A DEVELOPMENT OF HIGH SCHOOL CHEMICAL BONDING LEARNING UNITS INCORPORATED WITH INFORMATION PROCESSING THEORY

A DISSERTATION

BY

TEPPON LOMARAK

Presented in Partial Fulfillment of the Requirements for the

Doctor of Education Degree in Science Education

at Srinakharinwirot University

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The purpose of this study was to develop the chemical bonding learning units incorporated with information processing theory for high school students and examine the effectiveness of the learning units by assessing students' learning, science process skills, and scientific attitudes. The aim in designing the chemical bonding learning units was to minimize working memory demand and strategies to reduce working memory demand including presenting the abstract concepts in a stepwise fashion, changing the presentation order of the topics, and relating learning materials to prior knowledge were considered. The developed learning units were based on the science strand 3.1 and sub-standard of matter and properties in the Basic Education Curriculum B.E. 2551 for grade 10 students. The content of learning units included 7 concepts: (1) why do atoms bond; (2) ionic bonding; (3) covalent bonding; (4) strength of covalent bonds; (5) molecular geometry and polarity; (6) intermolecular forces; and (7) metallic bonding.

Sample of a pilot study group was 40 students of 10^{th} grade at Somdej Phra Yanna Sangworn school, Yasothorn province, Thailand. The instruction was undertaken across 23 learning periods during October 2010 through November 2010. The pilot study aimed to gain information for improving the quality of the learning units in terms of time allocation and the appropriateness of the instructional sequence. The results of t-test indicated that the students' achievement score after learning using the learning units was higher than that before at the 0.05 level of significance.

The learning units were implemented across 26 learning periods during December 2010 through February 2011 with 36 students of 10^{th} grade at Dhebsirin Pukae school, Saraburi province. The research instruments were the learning units, the Chemical Bonding and Structure Test, the Science Process Skills Test, and the Scientific Attitude Inventory II. The findings indicated that the class average normalized gain achieved at medium gain

level (<g> = 0.49) and students' achievement mean score after learning using the learning units was higher than before at the 0.05 level. The results indicated that students' science process skills score after using the learning units was higher than before at the 0.05 level of significance. These findings provided evidences to show that the learning units were effective to enhance students' conceptual understanding of chemical bonding concepts and science process skills. The students' scientific attitudes was in moderate level ($\bar{X}$=3.42) and the results of t-test indicated that students' scientific attitudes post-test were not significantly higher than the criterion score at high level (3.51), this may due to the timing which students involved in the learning units was not enough to build up more positive attitudes as expected.

การพัฒนาหน่วยการเรียนรู้เรื่อง พันธะเคมี ที่สอดแทรกทฤษฎีกระบวนการสารสนเทศ สำหรับนักเรียนชั้นมัธยมศึกษาตอนปลาย

บทคัดย่อ

ของ

เทพพร โลมารักษ์

เสนอต่อบัณฑิตวิทยาลัย มหาวิทยาลัยศรีนครินทรวิโรฒ เพื่อเป็นส่วนหนึ่งของการศึกษา
ตามหลักสูตรปริญญาการศึกษาดุษฎีบัณฑิต สาขาวิชาวิทยาศาสตรศึกษา
มีนาคม 2555

