing concentration, disturbing equilibrium condition by changing pressure, and disturbing equilibrium condition by changing temperature.

For disturbing equilibrium condition by changing concentration, it was found that most of students, about 67 percent, had a sound understanding. The other students had partial understanding, no understanding, and misconception. It was found that there was about 7 percent of students having a misconception in this aspect. These students believed that predictions could not be made about any changes from disturbing equilibrium condition by changing concentration because it is a reversible reaction.

For topic of disturbing equilibrium condition by changing pressure, it was found that most of students, about 58 percent, had a misconception in this aspect. These students believed that if the pressure of the reaction is increased by decreasing the volume of the vessel, there will be more products because molecules of reactants are close, so, the rate of reaction increases. This meant that reactants become products.

In the last topic, disturbing equilibrium condition by changing temperature, it was found the most of the students, about 73 percent, had sound understanding. The other students, about 13 percent, had a misconception or no understanding. Students who had a misconception believed that predictions could not

be made about any change from disturbing equilibrium condition by changing temperature because it is a reversible reaction.

4.1.5 Chemical Equilibrium in Living Things and in Industrial Applications

About 42 percent of the students had a partial understanding of chemical equilibrium in living things and in industrial applications. The other students held sound understanding or no understanding. About 31 percent of students had a sound understanding of this concept. These students could explain the use of Le Châtelier's principle to apply in rescuing carbonmonoxide poisoned person and in the ammonia production by the Haber process. Students who had a partial understanding could explain how to rescue that person and how to increase the amount of ammonia correctly but not provide the reasons. About 27 percent of students did not write any answer. It could be implied that these students might not understand this concept.

4.2 Students' Capabilities in Integrated Science Process Skills

Students were assessed for their capabilities in five integrated science process skills: identifying and controlling variables; interpreting data; formulating hypotheses; defining operational definition; and experimenting. Students were asked to complete the survey. Their responses in the integrated science process skills survey section were categorized into five types (detailed in Chapter Three: Methodology). Distribution of students' responses is presented in Table 6.3 and is described below.

Table 6.6 Distribution of students' capabilities of integrated science process skills: findings from School B (N=45)

Integrated science process skills	No. of students (percentage)						
	A	B	Total ^a	C	D	E	Total ^b
Identifying and controlling variables	3 (6.7)	1 (2.2)	4 (8.9)	-	13 (28.9)	28 (62.2)	41 (91.1)
Interpreting data	8 (17.8)	22 (48.9)	30 (66.7)	14 (31.1)	-	1 (2.2)	15 (33.3)
Formulating hypotheses	7 (15.6)	9 (20.0)	16 (35.6)	18 (40.0)	-	11 (24.4)	29 (64.4)
Defining operational definition	14 (31.1)	17 (37.8)	31 (68.9)	6 (13.3)	-	8 (17.8)	14 (31.1)
Experimenting							
• Collecting data	12 (26.7)	32 (71.1)	44 (97.8)	-	-	1 (2.2)	1 (2.2)
• Drawing conclusions	12 (26.7)	15 (33.3)	27 (60.0)	17 (37.8)	-	1 (2.2)	18 (40.0)

^a Classified as successful categories which include Types A and B.

^b Classified as unsuccessful categories which include Types C, D, and E.

4.2.1 Identifying and Controlling Variables

The findings revealed that most of the students (91%) were unsuccessful in identifying and controlling variables. In the aspect of independent variable, most of these students were not able to identify an independent variable of the study of exothermic reaction of the given reaction. Many students thought that an independent variable of the given reaction might be the type of reaction, reactants, or reversible reaction. For dependent variable, most students did not answer the question, while some students provided irrelevant answers. These students thought that a dependent variable of the given situation might be energy, method to eliminate air pollutant, exothermic reaction, or reactant.

It was found that only nine percents of students were successful in identifying and controlling variables. This meant that these students could specify three types of variables from the given reaction correctly. There were only two percents of students identify dependent variables in terms of concentration of product rather than of chemical equilibrium. However, it could be implied that those students were successful in identifying and controlling variables.

4.2.2 Interpreting Data

There were about 67 percent of students successful in interpreting the given data of the experiment between steam and coal and about 33 percent were not. About 18 percent of student answers were categorized as being Type A. These students interpreted the given data in terms of equilibrium constant first, then they explained those data by considering the relationship between equilibrium constant and temperature. They explained that when the temperature of the reaction increased, it was found that equilibrium constant increased, too. This meant that this reaction is an endothermic reaction. It was found that there were about 49 percent of student answers which were categorized as being Type B. These students explained the relationship between temperature and product concentration rather than equilibrium.

However, they could analyze the given data to determine type of the reaction and provide a correct reason, although it might be not the same as expected answer. For students who were unsuccessful, it was found that their answers were categorized into Type C and Type E. About 31 percent of the students explained that the concentration of products and reactants changes because the temperature is changed.

4.2.3 Formulating Hypotheses

Most of the students were unsuccessful in formulating hypotheses of the reduction reaction of dangerous air pollutants. About 64 percent of students were unsuccessful, while about 36 percent were successful. The unsuccessful students ambiguously formulated the hypothesis of the given reaction. For example, temperature effected an exothermic reaction, or the given reaction is an exothermic reaction if temperature is changed. Successful student answers were found in Type B more than in Type A. About 20 percent of successful students stated that when the temperature of the reaction increases, the concentration of nitrogen gas and carbonmonoxide gas [products] should increased if this reaction is an endothermic reaction, while about 16 percent specifically stated that the reaction should be an endothermic reaction if the equilibrium constant increases when the temperature of the reaction is increased.

4.2.4 Defining Operational Definition

Most students were successful in defining operational definition. There were about 69 percent of students successful in defining how to measure the equilibrium constant of the reaction between steam and coal, while about 31 percent were unsuccessful. For successful students, it was found that their answers were Type B more than Type A. Students who answered as Type B did not specify how to measure the equilibrium constant of the given reaction. They only provided the meaning of equilibrium constant. Unsuccessful students answered as Type E and Type C. Some of the students whose answers were Type C indicated that an equilibrium constant is a

constant value of an equilibrium state. Some students noted that equilibrium constant could be measured from the reaction which is in equilibrium. From this it could be implied that these students did not have the science process skill of defining operational definition. In fact, they could not measure the equilibrium constant directly from the experiment. They have to find out each concentration of all substances in the reaction, then those concentrations were brought to calculate for the numerical data of equilibrium constant.

4.2.5 Experimenting

For the science process skill of experimenting, students were assessed for the skills of collecting data and drawing a conclusion from the reaction between steam and coal. It was found that most of the students were successful in the skills of collecting data and drawing a conclusion. About 98 percent of students were successful in designing a table to collect data from the experiment. These students could design a table correctly, however, their tables were categorized to be Type B more than Type A. About 71 percent could arrange data from the experiment into their table correctly, but they did not design a special column for calculating the equilibrium constant. About 27 percent of student answers were Type A. These students arranged data from the experiment into their table, they also designed a special column to present the equilibrium constant.

For drawing a conclusion, most of the students were successful. It was found the about 60 percent of students were successful while about 40 percent were not. For successful students, only about 27 percent of answers were categorized as being Type A, while Type B answers were about 33 percent. Students who answered as Type B only concluded that the reaction between steam and coal is an endothermic reaction which could be observed from an increase of product concentration. These students could conclude the type of the reaction by using data from the experiment but they provided an incomplete reason for supporting their conclusion. Unsuccessful student answers could be separated into two types of

answer, Type C and Type E. About 38 percent of students presented general and unclear conclusions for this experiment. For example, some students only concluded that concentration of products varies from temperature, or concentration of products increases because of an increase of temperature. About 2 percent of the students did not answer the question.

4.3 Students' Attitudes towards Chemical Equilibrium Concepts and Teaching and Learning

This section describes students' attitudes toward teaching and learning about chemical equilibrium using four topic headings: difficulty of chemical equilibrium concept, usefulness of chemical equilibrium concept, interest in learning chemical equilibrium concept, preference of teaching chemical equilibrium concept. Data from the Questionnaire on Students' Attitudes toward Teaching and Learning about Chemical Equilibrium were scored, and then students' scores were categorized into five levels: high positive attitude (range from 4.50 to 5.00), positive (range from 3.50 to 4.49), moderate (range from 2.50 to 3.49), negative attitude (range from 1.50 to 2.49), and high negative attitude (range from 1.00 – 1.49). Students' attitudes towards each topic were presented in terms of mean score and standard deviation for each topic as shown in Table 6.7.

Table 6.7 Mean scores and standard deviations of students' attitudes towards chemical equilibrium concepts and teaching and learning: findings from School B (N=45)

Topic	Sub-topic	Scores of Students' Attitudes*	
		Mean Score	SD
Complexity of Chemical Equilibrium Concept	Difficult when dealing with exercises.	3.85	0.89
	Difficult to understand.	3.58	0.94
	Difficult when dealing numerical values and mathematical calculations.	3.91	0.73
	<i>Average Mean Score</i>	<i>3.78</i>	<i>0.85</i>
Usefulness of Chemical Equilibrium Concept	Usefulness in daily life	3.23	0.96
	Usefulness in a future career	3.01	1.01
	Usefulness in developing the country	3.24	0.93
	<i>Average Mean Score</i>	<i>3.16</i>	<i>0.97</i>
Interest in Chemical Equilibrium Concept	Want to learn more about the chemical equilibrium concept	3.13	0.87
	Concept is interesting	3.09	0.94
	Interested in chemical equilibrium concept because of doing laboratory	3.37	1.08
	<i>Average Mean Score</i>	<i>3.20</i>	<i>0.96</i>
Preference of Teaching and Learning about Chemical Equilibrium	Study in small groups is better than by individuals	4.24	0.92
	Discussion could enhance understanding of chemical equilibrium concept	4.19	0.87
	Doing exercises could enhance understanding of chemical equilibrium concept	3.96	0.97
	Learning from doing activities is better than lecturing	4.31	0.83
	<i>Average Mean Score</i>	<i>4.12</i>	<i>0.93</i>
	Overall	3.57	0.93

*Scores of students' attitudes are high positive (4.49 -5.00), positive (3.49 – 4.50), moderate (2.49 – 3.50), negative (1.50 – 2.49), and high negative (1.00 – 1.49)

As can be seen in Table 6.7, the mean score of the overall students' attitude was about 3.57 (SD = 0.93). This showed that students in School B had a positive attitude toward teaching and learning about chemical equilibrium. There were two topics that students had a positive attitude towards: preference of teaching and learning and complexity of chemical equilibrium concept. It was found that students held moderate attitudes towards the two topics covering the usefulness of the chemical equilibrium concept and interest in chemical equilibrium concept.

In the topic of preference of teaching and learning, the findings showed that students in School B held positive attitudes with the highest mean score (about 4.12). Students' attitude scores for each statement ranged from the most to the least as following: learning from doing activities is better than lecturing; study in small groups is better than by individuals; discussion could enhance understanding of chemical equilibrium concept; and doing exercises could enhance understanding of chemical equilibrium.

For topic of complexity of chemical equilibrium concept, the findings were that the mean score of student's attitudes was about 3.78. This showed that students held positive attitudes for this topic. Students' attitudes toward each statement in this topic ranged as following: difficulty when dealing with numerical values and mathematical calculations; difficulty when dealing with exercises; and difficult to understand.

For topic of interest in chemical equilibrium concept, it was found that mean score of student's attitude was about 3.20 was third. The lowest student attitude mean score was attitude toward usefulness of the chemical equilibrium concept. The mean score was only 3.16. This meant that those students held moderate attitudes toward those topics.

Case Study Three [School C]: Findings from the Implementation of the Chemical Equilibrium Learning Unit (CELU)

1. Context of the Case Study Three: School C

1.1 School Context

School C is a medium government secondary school located in a rural area of Chanthaburi Province. The total number of students in Thai 2005 academic year was about 900 students of which there were about 750 students in lower secondary level (Grade 7 to Grade 9) and there were about 150 students in the upper secondary level (Grade 10 to Grade 12). The students mostly came from average income families. There were nine science teachers from a total of forty six teachers in the school, one of them did not teach because he was studying for a Master's Degree. There was only one classroom for Grade 11 level. It was called the *Science and Mathematics Program* classroom. Science subject in upper secondary level consists of Physics, Biology, and Chemistry. The students in the *Science and Mathematics Program* had to study Science for nine periods a week in which three periods were Chemistry, similar to the two schools discussed previously. Each period was about 50 minutes. In total, in the second semester of 2005 academic year, there were only 30 periods per semester for studying Chemistry because of many school activities and public holidays. Because of this, the students were asked to learn more on holidays, either on Saturday or on Sunday. For Grade 11, the students who were in the *Science and Mathematics Program* were planned to study chemical equilibrium concepts for eighteen periods.

1.2 Classroom Context

The chemical equilibrium concept was taught in the only chemistry laboratory room in School C. The room was decorated in a similar pattern to Schools A and B but it is smaller than those. The teacher's table which was only 1 meter long

was placed in front of the laboratory room. Above the teacher's table, there was a television hung on the ceiling. There were three cupboards in the room which were placed at the back. The scientific instruments were inside the cupboards. There were four computer places on one side of the laboratory room. On the other side of the laboratory room, near the windows, there were three sinks on the top of cupboards. There were only seven tables and 55 chairs in the classroom. During study, the students were divided into seven groups and sat around the tables as shown in Figure 6.4.

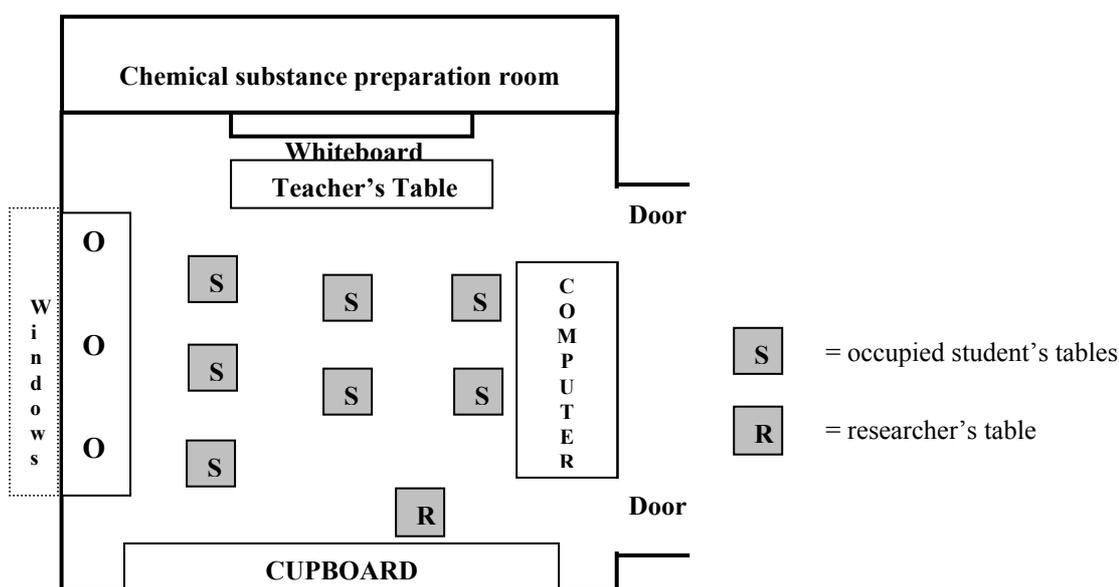


Figure 6.4 Classroom Context of School C

1.3 Teacher's Background

Miss Patcharee was a 34-year-old teacher. Her formal qualification is a Bachelor degree in Education in Chemistry. She had nine years' experience in secondary science teaching both in lower and upper secondary level. In the previous year, the chemical equilibrium concept had been taught by another teacher. In 2005 academic year, that teacher changed to teaching mathematics, and Miss Patcharee was assigned to teach the chemical equilibrium concept. She was worried about the concept because she had never taught it before. Regularly, she had taught chemistry

about the concept of gas, liquid, and stoichiometry. Then, she had to take time to prepare herself and to prepare teaching materials. Miss Patcharee's school loading work was not only science teaching in both lower and upper secondary level, but also being the secretary of the school administration.

1.4 Students' Background

Fifty five students who were in Grade 11, 23 male and 32 female, and studied chemistry with Miss Patcharee in the second semester of Thai 2005 academic year participated in this research study. These students were average competency in Science and Mathematics. Less than a half of the students in this classroom decided to study in the *Science and Mathematic Program* classroom because they wanted to study at tertiary level, whether or not it involved science subjects. These paid attention in studying all subjects. But more than a half of the students had to be in classroom because they had no choice for selection. They had no plans for further study.

2. Teacher's Implementation of the CELU into the Classroom

Before implementing the CELU in her classroom, Miss Patcharee had about five weeks to prepare herself and her teaching materials. She started to implement the CELU on the first week of January, 2006 and finished on the last week of February, 2006. Students could not study regularly because there were many school activities, for example, sports day, evaluating school. Because of many public holidays and school activities, some teaching and learning periods were canceled. Miss Patcharee had to make appointments with students to learn the chemical equilibrium concept on Saturday which is a holiday. In total, Miss Patcharee spent about fifteen periods for implementing the CELU which was less than the planned time. This section describes the way in which Miss Patcharee implemented the CELU in her classroom.

2.1 Teaching Preparation

Miss Patcharee made a major attempt to follow the learning activities as described in the teacher manual of the CELU. She had read and tried to understand all of learning activities before conducting those activities in the classroom. If there was a laboratory involved in the teaching and learning process, she usually completely prepared chemical substances and laboratory equipment in the morning before teaching. She did laboratory by herself in order to observe results before implementing the laboratory in the classroom. However, she faced many difficulties in teaching because of time limitations, and students' prior knowledge which are described in the next section.

In the first period of the implementation, Miss Patcharee informed students that they were in the process of doing research. Then, she asked students to divide into new groups which mixed ability. Because of the limitations of the laboratory room, there could be only seven groups. So there were eight students in each group. Students were directed into their groups by Miss Patcharee. However, they were not worried about this. They were asked to sit in these groups throughout the implementation of the CELU but they did not. It was found that some students moved to sit with their close friends, although Miss Patcharee asked those students to sit in a separate group.

2.2 Teaching Practice

Miss Patcharee attempted to follow teaching process as described in the teacher manual of the CELU as much as possible. However, she usually skipped some process which involved discussion within a small group because of the limitations of time. She usually assigned students to answer questions for discussing the result from laboratory as homework. She said that there was no time to do that activity, then students should take the responsibility of answering questions. At the beginning of the implementation, it was found that teaching and learning process quite was consistent

with learning activities as described in the teacher manual. Students were probed about their prior knowledge by being challenged to explain various situations. After implementing the CELU for four lessons, teaching and learning periods had to be canceled for two weeks (six periods) because of school activities. Then, Miss Patcharee decided to make an appointment with the students to study on Saturday. Students were taught all day on Saturday, from 9.00 to 15.00. At this stage, students spent all day to study three concepts: equilibrium constant expression, the relationship between equilibrium constant and chemical equation, and calculation of equilibrium constant. For lesson eight, they were taught during the regular school day. For lessons nine and ten, students were asked to study on Saturday and on Sunday again. They spent three hours on Saturday morning to study the effect of changing temperature on equilibrium condition and three hours on Sunday morning to learn chemical equilibrium in living things and in industrial application. The ways that Miss Patcharee implemented the CELU were described below.

2.2.1 The Way of Asking Questions

A number of questions and discussion activities were skipped or done hastily to finish teaching and learning activities on time. If it was found that there was no time for discussion, the teacher usually read the question to the whole class, and then answered the question herself. Students only took notes or key words into worksheet. The teacher acted as an expert in the classroom. There were a few students who answered the questions. Miss Patcharee usually summarized the answer to each question for the whole class. Then, she waited for students taking notes into the worksheet. If she wanted students to think, she would not answer the question but she assigned students to find out the answer by themselves, and then, the answer was sent to her. All the questions that were asked were questions in the student worksheet. This might influence student's behavior during learning. Students rarely were challenged and motivated to think, and they usually kept quiet if they did not know the right answer. They only waited for the right answers from the teacher and wrote key ideas into their worksheet.