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การวิจัยนี้มีวัตถุประสงค์เพื่อพัฒนาหน่วยการเรียนรู้ เรื่อง พันธะเคมี ที่สอดแทรกทฤษฎีกระบวนการสารสนเทศ สำหรับนักเรียนชั้นมัธยมศึกษาตอนปลาย และศึกษาประสิทธิภาพของหน่วยการเรียนรู้โดยการประเมินผลสัมฤทธิ์ทางการเรียน ทักษะกระบวนการทางวิทยาศาสตร์ และเจตคติเชิงวิทยาศาสตร์ของนักเรียนชั้นมัธยมศึกษาตอนปลาย การออกแบบหน่วยการเรียนรู้มีจุดมุ่งหมายเพื่อลดการใช้หน่วยความจำปฏิบัติการสำหรับการประมวลผลข้อมูล โดยใช้กลยุทธ์เพื่อลดการใช้หน่วยความจำปฏิบัติการ ที่ประกอบด้วย การนำเสนอเนื้อหาที่ซับซ้อนในรูปแบบที่เป็นขั้นตอน การปรับเปลี่ยนลำดับของการนำเสนอเนื้อหา และการเชื่อมโยงเนื้อหาในหน่วยการเรียนรู้ให้สอดคล้องกับพื้นฐานความรู้เดิมของนักเรียน หน่วยการเรียนรู้พัฒนาขึ้นตามมาตรฐานการเรียนรู้ของหลักสูตรการศึกษาขั้นพื้นฐานพุทธศักราช 2551 สาระวิทยาศาสตร์ที่ 3.1 เรื่องสารและสมบัติของสาร สำหรับนักเรียนมัธยมศึกษาปีที่ 4 เนื้อหาของหน่วยการเรียนรู้ เรื่อง พันธะเคมี ประกอบด้วยหน่วยการเรียนรู้ 7 หน่วย ได้แก่ (1) ทำไมอะตอมจึงสร้างพันธะระหว่างกัน (2) พันธะไอออนิก (3) พันธะโคเวเลนต์ (4) ความแข็งแรงของพันธะโคเวเลนต์ (5) รูปร่างและสภาพขั้วของโมเลกุล (6) แรงยึดเหนี่ยวระหว่างโมเลกุล และ (7) พันธะโลหะ

กลุ่มตัวอย่างของการศึกษานำร่องเป็นนักเรียนชั้นมัธยมศึกษาปีที่ 4 โรงเรียนสมเด็จพระญาณสังวร จ.ยโสธร จำนวน 40 คน การศึกษานำร่องใช้เวลาสอน 23 คาบเรียน ระหว่างเดือนตุลาคม 2553 ถึงเดือนพฤศจิกายน 2553 โดยมีเป้าหมายเพื่อใช้ในการปรับปรุงคุณภาพของหน่วยการเรียนรู้ ทั้งในด้านเวลา และความเหมาะสมของลำดับขั้นตอนในการสอน ผลของการทดสอบค่าที (t-test) พบว่า หลังการเรียนรู้โดยใช้หน่วยการเรียนรู้ที่พัฒนาขึ้น นักเรียนกลุ่มศึกษานำร่องมีคะแนนผลสัมฤทธิ์ทางการเรียนสูงกว่าก่อนเรียนอย่างมีนัยสำคัญทางสถิติที่ระดับ .05

หน่วยการเรียนที่พัฒนาขึ้นนำมาใช้สอนกลุ่มตัวอย่างจำนวน 26 คาบเรียน ในช่วงเดือนธันวาคม 2553 ถึงเดือนกุมภาพันธ์ 2554 โดยกลุ่มตัวอย่างเป็นนักเรียนชั้นมัธยมศึกษาปีที่ 4 โรงเรียนเทพศิรินทร์ พุแค จ.สระบุรี จำนวน 36 คน เครื่องมือที่วิจัยประกอบด้วย หน่วยการเรียนรู้ เรื่อง พันธะเคมี แบบทดสอบวัดผลสัมฤทธิ์ เรื่อง พันธะเคมีและโครงสร้าง แบบทดสอบวัดทักษะกระบวนการ และแบบวัดเจตคติเชิงวิทยาศาสตร์ ผลการวิจัยพบว่า นักเรียนทั้งชั้นมีคะแนน normalized gain อยู่ในเกณฑ์