2.2.2 The Realization of the Importance of Students' Prior Knowledge

Finding out students' prior knowledge is one of important learning activities of the CELU. Miss Patcharee followed those learning activities as described in the teacher manual at the beginning of the implementation. She brought everyday life examples to find out student conceptions of the nature of equilibrium. For example, perfume in closed glass bottle and nail cleaning substance in opened bottle were introduced to students. Students were asked to identify whether those examples could be in equilibrium and provide their reasons. Then, the definition of equilibrium was generated by students based on those examples. However, that activity was done as a whole class. Each student had no time to think about the given situation to find out their prior knowledge, individually. Miss Patcharee still found out students' prior knowledge before teaching new concept. However, students were not challenged to probe their prior knowledge. Data from classroom observations showed that Miss Patcharee usually explained the right concept to the students immediately, if she found that students answered the questions wrongly, especially in the later lessons. This strategy of teaching looked like reminding students to remember basic concepts rather than eliciting students' prior knowledge. So the teaching and learning process occurring in Miss Patcharee's classroom tends to start from the teacher's expectation rather than students' understanding.

2.2.3 The Teaching Activities

Miss Patcharee had tried so hard to follow teaching activities as described in the teacher manual of the CELU. She attempted to do all the steps in each lesson plan. However, she faced numerous difficulties in teaching because of the time limitations. Miss Patcharee usually adapted teaching activities as suggested in the teacher manual of the CELU to suit the time available. For example, doing hands-on and minds-on laboratory in many lesson plans was changed a demonstration. Discussions in a small group were often skipped or changed to become homework.

She often told students the conclusions of activities rather than encouraging them to reach conclusions by themselves. This is evident by classroom observation, Miss Patcharee usually read the answer from the teacher manual while students were asked to take notes in their worksheet. After that, she assigned students to send her their worksheet at the end of period.

Group work was rarely emphasized in the teaching activities. Although, teaching activities in each lesson in a teacher manual of the CELU realized the importance of group work and cooperative learning, it was quite difficult to implement in Miss Patcharee's classroom. At the beginning of the implementation, Miss Patcharee asked students to sit in groups which consisted of mixed competency students. However, data from classroom observation showed that students were not encouraged to study within their group. Only high competence students paid attention in learning while the other students in the group waited for their friend's answers and took notes. Moreover, another possible reason for unsuccessful working in groups might be the time limitations. As mentioned above, activities involving discussion usually were skipped but were assigned as homework, then students had little opportunity to share their ideas or discuss together. Subsequently, student thinking ability might not be developed as much as desirable.

2.2.4 The Strategies for Assessment

Miss Patcharee attempted to employ various techniques of assessment to evaluate student knowledge acquisition, such as discussion with the teacher, doing exercises in student worksheets. However, the evidence from classroom observation revealed that most of assessment strategy was concerned with students' worksheets. She asked students to send her worksheets at the end of each period. She collected and marked student worksheets regularly and returned those worksheets to students at the beginning of next period. Miss Patcharee usually spent about five minutes to talk about student worksheets. She recorded each student's mistakes from the worksheets and brought those mistakes to discuss in the whole

classroom. Students who made mistakes would revise their work using Miss Patcharee's description and sent it back to her again.

Miss Patcharee also created a special worksheet which looked like a summary of the chemical equilibrium concept for her students because she worried that teaching activities in the CELU might not be enough for her students. She asked students to complete that worksheet and send it to her. Then, Miss Patcharee did the same process as described above.

2.3 Summary of Teacher's Implementation of the CELU into the Classroom

Overall, it could be said that teaching and learning process of School C was quite far from constructivist-based perspectives. It tended to be teacher-centered, subject-oriented, or transmitting of knowledge from the teacher to students. Although, Miss Patcharee attempted to follow teaching activities as described in the teacher manual of the CELU, she was only successful in some lessons, such as reversible reaction, dynamic equilibrium, and disturbing the equilibrium condition by changing temperature. This occurred due to the limitation of time. Teaching and learning activities employed in Miss Patcharee's classroom usually involved a transmission of knowledge from the teacher to students. Students always took notes and completed their worksheets. They rarely were challenged to develop their thinking ability. It could be said that teaching and learning process was quite one way rather than iterative.

3. Students' Learning about Chemical Equilibrium during the Implementation of the CELU

This section focuses on the way of students' learning about chemical equilibrium during the implementation of the CELU. Data from various sources, for example classroom observations, interviews, or student's worksheets, were used to

describe how students learned about chemical equilibrium concept. The factors involved in students' learning are discussed below.

Although, the CELU emphasized teaching and learning by doing hands-on and mind-on activities, students in Miss Patcharee's classroom rarely had a chance to deal with those activities when compared to other two schools, Schools A and B. However, students in Miss Patcharee's classroom said that they had more opportunities to do activities than in the past. Considering the emphasis on hands-on and mind-on activities implemented in School C, it could help students to develop their understanding about the concept. For example, in the lesson of dynamic equilibrium, students were encouraged to engage with the concept by using the *Small Bead Game*. They were asked to link the game to the concept and come up with the definition of the concept of dynamic equilibrium. Data from students' interviews showed that most of the students believed that the game could help them understand the concept. When they were asked to describe the characteristic of dynamic equilibrium, most of them usually referred to the game and explained correctly, either completely or incompletely. Moreover, they believed that learning by doing activities could help them have more understanding of the concept rather than doing exercises or reading from a book because they could imagine easily.

4. Students' Learning Outcomes for Chemical Equilibrium after the Implementation of the CELU

This section focuses on students' learning outcomes for chemical equilibrium in terms of students' conceptions of chemical equilibrium, students' integrated science process skills for chemical equilibrium, and students' attitudes toward teaching and learning about chemical equilibrium. The details of each topic are described below.

4.1 Students' Conceptions about Chemical Equilibrium

The students' conceptions of chemical equilibrium sought consisted of five topics: changes to achieve equilibrium, equilibrium in chemical reaction, equilibrium constant, factors affecting equilibrium conditions and Le Châtelier's principle, and equilibrium in living things and in industrial applications. The students' responses on the survey were categorized into five categories as detailed in Chapter Three: Methodology. The results from survey are shown in Table 6.8.

Table 6.8 Distribution of students' conceptions of chemical equilibrium: findings from School C (N = 55)

Topics	No. of students (percentage)				
	SU*	PU*	PU & MU*	MU*	NU*
Changes to achieve equilibrium	7 (12.7)	21 (38.2)	2 (3.6)	11 (20.0)	14 (25.5)
Equilibrium in chemical reaction					
• Reaction of hydrogen gas and iodine gas	8 (14.5)	-	-	22 (40.0)	25 (45.5)
• Ammonia production by Haber process	-	-	38 (69.1)	4 (7.3)	13 (23.6)
Equilibrium constant					
• Equilibrium expression	36 (65.5)	-	-	-	19 (34.5)
• Calculating equilibrium constant	6 (10.9)	32 (58.2)	-	-	17 (30.1)
• Interpreting equilibrium constant	39 (70.9)	-	-	10 (18.2)	6 (10.9)

*SU = Sound understanding, PU = Partial understanding, PU & MU = Partial understanding with specific misconception, MU = Misconception, NU = No understanding

Table 6.8 (Continued)

Topics	No. of students (percentage)				
	SU*	PU*	PU & MU*	MU*	NU*
Factors affecting equilibrium condition and Le Châtelier's principle					
• Disturbing equilibrium condition by changing concentration	12 (21.8)	29 (52.7)	-	8 (14.5)	6 (10.9)
• Disturbing equilibrium condition by changing pressure	1 (1.8)	5 (9.1)	-	15 (27.3)	34 (61.8)
• Disturbing equilibrium condition by changing temperature	38 (69.1)	-		7 (12.7)	10 (18.2)
Chemical equilibrium in living things and in industrial applications	19 (34.5)	24 (43.6)			12 (21.8)

***SU** = Sound understanding, **PU** = Partial understanding, **PU & MU** = Partial understanding with specific misconception, **MU** = Misconception, **NU** = No understanding

4.1.1 Changes to achieve Equilibrium

Students' conceptions of changes to achieve equilibrium could be assessed by using information from a graph to identify equilibrium state. The findings indicated that the majority of the students' conceptions about changes to achieve equilibrium were categorized as being partial understanding. As listed in Table 6.8, the results showed that about 38 percent of students had partial understanding. These students could identify that the change could be in equilibrium from the sixth second. They only gave the reason that it could be seen from the graph. About 26 percent of students had no understanding of this topic. There were about 20 percent of students who had misconceptions about this topic. These students believed that the given reaction could not be equilibrium because the reaction constantly increased and decreased in the same time. However, about 13 percent of students had sound understanding of this topic. These students could indicate that the change is in equilibrium because each substance's concentration in the change is constant. They described that the slope of graph is constant from the sixth second because the rate of forward reaction equals the rate of reverse reaction and the concentration of each substance is constant. It was also found that about 4 percent of students had a partial understanding with specific misconceptions. The students who had partial understanding with specific misconceptions understood that the given reaction could be in equilibrium from the sixth second because no change occurred. This showed that these students had a misconception about the characteristics of dynamic equilibrium.

4.1.2 Equilibrium in Chemical Reaction

The reaction between hydrogen gas and iodine gas was given to students to find out their conceptions of equilibrium in chemical reaction. The scientist found that reaction occurs after mixing both gases (equal molar amounts) into the vessel. Measurements were made on the second hour and again on the fourth hour: both showed that 2 mol of hydrogen gas, 2 mol of iodine gas, and a mol of

hydrogen iodide gas were all present. Students were asked to explain why the observed data from the experiment is like that. The results showed that the majority of students had no understanding of equilibrium in chemical reaction. As listed in Table 6.8, about 46 percent of students did not answer the question. It was found that about 40 percents of students had misconceptions. One group of these students believed that the amount of each substance is constant because equilibrium constant is no change. They explained that at the equilibrium, nothing was changed. Another group of these students believed that the amount of each substance is constant because the reaction has taken place completely, and there was no change at the equilibrium. About 15 percent of students had sound understanding. These students could indicate that the given situation is in equilibrium state because the given reaction is a reversible reaction. The amount of each substance in the reaction is constant because the rate of forward and reverse reaction is equal.