ระดับปานกลาง (<g> = 0.49) และค่าเฉลี่ยของคะแนนผลสัมฤทธิ์ทางการเรียนหลังเรียนสูงกว่าก่อนเรียนอย่างมีนัยสำคัญทางสถิติที่ระดับ .05 ผลการวิจัยพบว่า ทักษะกระบวนการทางวิทยาศาสตร์หลังเรียนสูงกว่าก่อนเรียนอย่างมีนัยสำคัญทางสถิติที่ระดับ .05 จากข้อค้นพบเหล่านี้ใช้เป็นหลักฐานที่บ่งชี้ว่าหน่วยการเรียนรู้ที่พัฒนาขึ้น มีประสิทธิภาพในการพัฒนาความเข้าใจมโนมติ เรื่อง พันธะเคมี และทักษะกระบวนการทางวิทยาศาสตร์ คะแนนเฉลี่ยของเจตคติเชิงวิทยาศาสตร์ของนักเรียนอยู่ในระดับปานกลาง ($\bar{X}$=3.42) และผลการวิเคราะห์ด้วยการทดสอบค่าที (t-test) พบว่าเจตคติเชิงวิทยาศาสตร์หลังเรียน ต่ำกว่าคะแนนเกณฑ์ที่ระดับสูง (3.51) ทั้งนี้อาจเป็นเพราะเวลาที่ใช้ในการจัดการเรียนรู้ไม่มากพอที่จะพัฒนานักเรียนให้มีเจตคติเชิงวิทยาศาสตร์ในเชิงบวกสูงตามเกณฑ์ที่คาดหวังไว้

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The dissertation titled

"A Development of High School Chemical Bonding Learning Units Incorporated with Information Processing Theory"

By

Tepporn Lomarak

has been approved by the Graduate School as partial fulfillment of the requirements for the Doctor of Education degree in Science Education of Srinakharinwirot University.

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(Assoc. Prof. Dr. Somchai Santiwatanakul)

March…., 2012

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Tepporn Lomarak

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

Table Page

LIST OF FIGURES

Figure Page

CHAPTER 1
INTRODUCTION

Background

Chemistry, one of the most important subjects among the sciences, is a fundamental and an indispensable knowledge in the curriculum for high school level students. Chemical bonding has long been recognized as a key concept area (Fensham. 1975), and therefore a thorough understanding of this topic is essential for almost every other topic in chemistry (Fensham. 1975; Gillespie. 1997; Hurst. 2002). One of the teaching goal in chemistry is to develop more effective and scientifically aligned strategies to teach the key concept of chemical bonding. However, many studies indicated that traditional approach of teaching bonding is problematic. Especially, where the teaching of chemistry adopts the traditional lecture method in which knowledge is simply transmitted as a unidirectional stream of data flowing from lecturer to student. There are studies which indicate that students lack a deep conceptual understanding in some key concepts such as chemical bonding and fail to integrate their mental models into a coherent conceptual framework (Bodner; & Domin. 1998; Griffiths; & Preston. 1992; Peterson; & Treagust. 1989; Taber. 2001). Furthermore, bonding is considered to be a complex concept by both teachers and students (Gabel. 1999; Robinson. 2003; Taber. 1998, 2001).

Johnstone (1991) classified matter into three levels which are macroscopic (physical phenomena), microscopic (particles), and the symbolic levels (chemical language and mathematical models). Many students have found it difficult to see the relationships across the three levels (Kozma; & Russell. 1997). Further they have found it is practically impossible to switch their thinking spontaneously among these levels. Gabel (1999) claimed that, in classroom practice, most teachers do not realize how to assist students to transition from one level to another. Thus students become confused rather easily.

The difficulties experienced by students in chemistry have been well documented. Chemistry involves the study of the nature of materials as well as the properties and interactions of the substances from which they are composed, and consequently students encounter complex concepts, entities and phenomena that are abstract and unobservable. This requires students to understand and be able to use multiple representations visually, verbally and mentally in conjunction with physical phenomena in a classroom (Gabel. 1999; Johnstone. 1996; Kozma; et al.1997). Explaining chemical bonding concepts demand a mental picture or model development to represent and explain the sub- microscopic level of the observed substances. The concepts of chemistry can be presented and explained using teaching resources such as chemical models. The understanding of relationships between various types of models and their representations induce and provide effective learning with clear explanations for students' understanding.

Information processing theory studies the flow of information through the cognitive system. It tries to explain how people acquire, interpret, store and retrieve, and manipulate information. Like the computer, the human mind is a system that processes, interprets, stores and retrieves information. This theory suggests a simplified mechanism for the learning process and leads to an understanding of the limitation of learning when we attended to a stimulus being passed into short term memory (Atkinson; & Shriffrin. 1968), or working memory space (Baddeley. 1986).

Working memory (WM) is viewed as a capacity-limited, unitary memory store which temporarily keeps information for further processing. Information in WM decays after two seconds if not rehearsed (Miyake; & Shah. 1999). Rehearsed information is encoded and saved in long-term memory (LTM). Miller (1956) found that the average capacity of the working memory is about seven plus or minus two (7 ± 2) separate 'chunks' or pieces of information. This is controlled by the student's previous knowledge, experience and acquired skills (Johnstone; & El-Banna. 1986). Chunking is the process through which learners group pieces of information together in a way that allows them to hold more information. As there are different ways of chunking, there are differences between the knowledgeable person (e.g., teacher, adult, expert) and the novice (e.g., student, child, beginner) in the size and number of information units perceived in a situation (Danili; & Reid. 2004: 207). The WM space permits a learner to keep information long enough to make sense of sequences of words and directions to solve problems or to make decisions.

Therefore, WM is the part of the brain that holds information, works on it, organizes it and arranges it, before storing it in the LTM (Baddeley. 1986).

Social constructivism emphasized by Vygotsky (1978) indicates that students learn concepts or construct meaning through their interactions and interpretations. Knowledge is not something that is simply memorized; it is constructed by the student according to his/her past experiences. Teachers can use Vygotsky's ideas to create learning environments in which students have contacted with others who have different level of expertise. Vygotsky's zone of proximal development (ZPD) is described as the difference in performance between what a student can accomplish with and without assistance from a more knowledgeable or capable person (Vygotsky. 1978: 86). According to the ZPD, time allowance, relevant support and good student guidance can be of great assistance in the development of chemical knowledge and scientific process skills for students.

The learning units which promoted learning outcomes should include appropriate tasks within the limits of the ZPD. If the task difficulty is higher than the ZPD, the cognitive capacity of the leaner would not be sufficient to deal with the task; in other words the cognitive load would exceed the capacity of working memory of the learner. If the task difficulty is lower than the ZPD, the learner would be under-challenged and a great deal of the available cognitive capacities would remain unused in the learning process. Accordingly, the difficulty of learning task has to be adapted for the learner by choosing other tasks or defining other task performance conditions. According to these principles, new learning units should be developed, with reduce complexity and difficulty for the understanding of chemical concepts.

The constructivist approach has been cited by many research studies and suggests the advantage of the social nature in the classroom to improve classroom discourse, increasing achievement in science, science process skills and influencing scientific attitude as well as scientific knowledge. From this approach, the curriculum was programmed with activities to encourage students to construct scientific knowledge actively. The teacher's role is to be the "facilitator" who provided the appropriate opportunities for the learners to undertake the construction. The focus is on the learners' thinking about scientific ideas which come from the elicitation of existing ideas, their subsequent re-conceptualizing including exposure to conflict situations, and the development and evaluation of new or more scientific ideas. Consequently, instruction in science offers many opportunities for students to engage actively in the constructivist approach of learning (Fredericks. 1998: 17).