Another situation also was given to students, the ammonia production by the Haber process. Students were asked to choose a diagram which could be snapshot of equilibrium conditions of the ammonia production process and to provide their reason. The findings showed that none of students had sound understanding or partial understanding of this topic. It was found that the majority of the students had a partial understanding with specific misconception, as listed in Table 6.8. About 69 percent of students understood that there must be all substances at equilibrium because of reversible reaction. However, these students believed that the amounts of each substance which presented in the equilibrium are equal to stoichiometric coefficient of each substance. So, they believed that at the equilibrium, there will be two molecules of nitrogen gas, two molecules of ammonia gas, and three molecules of hydrogen gas. There were about 24 percent of students who had no understanding of this topic. These students did not answer the question. Another category of students' conceptions about equilibrium in chemical reaction, misconception, was held by about 8 percent of students. These students believed that at the equilibrium, there was only molecules of ammonia gas. They believed that chemical reaction occurred when the reactants were totally changed to being products.

These meant that students who had a misconception of this topic had no understanding of reversible reaction.

4.1.3 Equilibrium Constant

Students' conceptions about equilibrium constant could be separated to be three topics; expression of equilibrium constant equation, calculation of equilibrium constant, and interpretation of equilibrium constant. The findings showed that the majority of students held sound understanding about equilibrium constant except in the topic of calculating equilibrium constant. About 66 and 70 percent of students held sound understanding about the concept equilibrium expression and interpretation of equilibrium constant, respectively. They could write the equation to express the relationship between equilibrium constant and concentrations of each substance in a chemical reaction. These students understood that the equilibrium expression could be written as a mathematical formula which relates to the chemical equation.

For topic of calculating equilibrium constant, the results showed that about 58 percent of students had partial understanding. These students could write an equation expression of the given chemical reaction but they had difficulties in the calculation step. Some of them did every step correctly but incorrect mathematical calculations, so they could not find the iodine concentration at equilibrium. Some of them could not do the last step of calculation which is solving the mathematical equation to find out the iodine concentration. These only showed some mistakes concerned with mathematical obstacles rather than a misconception.

For another topic, interpreting equilibrium constant, the finding showed that students' conceptions of this topic were sound understanding, misconceptions, and no understanding. The equilibrium constant for a reaction tells the scientist whether the reaction favors the reactants or the products. About 71 percent of the students understood that if the equilibrium constant is more than one,

then the reaction favors products while a small K , less than one, indicates only a small proportion of product will be formed. These students could indicate the majority substances which occurred at the equilibrium and provided reasons correctly. There were about 18 percent of students had misconceptions about this concept. These students described that it could not be identified which substances should be major due to reversible reaction. At the equilibrium, it is reversible reaction. Then, all substances continuously change from reactants to products, and from products to reactants. About 11 percents of students had no understanding.

4.1.4 Factors Affecting Equilibrium Conditions and Le Châtelier's Principle

Factors affecting equilibrium conditions and Le Châtelier's principle concept consist of three aspects; disturbing equilibrium condition by changing concentration, disturbing equilibrium condition by changing pressure, and disturbing equilibrium condition by changing temperature.

For disturbing equilibrium condition by changing concentration, it was found that most of students, about 53 percent, had a partial understanding of this topic. About 22 percent of students held sound understanding on this topic. The other students had misconceptions and no understanding. It was found that there was about 15 percent of students had misconception about this aspect. These students believed that predictions could not be made about any changes from disturbing the equilibrium condition by changing concentration because they believed that there was nothing changed even if the concentration of some substance was increased. These resulted from the students belief that a complete chemical reaction takes place.

For topic of disturbing the equilibrium condition by changing pressure, it was found that most of students, about 62 percent, had no understanding of this topic. They did not answer the question. There were about 27 percent of the students had a misconception about this aspect. These students believed that if the

pressure of the reaction is increased by decreasing volume of the vessel, there will be more products because molecules of reactants are close, so, the rate of reaction increases. This meant that all reactants become products. However, there were about 9 and 2 percent of students who had partial understanding and sound understanding of this topic, respectively.

The last topic, disturbing equilibrium condition by changing temperature, it was found most of the students, about 69 percent, had sound understanding. About 18 and 13 percent of students had no understanding and misconception for this topic. Students who had a misconception could be categorized as being two types. One believed that predictions could not be made about any change from disturbing equilibrium condition by changing temperature because it is a reversible reaction. Another believed that no change occurred because the reaction is in equilibrium. So, the system is constant.

4.1.5 Chemical Equilibrium in Living Things and in Industrial Applications

The majority of students, about 44 percent, had a partial understanding of chemical equilibrium in living things and in industrial applications. There were about 35 and 22 percent of students who had sound understanding and no understanding, respectively. The students who had a sound understanding of this concept could explain the use of Le Châtelier's principle to apply in rescuing a person poisoned by carbonmonoxide and in the ammonia production by the Haber process. The students who held partial understanding could explain how to rescue that person and how to increase the amount of ammonia correctly but could not provide the reasons. About 22 percents of students did not write any answer, from which it could be implied that those students might not understand this concept.

4.2 Students' Capabilities in Integrated Science Process Skills

Students' capabilities were assessed in five integrated science process skills: identifying and controlling variables; interpreting data; formulating hypotheses; defining operational definition; and experimenting. Students were asked to complete the survey. Their responses, in the integrated science process skills survey part, were categorized into five types (detailed in Chapter Three: Methodology). Distribution of students' responses is presented in Table 6.9 and is described below.

Table 6.9 Distribution of students' capabilities in integrated science process skills: findings from School C (N=55)

Integrated science process skills	No. of students						Total ^b
	A	B	Total ^a	C	D	E	
Identifying and controlling variables	2 (3.6)	-	2 (3.6)	4 (7.3)	11 (20.0)	38 (69.1)	53 (96.4)
Interpreting data	-	6 (10.9)	6 (10.9)	-	13 (23.6)	36 (65.5)	49 (89.1)
Formulating hypotheses	4 (7.3)	14 (25.4)	18 (32.7)	5 (9.1)	-	32 (58.2)	37 (67.3)
Defining operational definition	-	21 (38.2)	21 (38.2)	7 (12.7)	-	27 (49.1)	34 (61.8)
Experimenting							
• Collecting data	-	39 (70.9)	39 (70.9)	-	-	16 (29.1)	16 (29.1)
• Drawing conclusions	-	12 (21.8)	12 (21.8)	23 (41.8)	-	20 (36.4)	43 (78.2)

^a Classified as successful categories which include Types A and B.

^b Classified as unsuccessful categories which include Types C, D, and E.

4.2.1 Identifying and Controlling Variables

The findings revealed that most of students (96%) were unsuccessful in identifying and controlling variables. Most of students were unsuccessful in identifying all of variables: i.e. independent variable, dependent variables, and variables to be held constant. Most of them (70%) did not answer the question. Twenty percent and seven percent of students answered as Type D and Type C, respectively. It was found that only four percent of students were successful in identifying those three variables of the given reaction and answers which were categorized as Type A.

4.2.2 Interpreting Data

About 89 percent of students were unsuccessful in interpreting the given data of the experimentation using steam and coal and about 11 percent were successful. It was found that most of the students who were categorized as being unsuccessful, about 66 percent did not answer anything, while about 24 percent of student answers were in Type D. For the Type D answer, these students did not use data from experimentation to describe and predict the type of the given reaction. They only answered that the reaction will be an endothermic reaction if energy is a reactant, or the reaction will be an exothermic reaction if energy is a product. However, about 11 percent of students were successful in interpreting data. Successful student answers were all Type B. These students explained the relationship between temperature and product concentration rather than equilibrium. However, they could analyze the given data to determine type of the reaction and provide reason, correctly although it might not be the same as the expected answer.

4.2.3 Formulating Hypotheses

Most of the students were unsuccessful in formulating hypotheses for the reduction reaction of dangerous air pollutants. About 67 percent of students

were unsuccessful, while about 33 percents were successful. The unsuccessful students ambiguously formulated an hypothesis of the given reaction. For example, an exothermic reaction was effected by changing temperature. On the other hand, successful student answers were Type B more than Type A. About 25 percent of the students successfully stated that when the temperature of the reaction increases, concentration of nitrogen gas and carbonmonoxide gas [products] should increase if this reaction is an endothermic reaction, while about seven percent specifically stated that the reaction should be an endothermic reaction if the equilibrium constant increases when temperature of the reaction is increased.

4.2.4 Defining Operational Definition

Most of students were unsuccessful in defining operational definition. There were about 62 percents of students successful in defining how to measure the equilibrium constant of the reaction between steam and coal, while about 38 percent of students were unsuccessful. For unsuccessful students, their answers were categorized as Type E and Type C. For students who answered as Type C, some of them indicated that the equilibrium constant is a constant value of equilibrium state or explained that the equilibrium constant could be measured from the equilibrium state. This could imply that these students did not have science process skill of defining operational definition. In fact, they could not measure the equilibrium constant directly from the experiment. They have to find out each concentration of all substances in the reaction, then those concentrations were brought to calculate for numerical data of the equilibrium constant. For successful students, it was found that their answers were only Type B. These students did not specify how to measure the equilibrium constant of the given reaction. They only provided the meaning of equilibrium constant which is the ratio between the multiplication of concentration of products and the multiplication of concentration of reactants.

4.2.5 Experimenting

For science process skill of experimenting, students were assessed in the skills of collecting data and drawing a conclusion from the reaction between steam and coal. It was found that most students were successful in the skills of collecting data. About 71 percent of students were successful in designing a table to collect data from the experiment. These students could design a table correctly, however, their tables were categorized as being Type B. All of them could arrange data from the experiment into their table correctly, but they did not design a special column for calculating the equilibrium constant.

For drawing a conclusion, most students were unsuccessful. It was found that about 78 percent were unsuccessful while about 22 percent were successful. For unsuccessful students, student answers could be separated into two types of answer, Type C and Type E. About 42 percent of students presented a general and unclear conclusion for this experiment. For example, some students only concluded that concentration of products varies from temperature, or concentration of products was different depending on temperature. About 36 percent of students did not answer the question. For successful students, it was found that their answers were categorized as being only Type B. About 22 percent of students who answered as Type B only concluded that the reaction between steam and coal is an endothermic reaction which could be observed from an increase of product concentration. These students could conclude type of the reaction by using data from the experiment but they provided incomplete reason for supporting their conclusion.

4.3 Students' Attitudes towards Teaching and Learning about Chemical Equilibrium

This section describes students' attitudes toward teaching and learning about chemical equilibrium under four topics: difficulty of chemical equilibrium concept, usefulness of chemical equilibrium concept, interest in learning chemical

equilibrium concept, preference of teaching chemical equilibrium concept. Data from the Questionnaire on Students' Attitudes toward Teaching and Learning about Chemical Equilibrium were scored, and then students' scores were categorized into five levels: high positive attitude (range from 4.50 to 5.00), positive (range from 3.50 to 4.49), moderate (range from 2.50 to 3.49), negative attitude (range from 1.50 to 2.49), and high negative attitude (range from 1.00 – 1.49). Students' attitudes towards each topic were presented in terms of mean score and standard deviation for each topic as shown Table 6.10.

Table 6.10 Mean scores and standard deviations of students' attitudes towards chemical equilibrium concepts and teaching and learning: findings from School C (N=55)

Topics	Sub-topic	Scores of Students' Attitudes*	
		Mean Score	SD
Complexity of Chemical Equilibrium Concept	Difficult when dealing with exercises.	3.56	0.92
	Difficult to understand.	3.53	0.89
	Difficult when dealing with numerical values and mathematical calculations.	3.87	0.91
	<i>Average Mean Score</i>	<i>3.65</i>	<i>0.91</i>
Usefulness of Chemical Equilibrium Concept	Usefulness in daily life	3.13	1.03
	Usefulness in a future career	3.01	0.98
	Usefulness in developing the country	3.47	1.01
	<i>Average Mean Score</i>	<i>3.20</i>	<i>1.01</i>
Interest in Chemical Equilibrium Concept	Want to learn more about the chemical equilibrium concept	2.93	0.98
	Concept is interesting	3.21	0.84
	Interested in chemical equilibrium concept because of doing laboratory	3.57	1.05
	<i>Average Mean Score</i>	<i>3.24</i>	<i>0.96</i>
Preference of Teaching and Learning about Chemical Equilibrium	Study in small groups is better than by individuals	3.68	0.88
	Discussion could enhance understanding about chemical equilibrium concept	3.79	0.94
	Doing exercises could enhance understanding about chemical equilibrium concept	3.51	1.03
	Learning from doing activities is better than lecturing	3.86	0.97
	<i>Average Mean Score</i>	<i>3.71</i>	<i>0.96</i>
	Overall	3.45	0.96

*Scores of students' attitudes are high positive (4.49 -5.00), positive (3.49 – 4.50), moderate (2.49 – 3.50), negative (1.50 – 2.49), and high negative (1.00 – 1.49)

As can be seen in Table 6.10, the mean score of the overall students' attitude was about 3.45 (SD = 0.96). This meant that students in School C held a moderate attitude toward teaching and learning about chemical equilibrium. There were two topics to which students held positive attitudes, while students held a moderate attitude toward the other topics. Topics that students held a positive attitude towards were preference of teaching and learning and complexity of chemical equilibrium concept. For another two topics, usefulness of chemical equilibrium concept and interest in chemical equilibrium concept, it was found that those students held moderate attitudes towards them.

In the topic of preference of teaching and learning, the findings showed that students in School C held positive attitudes with the highest mean score (about 3.71). Student attitude scores for each statement ranged from the most to the least as the following: learning from doing activities is better than lecturing; discussion could enhance understanding about chemical equilibrium concept; study in small groups is better than by individuals; and doing exercises could enhance understanding of chemical equilibrium. The lowest student attitude mean score was the attitude toward usefulness in the chemical equilibrium concept. The mean score was only 3.20 which meant that those students held moderate attitudes toward this topic.

Summary of Findings from the Implementation of the Chemical Equilibrium Learning Unit (CELU)

This section focuses on an analysis across three cases of the study. Teachers' implementation of the CELU and students' learning during and after implementing the CELU are compared to provide a holistic view. These aspects are described below.

1. Teachers' Implementation of the CELU into Their Classroom

Three teachers were involved in the implementation of the CELU into the classroom. Each teacher had their own way for implementing the CELU. Some of

them followed teaching activities as described in a teacher manual of the CELU. Some of them adapted those activities to be appropriate to their students, or some decided to omit some activities. These might result from those teachers having different views of teaching and learning. Mrs. Malinee, Miss Waleerat, and Miss Patcharee, three chemistry teachers, were individually different in terms of teaching background, in particular knowledge of content, belief about teaching and learning, or task responsibility. These might influence the different way of the implementation of the CELU. In the implementation of the CELU into those teachers' classroom, it could be noted that Mrs. Malinee and Miss Waleerat tended to use teaching practices consistent with constructivist-based perspective, while Miss Patcharee attempted to be involved in that perspective. However, Miss Patcharee's teaching practices tended to be teacher-centered and emphasized subject orientation rather than emphasizing providing learning opportunities based on students' prior knowledge.

Belief about teaching and learning had affected teaching practices. The teacher who believed that constructivist-based perspectives could enhance students' learning outcomes, tended to follow teaching activities as described in the teacher manual. Teaching and learning activities such as probing students' prior knowledge, motivating students to be involved in conversation, asking open-ended questions, doing hands-on and mind-on activity, working in groups were realized as important activities during the teaching and learning process. For example, Miss Waleerat who believed that teaching from constructivist-based perspectives could be effective in her classroom employed various activities to encourage students to be active during learning. Students were motivated to engage in probing prior knowledge, either by discussion or paper and pencil test. Students' prior knowledge was brought to be starting point for teaching and learning a new concept. This is consistent with the suggestion of Asoko (1995) which described that the way of matching constructivist-based perspectives of learning with effective science teaching should recognize finding what the learner's knowledge and understanding are, and then providing learning experiences which start from there.

Additionally, giving students opportunities to test or bring their understanding to explain new situations should be considered. The teacher should challenge students to explain new situations by using their own ideas. Then, the question-asking ability of each teacher influenced the implementation of the CELU. Teachers who tended to have constructivist-based perspectives focused on the way of asking questions. They usually challenged students to answer open-ended questions for motivating students' thinking ability. Teacher's question-asking ability also influenced the way of discussion in a whole class. Teacher who had high questioning ability could motivate students to engage in discussion better than those who did not. These might directly result in improving students' thinking ability. Students who were motivated to be involved in classroom discussion tended to have thinking skills higher than another.

Interestingly, three teachers gave important key aspects of the implementation of the CELU. They suggested that the process of initial workshop and meetings could help them have more understanding about the implementation of the CELU. They also had a chance to share strategies of teaching and learning together. Miss Waleerat summarized at the last meeting that she felt more comfortable during teaching and learning during the implementation of the CELU. At the beginning of the implementation, she was uncertain whether or not the CELU was effective in the real classroom. However, each meeting could help her implement the CELU effectively. Then, the CELU not only helped students to develop their learning outcomes about chemical equilibrium concept, but also helped teachers to develop their teaching and learning to promote constructivist-based perspectives.

2. Students' Learning from the Implementation of the CELU

Students' learning was investigated during the implementation of the CELU. Data from various sources showed that learning processes supporting students to meet with expected learning outcomes for chemical equilibrium concepts involves many learning activities which are described below.

Data from classroom observations showed that doing hands-on and mind-on activities could encourage students' learning. Informal student interviews also confirmed that students thought that they had more understanding when they had a chance to do activities such as laboratory work, or playing games than learning by lecturing. These findings were similar to the study by Stohr-Hunt (1996) who reported that the more the students practice, the better they can understand science.

In aspects of students' conceptions about chemical equilibrium, the findings indicated that students from two schools (School A and School B) seemed to be successful in acquiring conceptual understanding of chemical equilibrium. The majority of students from those two schools had sound understanding about chemical equilibrium. Interestingly, the majority of students from School A had sound understanding of all topics about chemical equilibrium. In the case of School B, there were three topics in which the majority of students had sound understanding. These topics were equilibrium constant (equilibrium expression, calculating equilibrium constant, and interpreting equilibrium constant), factors affecting equilibrium conditions and Le Châtelier's principle (changing temperature and concentration), and changes to achieve equilibrium. However, the findings from School C showed that there were only two topics in which the majority of students held sound understanding. These topics were equilibrium constant (interpreting equilibrium constant and equilibrium expression), and factors affecting equilibrium conditions and Le Châtelier's principle (changing temperature).

It could be seen that students from those three schools could better develop their learning' outcomes when they were engaged with teaching and learning activities rather than passive learning. As Watson (2000) suggests, scientific concepts and theories are often counter-intuitive and have to be constructed in the classroom by talking or reading about phenomena as well as by seeing them. These were evidenced by data from classroom observations and student interviews. Most of the students from the three schools thought that they could understand dynamic equilibrium concept easily because they had a chance to play the *Small Bead Game*. They brought

information from the game to link with the characteristics of dynamic equilibrium. Hence, these students ended up with the definition of dynamic equilibrium. Then, these students were sure that they understood dynamic equilibrium rather than having only memorized the concept.

Classroom interactions involved the teacher and students interactions and students to students interactions. These directly related to classroom conversations. It was found that students could develop their learning outcomes for the chemical equilibrium concept if they were challenged to be involved in classroom observation. As Carr *et al.* (1994) suggested, the most important feature of an approach to science classes, which addresses the difficulty of changing ideas, is conversation. The teacher and students discussion brought them towards the understanding of scientific ideas. These strategies were quite useful to support students to gain expected learning outcomes for the chemical equilibrium concept.

However, it could be noted that there were two factors which influenced classroom interactions, especially interactions between the teacher and students. Characteristically the questions should be open-ended questions which challenge students to think and to find out the answers. Teacher's feedback was also important in driving discussion. As seen in the case study of School A, Mrs. Malinee did not indicate that the student answered wrongly. She often asked more questions to provide some explanations to the student. This could help students enhance their conceptual understanding of the chemical equilibrium concept.

Summary of the Chapter

The Chemical Equilibrium Learning Unit (CELU) was implemented by three teachers from three schools in Chanthaburi Province. Before implementing the CELU in the classroom, an initial workshop was arranged to introduce the outline and details of the CELU. Those three teachers were briefed on how to implement the CELU in their classrooms. They were then asked to comment and give suggestions on each

lesson for the CELU. During the implementation of the CELU, those three teachers were asked to meet together to discuss their implementation and share ideas to improve the implementation of the CELU so that it could become more effective.

Each teacher had their own way of implementing the CELU. Factors which influenced the implementation of the CELU by each teacher involved their beliefs about teaching and learning using a constructivist-based perspective. The teacher who tended to believe that the perspective could help students meet the achievement of expected learning outcomes tried to implement the CELU as described in the teacher manual of the CELU as much as possible. On the other hand, the teacher who tended to be a traditional teacher rarely emphasized the importance of teaching and learning activities describing in the CELU. This teacher only emphasized content knowledge and tended to transmit all content knowledge to the whole class.

After implementing the CELU, it was found that the CELU could help students develop their learning outcomes for chemical equilibrium concepts. Learning activities which were effective in supporting students to develop their learning outcomes involved hands-on and mind-on activities, discussions, working in groups, and self and peer assessment.

The next chapter, the last chapter of this thesis, will give an overall summary of this study. Findings from each phase are summarized, and implications of the study will be discussed.

CHAPTER VII

DISCUSSIONS, CONCLUSIONS, AND IMPLICATIONS OF RESEARCH STUDY

Overview of the chapter

This chapter focuses on summary of research findings and their implication to the science teaching and learning. The research framework firstly was reviewed in terms of research objectives and questions, and methodology. Then, the discussions and conclusions of the findings from research study are described. Those findings include Thai high school students' learning outcomes about chemical equilibrium in academic year 2004, teachers' implementation of the Chemical Equilibrium Learning Unit (CELU) and students' learning during and after the implementation of the CELU in academic year 2005. At the end of the chapter, some suggestions and implications for the further study are presented.

Research Framework

This section briefly describes research framework in terms of research objectives and questions, and methodology of the study. Each aspect was presented below.

1. Research Objectives and Questions

The aim of the study was to find out Thai high school students learning outcomes about chemical equilibrium concept in academic year 2004. Then, the findings were used as an important suggestion for developing an intervention, the Chemical Equilibrium Learning Unit (CELU), for improving teaching and learning

chemical equilibrium to be consistent with Thai educational reforms. To achieve this aim, the research questions are specified as the following.

1.1 What are Thai high school students' learning outcomes about chemical equilibrium concept in the current educational situation in Thai academic year 2004?

1.2 How do Thai Grade-11 chemistry teachers implement the Chemical Equilibrium Learning Unit into their classroom?

1.3 How do Thai Grade-11 students learn chemical equilibrium concept during the implementation of the Chemical Equilibrium Learning Unit?

1.4 What are Thai Grade-11 students' learning outcomes about chemical equilibrium concept after the implementation of the Chemical Equilibrium Learning Unit?

2. Research Methodology

This research was divided into two phases: exploratory phase and development and implementation of the learning unit phase.

2.1 Phase I: An Exploratory Phase

In Phase I or exploratory phase, students' learning outcomes which consisted of students' conceptions about chemical equilibrium concept, students' capability of science process skills, and students' attitude chemical equilibrium concept and teaching and learning were investigated. Chemical Equilibrium Concept and Science Process Skill Survey, and Questionnaire on Students' Attitudes toward Chemical Equilibrium Concept and Teaching and Learning were administered with 125 high school students from three schools in Chanthaburi Province during the second week of February 2005, after completely finishing chemical equilibrium

concept. The implications of the findings in exploratory phase were used as one of guiding principles in developing the Chemical Equilibrium Learning Unit (CELU).

2.2 Phase II: Development and Implementation of the Chemical Equilibrium Learning Unit (CELU)

In phase II or development and implementation of the CELU phase, the Chemical Equilibrium Learning Unit (CELU) was developed to improve teaching and learning about chemical equilibrium concept for Thai Grade-11 classrooms. After that the CELU was implemented in three classrooms from three schools in Chanthaburi Province during the second semester of Thai academic year 2005. Three teachers and 148 students from three schools had participated in this study. Multi case studies were employed for the second phase. Various methods of data collection were used to find out the implementation of the CELU of each teacher, and students' learning outcomes about chemical equilibrium concept from those three schools.

Discussions and Conclusions of the Phase I: Exploratory Phase

The Phase I aimed to find out Thai high school students' learning outcomes about chemical equilibrium concept which consisted of students' conceptions about chemical equilibrium, students' capabilities of science process skills and students' attitude toward chemical equilibrium concept and teaching and learning. The findings of each aspect of students' learning outcomes are summarized as below.

1. Students' Conceptions about Chemical Equilibrium Concept

The findings from the Chemical Equilibrium Concept and Science Process Skills Survey revealed that Thai high school students had difficulties to understand chemical equilibrium concept. It was found that student's conceptions about chemical equilibrium ranged from sound understanding to no understanding. The few of these students held sound understanding regarding as scientific concept about chemical

equilibrium. A majority of the students held partial understanding about the topic of factors affecting equilibrium conditions and Le Châtelier's principle. For the topics of changes to be equilibrium and equilibrium in chemical reaction, the findings showed that a majority of the students held partial understanding with specific misconception. The last two topics, equilibrium constant and chemical equilibrium in living things and in industrial applications, it was found that most of the students held no understanding. Interestingly, student's misconceptions were found in all topics of chemical equilibrium concept. Especially, in the topic of changes to be equilibrium and of equilibrium in chemical reaction, it was found that many students held various misconceptions which concerned with dynamic equilibrium and reversible chemical reaction. These findings were consistent with the oversea research study which revealed that the nature of chemical equilibrium is one of the difficulty concept for studying about equilibrium (Garnett *et al.*, 1995). Van Driel (2002) revealed that one source of the difficulty in understanding the nature of chemical equilibrium might generate from an abstract of the concept. As seen from the findings, many Thai high school students failed to describe the characteristics of chemical equilibrium at microscopic level. To decrease these misconceptions, teaching and learning about chemical equilibrium should more emphasize at microscopic level. It was also found that Thai high school students held various characteristic conceptions which were called alternative conceptions, similarly as suggestion in the literature (e.g. Benerjee, 1991; Huddle and Pillay, 1996).

2. Students' Capabilities of Science Process Skills

In aspect of students' capabilities of science process skills, integrated science process skills which consist of five skills were focused. These skills were identifying and controlling variables, interpreting data, formulating hypotheses, defining operational definition, and experiment. The findings revealed that most of students' capabilities of science process skills were categorized to be unsuccessful in the process skills of identifying and controlling variables, interpreting data, defining operational definition, and experimenting. For the process skills of formulating

hypotheses, it was found that a majority of the students were successful. One source of difficulties might generate from a lack of understanding in chemical equilibrium concept. When looking back to students' conceptions, it was found that Thai high school students rarely held sound understanding about chemical equilibrium concept. These might influence to students' capabilities of science process skills. As Harlen (1999) suggested, science process skills should be studied in relation to specific science content since any task involving the skills will be influenced by the nature of the subject content as well as the ability to use the skills. These findings suggested that teaching and learning about chemical equilibrium should emphasize both concepts and science process skills in the same time.

3. Students' Attitude toward Chemical Equilibrium Concept and Teaching and Learning

The last aspect of students' learning outcomes about chemical equilibrium is students' attitude toward chemical equilibrium concept and teaching and learning. It was found that Thai high school students held moderate attitudes towards all four topics which are difficulty of chemical equilibrium concept, usefulness of chemical equilibrium concept, interest in learning chemical equilibrium concept, preference of teaching chemical equilibrium concept.

4. Summary of Students' Learning Outcomes about Chemical Equilibrium in Thai Academic 2004

In summary, the findings from Thai high school students from Chanthaburi Province in academic year 2004 showed that most of these students seemed to be far from successful in learning chemical equilibrium concept. Their learning outcomes which consist of conceptual understanding, integrated science process skills, and attitude toward chemical equilibrium concept and teaching and learning were mostly seemed to be far from acquiring meaningful learning about chemical equilibrium concept as stated in the National Science Curriculum Standard. These findings

suggested that teaching and learning about chemical equilibrium needed to be improved for enhancing students' learning outcomes about chemical equilibrium concept.

Discussions and Conclusions of the Phase II: Development and Implementation of the Chemical Equilibrium Learning Unit (CELU)

1. The Development of the Chemical Equilibrium Learning Unit (CELU)

The Chemical Equilibrium Learning Unit (CELU) was designed to promote students learning's outcomes about chemical equilibrium concept. The aims of the CELU are to enhance scientific understanding or sound understanding about chemical equilibrium concept, integrated science process skills, and attitude toward chemical equilibrium concept and teaching and learning. The CELU was guided by constructivism as learning theory employed in the CELU, visions of learning science as framework for the CELU, and teaching strategies employed in the CELU were suggested by the early research study. The process of development the CELU consisted of four steps: exploring students' learning outcomes about chemical equilibrium concepts in the 2004 Thai academic year, identifying expected learning outcomes for chemical equilibrium concepts, designing and developing the CELU, and revising and developing instructional materials of the CELU.

The CELU consists of 11 lessons which cover five topics of chemical equilibrium concept: changes to be equilibrium, equilibrium in chemical reaction, equilibrium constant, factors affecting equilibrium condition and Le Châtelier's principle, and chemical equilibrium in living things and in industrial applications. Integrated science process skills and students' attitudes toward chemical equilibrium concept and teaching and learning also were emphasized to be a part of expected learning outcomes about chemical equilibrium concept. The CELU consisted of a teacher manual, student manual, and instructional materials. Totally, the CELU was planned to implement in the classroom for 18 periods or one and a half months (3

periods per week). Each period was about 50 minutes. Before implementing the CELU, three participated teachers from three schools were asked to attend the initial workshop to share their ideas for developing the CELU more effectively.

2. The Implementation of the CELU in the Classroom

The way of implementing the CELU of each teacher depends on the teacher's views of teaching and learning. Three participated teachers was individually different in terms of teaching background, teaching experiences, in particular content of knowledge, belief about teaching and learning, or task responsibility. Then, those teachers had their own way of implementing the CELU in the classroom. All teachers participated in the initial workshop before implementing the CELU into their classroom in order to understand how to implement the CELU effectively and realize benefits of implementing the CELU. The findings indicated that there were two teachers as constructivist-based perspectives teaching, while another was not. It could be seen that the teachers who tended to believe an effectiveness of constructivist-based perspective of teaching and learning chemical equilibrium concept tried to adapt learning activities as described in a teacher manual of the CELU to be appropriate for their students. These teachers also emphasized the nature of students in the classroom and attempted to begin teaching and learning activities from students' existing ideas. Students were challenged to realize what they had known individually. Here is a characteristic of constructivist-based perspectives of teaching and learning. As Asoko *et al.* (1995) suggested, effective science teaching based on constructivist-based perspectives should recognize two aspects which are finding what students' existing ideas and providing learning experiences which state from there. The findings also showed that two teachers realized the important of social processes. Students were encouraged to work in group collaboratively. Each student in each group had their own responsibility to complete the task. Those two teachers also emphasized discussion by giving enough time for students in each group to share their ideas together and come up with the conclusion. These strategies could enhance an effectiveness of the CELU when it was implemented in the classroom. However, one

teacher from this study could not implement the CELU in her classroom effectively. Although this teacher tried to implement teaching strategies as described in the CELU, it was ineffective. Sources of ineffectiveness might generate from the limitation of time and students' existing ideas relating to chemical equilibrium concept. Teacher's belief also influenced the way of the implementation. As seen from the teacher from School C, She rarely emphasized social process. Working in group and discussion usually were skipped during the implementation of the CELU. Consequently, students hardly engage in learning activities. Teaching and learning in School C tended to be transfer of knowledge from teacher to students rather than constructivist-based perspectives of learning.

3. Effect of the CELU on students' learning outcomes about chemical equilibrium

In aspects of students' conceptions about chemical equilibrium, the findings indicated that students from three schools seemed to be successful in acquiring conceptual understanding about chemical equilibrium in the topic of factors affecting equilibrium conditions and Le Châtelier's principle (changing temperature). It could be seen from the findings that a majority of the students from those three schools held sound understanding in that topic. Look back to teaching activities employed in teaching and learning about disturbing equilibrium condition by changing temperature, students were challenged to observe the color changes of cobalt complexes when temperature changed. This activity seemed to be effective for promote scientific conception about this topic for these students. Another teaching activity that quite was effective was teaching about the nature of equilibrium using the *Small Bead Game*. The findings showed that a majority of the students from School A and School B held sound understanding for topic of changes to be equilibrium, while a majority of the students from school C held partial understanding for this topic. These could be implied that most of those students understood about dynamic equilibrium and reversible reaction, consequently they held sound understanding about changes to be equilibrium. Comparing to the previous studies,

Thai context and oversea context, those studies revealed that students faced difficulties to understand the nature of equilibrium (Garnett *et al.*, 1995). Findings in this study showed that teaching and learning using the *Small Bead Game* which was an example of analogy seemed to be successful. However, there was an important point to be awareness about teaching by analogy. The teacher should help students to clarify the differences between analogy and target concept. Discussion about those differences was necessary. As seen from the findings, teachers from School A and B gave students a chance to discuss about those differences and challenged students to define dynamic equilibrium using information from the *Small Bead Game*, while the teacher from School C only encouraged students to deal with the game. She did not emphasis on discussion about the differences between analog and target concept and on defining dynamic equilibrium term. These findings confirmed the study of Harrison and Treagust (1993) that suggested about mapping between shared and unshared attributes of analogy.

However, the findings showed that some students still held common misconceptions after implementing the CELU. Common misconceptions were predominantly found in School C especially in the topics of equilibrium in chemical reaction, factors affecting equilibrium conditions and Le Châtelier's principle, and changes to be equilibrium. The causes of misconceptions might involve with the way of implementing the CELU of the teacher. These findings were similar to the findings from School B. If classroom observations were considered; it was found that the teacher from School B implemented the lesson of factors affecting equilibrium conditions and Le Châtelier's principle of the CELU hastily comparing to other lessons. Students hardly were challenged with higher order thinking questions to motivate thinking. Then, some of these students made incorrect predictions related to the effect of changing equilibrium (changing concentration, pressure, and temperature).

On the other hand, the findings showed that a majority of the students from School A and School B were able to be successful in defining operational definition,

experimenting (in terms of collecting data and making conclusion), and interpreting data while a majority of the students from School C only were able to be successful in experimenting in terms of collecting data. These findings suggested that some teaching activities employed in the CELU, especially activities related to the skills about identifying and controlling variables and formulating hypotheses should be improved to enhance students' capabilities of those skills. However, students' capabilities of science process skills made a significant contribution to their scientific understanding about chemical equilibrium. As seen from the findings, students who were successful in attaining integrated science process skills related to chemical equilibrium concept seemed to have scientific conceptions about chemical equilibrium concept as well. These findings confirmed the study of Akkus *et al.* (2003) who suggested that chemical equilibrium which is an abstract and theoretical entities concept required students to function at the aspects of science process skills to attain comprehension.

Finally, it could be noted that the way of implementing the CELU of each teacher were took into account as important process to be successful in implementing the CELU for promoting students' learning outcomes about chemical equilibrium. The teacher who emphasized students' existing ideas, active learning, and social process (giving opportunity for discussion in group or to the whole class) tended to be successful in promoting students' learning outcomes about chemical equilibrium.

Implications of the Research Study

This research study provided an example of a learning unit about chemical equilibrium which was constructivist-based perspectives. The focus of this study has highlighted the development and the implementation of the Chemical Equilibrium Learning Unit (CELU). The CELU was guided by constructivist-based perspectives of teaching and learning, National Education Act of 1999, and previous research study about Thai high school students' learning outcomes about chemical equilibrium in Thai academic 2004. Guiding principles then were generated from these three

impacts. This study also described how each teacher implements the CELU into the classroom and how that implementation effects on students' learning outcomes. The findings therefore did not only have implications for teaching and learning about chemical equilibrium to promote students' learning outcomes about chemical equilibrium, but also have implications for in-service teacher professional development in Thai educational context.

The findings of students' learning outcomes about chemical equilibrium have implications for teaching chemical equilibrium. The CELU seemed to be effective for students from three schools in Chanthaburi Province. To attain expected learning outcomes about chemical equilibrium, the instruction should put emphasis on probing students' existing ideas and start to teach new concept by linking with students' existing ideas. Then, teaching activities that emphasized active learning and social process should be engaged. During teaching new concept, formative assessment should be realized to be important strategy to promote students' learning outcomes. These instructional strategies seemed to be suitable for students who were in different schools to gain scientific conceptions about chemical equilibrium. These findings might give some suggestions for related person who would like to improve teaching and learning about chemical equilibrium or other related concepts.

The findings of this study also have implications for in-service teacher professional development, especially in Thai context. A uniqueness of this study is the development and the implementation of the Chemical Equilibrium Learning Unit (CELU). An arrangement of content and teaching strategies employed in the CELU was informed by prior empirical research studies which were adapted to be appropriate for Thai context and to be consistent with the National Science Curriculum Standard. The findings suggested that the CELU could be implemented in real situation effectively. The teacher who implemented the CELU was perceived as the important person. To persuade the teacher to understand and realized importance of using constructivist-based perspectives to teach chemical equilibrium concept, the findings suggested that giving opportunities for the teacher to develop the learning

unit by working with the researcher is an important process. As described, the teacher who participated in the research study had a chance to be a part of the development of the learning unit by attending initial workshop. Negotiation among the teacher, researcher and science educators leads to effective teaching strategies to promote students' learning outcomes about chemical equilibrium concept. Teaching meeting during the implementation of the CELU also support the way to implementation of each teacher to be effective.

Recommendation for the Future Research

This research study described here provides an insight of teaching and learning about chemical equilibrium concept from three schools in Chanthaburi Province. The Chemical Equilibrium Learning Unit was developed using context of schools in Chanthaburi Province. However, as worldwide literature suggested, misconceptions about chemical equilibrium seemed to be similar pattern. Therefore, it is quite interesting that whether the Chemical Equilibrium Learning Unit is effective in different context. The future study should be carried out in different schools which differ in school size, facilitation of teaching and learning, students' background to find out an effectiveness of the CELU.

This study could be an example for curriculum developers or science educators who are interested in improving teaching and learning about chemical equilibrium and related concepts. They could apply the process of the development of the CELU to develop a learning unit for other concepts. However, the development of a learning unit for each concept should put emphasis on the characteristics of content. It does not mean that teaching strategies employed in the CELU have to be effective in other content areas. The developer should adapt teaching strategies to be appropriate for each situation.

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APPENDICES

APPENDIX A

Chemical Equilibrium Concepts and Science Process Skills Survey



**Chemical Equilibrium Concepts
and
Science Process Skills Survey**

Description: This survey consists of seventeen questions relating to chemical equilibrium concepts. Please write answers to the questions in the space provided.

Student Information

Surname..... First name.....

School

Class..... ID.....

Date

Consider the following information; it deals with questions 1-6

Using the Haber ammonia synthesis process, consider the following gas-phase reaction, at equilibrium ($K_c = 1$):



If the reaction starts with an equal amount of nitrogen gas (N_2) and hydrogen gas (H_2), can you predict answers for the following questions?

1. Which of the following pictures in Diagram 1 is the best representation of snapshot of a very small portion of this system at equilibrium, and why?

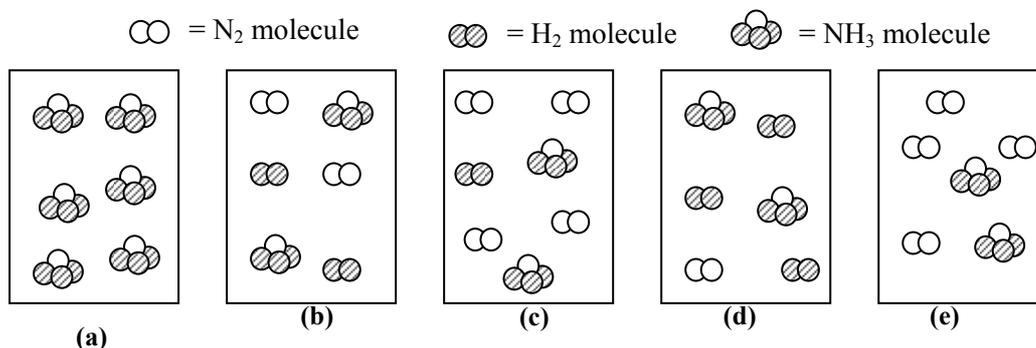


Diagram 1

Reason for choice

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2. 0.5 mole of nitrogen gas (N_2) is added to the ammonia (NH_3) production process in Question 1, at constant temperature and pressure. When the system reaches equilibrium, for each of the following (a) – (e), circle the best option: I = increase; D = decrease; R = right shift; L = left shift; S = stays the same; N = not able to predict. Explain why.

(a) The mass of nitrogen gas (N_2) will I D S N

Reason

(b) The mass of ammonia gas (NH_3) will I D S N

Reason

(c) The position of equilibrium will R L S N

Reason

(d) The equilibrium constant (K_c) will I D S N

Reason

3. Some ammonia chloride (NH_4Cl) is placed in the ammonia (NH_3) production process in Question 1. Ammonium chloride can decompose to give ammonia gas (NH_3) and hydrochloric acid (HCl) as shown in the equation:



When the system reaches equilibrium, for each of the following (a) – (e), circle the best option: I = increase; D = decrease; R = right shift; L = left shift; S = stays the same; N = not able to predict. Explain why.

(a) The mass of nitrogen gas (N_2) will I D S N

Reason

(b) The mass of ammonia gas (NH_3) will I D S N

Reason

(c) The position of equilibrium will R L S N

Reason

(d) The equilibrium constant (K_c) will I D S N

Reason

4. The pressure of the ammonia (NH_3) production process in Question 1 is increased. When the system reaches equilibrium, for each of the following (a) – (e), circle the best option: I = increase; D = decrease; R = right shift; L = left shift; S = stays the same; N = not able to predict. Explain why.

(a) The mass of nitrogen gas (N_2) will I D S N

Reason

(b) The mass of ammonia gas (NH_3) will I D S N

Reason

(c) The position of equilibrium will I D S N

Reason

(d) The equilibrium constant (K_c) will R L S N

Reason

5. The temperature of the ammonia (NH_3) production process in Question 1 is increased. When the system reaches equilibrium, for each of the following (a) – (e), circle the best option: I = increase; D = decrease; R = right shift; L = left shift; S = stays the same; N = not able to predict. Explain why.

(a) The mass of nitrogen gas (N_2) will I D S N

Reason

(b) The mass of ammonia gas (NH_3) will I D S N

Reason

(c) The position of equilibrium will I D S N

Reason

(d) The equilibrium constant (K_c) will R L S N

Reason

6. A small amount of catalyst is added into the ammonia (NH_3) production process in Question 1. When the system reaches equilibrium, for each of the following (a) – (c), circle the best option: I = increase; D = decrease; S = stays the same; N = not able to predict. Explain why.

(a) The rate at which ammonia gas (NH_3) is being formed will I D S N

Reason

(b) The rate at which ammonia gas (NH_3) is being disappeared will I D S N

Reason

(c) The equilibrium constant (K_c) will I D S N

Reason

Consider the following reaction; it deals with question 9 -13.



One mole of $A_{(g)}$ is placed in a flask at STP. The reaction is allowed to reach equilibrium. A graph of the mole percent of $A_{(g)}$ and $B_{(g)}$ versus time is shown in Diagram 2 below (Gas Constant $R = 0.082 \text{ L atm mol}^{-1} \text{ K}^{-1}$)

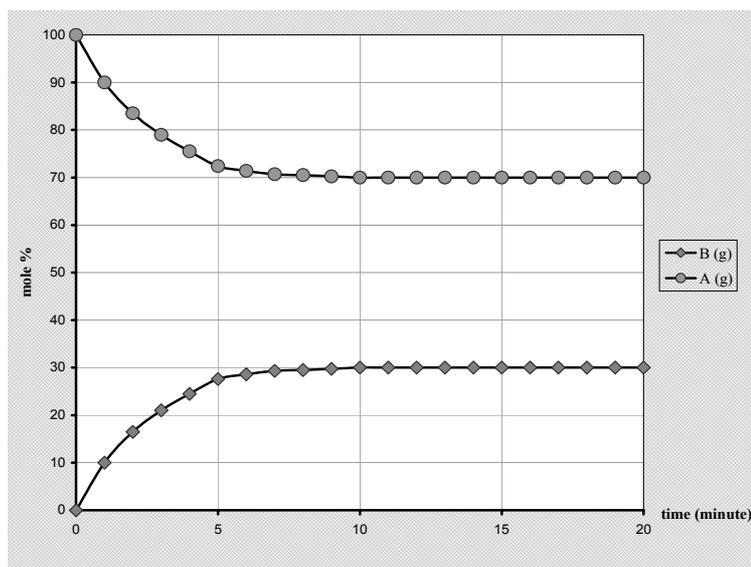


Diagram 2

9. Approximately, how long does this reaction take to reach equilibrium?

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10. What is the concentration (in units of mol L^{-1}) of $A_{(g)}$ and $B_{(g)}$ at equilibrium?

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11. Write the equilibrium constant (K_c) expression for this reaction.

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16. A student did an experiment to study the effect of temperature to equilibrium constant (K_c). He used the reaction between steam (H_2O) and coals (C). The product of this reaction is water gas which is a mixing gas between carbon monoxide gas (CO) and hydrogen gas (H_2).



The concentration of each substance at equilibrium is shown the following.

At 100 °C	Concentration of hydrogen gas (H_2) is 0.405 mol/dm ³ Concentration of carbon monoxide gas (CO) is 0.405 mol/dm ³ Concentration of steam (H_2O) is 0.836 mol/dm ³
At 200 °C	Concentration of hydrogen gas (H_2) is 0.486 mol/dm ³ Concentration of carbon monoxide gas (CO) is 0.486 mol/dm ³ Concentration of steam (H_2O) is 0.764 mol/dm ³
At 300 °C	Concentration of hydrogen gas (H_2) is 0.613 mol/dm ³ Concentration of carbon monoxide gas (CO) is 0.613 mol/dm ³ Concentration of steam (H_2O) is 0.624 mol/dm ³
At 400 °C	Concentration of hydrogen gas (H_2) is 0.776 mol/dm ³ Concentration of carbon monoxide gas (CO) is 0.776 mol/dm ³ Concentration of steam (H_2O) is 0.398 mol/dm ³
At 500 °C	Concentration of hydrogen gas (H_2) is 0.891 mol/dm ³ Concentration of carbon monoxide gas (CO) is 0.891 mol/dm ³ Concentration of steam (H_2O) is 0.206 mol/dm ³

- (a) Design the table to present these data.

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- (b) How do you know whether this reaction is endothermic or exothermic reaction?

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- (c) What is the conclusion of this experiment?

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APPENDIX B

Questionnaire on Students' Attitudes toward Chemical Equilibrium Concepts and
Teaching and Learning



Questionnaire on Students' Attitudes toward Chemical Equilibrium Concepts and Teaching and Learning

Responder's Information

School

Gender GPA Date.....

Description:

For the statement 1 – 30, please √ to the letter that best indicates your opinion. Use the following rating scale: Strongly Agree = SA, Agree = A, Neither = N, Disagree = D, Strongly Disagree = SD.

Items	SA	A	N	D	SD
1. Chemical equilibrium is easy concept in chemistry subject.					
2. Chemical equilibrium concept is useful to me in dairy life.					
3. Chemical equilibrium is difficult concept when it involves calculations.					
4. I understand chemical equilibrium concept very easily.					
5. Chemical equilibrium knowledge is necessary for my future career.					
6. For the development of country, it is not necessary to use the knowledge of chemical equilibrium.					
7. I make many efforts to understand chemical equilibrium concept.					
8. Chemical equilibrium concept will be useless after my graduation.					
9. When I try to solve chemical equilibrium exercises, my mind goes blank.					
10. The knowledge of chemical equilibrium can contribute to the development of country.					
11. I solve chemical equilibrium exercises very easily.					
12. My future career is independent from chemical equilibrium knowledge.					
13. I like chemistry course more than the others.					
14. I find chemistry course very interesting.					
15. I would like to have chemistry lessons more often.					
16. The best chemistry class are those when I do experiments.					
17. When doing laboratory, I would like to design my own experiments to solve a given problem.					
18. I learn more from doing experiments than by listening to the teacher's explanation.					
19. I like working in small groups in chemistry.					
20. I like the teacher to tell me what I have to do when doing experiments.					
21. Doing exercises is one of the best ways for me to understand chemistry.					
22. I like the teacher to check my homework everyday.					
23. Taking test help me know if I have understood what I have learned in chemistry class.					
24. One of the best ways for me to understand chemistry is to discuss it in class.					
25. Chemistry class is boring, when it involves doing experiments.					
26. I prefer to listen to teacher rather than from doing experiments.					
27. I would like to have a fewer chemistry lessons.					
28. Studying alone, I learn more than by studying in a small group.					
29. I do not much have interest in chemistry course.					
30. During chemistry course, I am bored.					

BIOGRAPHICAL DATA

- NAME:** Miss Yaowares CHAIYEN
- DATE OF BIRTH:** November 18, 1978
- PLACE OF BIRTH:** Chanthaburi, Thailand
- GRADUATION:** B.Sc. (Chemistry), Mahidol University since 2000
Dip. (Teaching Science), Mahidol University since 2001
- SCHOLARSHIPS:** The scholarships to pursue B.Sc. (Chemistry), Dip. (Teaching Science) and Ph.D. (Science Education) under the Project for the Production of Science and Mathematics Talented Teachers (PSMT) which conducted jointly by the Royal Thai Government Agencies and the Institute for the Promotion of Teaching Science and Technology (IPST).
- The scholarships for research funding from the Graduate School, Kasetsart University, Thailand.
- REWARDS:** International scholarship awards from the National Association for Research in Science Teaching (NARST) conference 2007 during April 15 – 18, 2007 at Louisiana, News Orleans, USA.