There has been considerable concern among science education researchers that the traditional approach of teaching the principles, theories, and contents of chemistry has lacked coherence (Office of the National Education Commission (ONEC). 2003). Unfortunately the majority of teachers still adopt the lecture method for teaching chemistry. It is widely argued (1) that student lack opportunities to practice science process skills and (2) that the curriculum tends to encourage memorization and fails to develop conceptual understanding (ONEC. 2001a; 2001b; 2003). There is considerable evidence that teaching and learning tends to focus on coaching students for university entry examination. Moreover, lack of sufficient knowledge and inappropriate scientific attitude are also the underlying causes of why students are unable to apply scientific knowledge to their daily life (Kaewdang. 1998: 35-47).

Worldwide research studies have indicated that the traditional approach of teaching chemical bonding is problematic. The results reveal that students lack any deep conceptual understanding in the key concepts regarding the chemical bonding (Griffiths; & Preston. 1992; Peterson; & Treagust. 1989; Taber. 2001) and fail to integrate their mental models into a coherent framework for scientific explanations (Bodner; & Domin. 1998; Griffiths; & Preston. 1992; Peterson; & Treagust. 1989; Taber. 2001). Moreover, the research studies indicated firstly that symbolic and microscopic representations are abstract (Ben-Zvi, Eylon; & Silberstein. 1988; Keig; & Rubba. 1993), and secondly that the chemical bonding concept is considered complicated (Gabel. 1996; Robinson. 2003; Taber. 1998, 2001), and constrained by the perceptual experiences from the daily lives of the students (Kozma; et al.1997).

Research study indicated that performance on chemistry problem-solving tasks is expected to drop when the information load exceeds the students' working memory capacity (Johnstone; & El-Banna. 1986). According to these results, working memory demand for cognitive task remained overload where abstract concepts of chemical bonding and structure were introduced without considering the students' working memory capacity.

Therefore, redesigning the instructional materials to reduce working memory demand on the tasks was recommended (Johnstone; & El-Banna. 1986).

Because of the many problems as outlined, the development of new learning units to facilitate students in gaining better conceptual understanding of chemical bonding was of considerable interest. The new learning units incorporated information processing theory to reduce working memory overload were proposed.

The purpose of developing the learning units was to improve the students' chemical bonding concepts. The aim in designing the proposed learning units was to minimize learning situations where an overloaded working memory was required. The effectiveness on students' learning outcomes which include achievement, science process skills, and scientific attitudes were examined. To achieve this goal, the learning units were developed using the inquiry learning cycle (Bybee. 2009). The curriculum materials were designed in the light of predictions suggested by information processing theory and every feature of learning units seeks to minimize the demands on working memory. Strategies to reduce cognitive load included presenting the abstract concepts in a stepwise fashion, changing the presentation order of the topics, and relating learning materials to prior knowledge were employed.

Purposes of the study

The purposes of the study were:

1. To develop learning units on chemical bonding incorporated with information processing theory for high school students.
2. To examine the effectiveness of the learning units by assessing students' learning achievement score, science process skills, and scientific attitudes.

Significance of the study

The significance of this study was the development of the chemical bonding learning units to enhance achievement score, science process skills, and scientific attitudes. The inquiry learning units utilized instructional activities incorporated with information processing theory including strategies to reduce working memory overload was employed. This study aims to explore the problems and to suggest ways in which the situation could be improved understanding of chemical bonding concepts. The study provided evidence on how to apply the developed learning units with an approach for inquiry teaching, sequential activities from redesigned curriculum materials to minimize limitations to learning caused by working memory overload. In addition, learning activities and instructional materials derived from this research study can be used by chemistry teachers directly or adapted for teaching scientific concepts to enhance learning achievement on chemical bonding, address students' alternative conceptions, develop the science process skills, and scientific attitudes.

Scope and limitation of the study

This study intended to develop and implement the high school chemical bonding learning units incorporated with information processing theory. The curriculum materials were based on sub-strand 3: Matter and Properties under standard Sc 3.1 of Thailand's Basic Education Curriculum B.E. 2551.

Participants

1. Participants during pilot study

A pilot study was carried out across 23 learning periods during October to November, 2010 with 40 students of 10^{th} grade at Somdej Phra Yanna Sangworn school, Yasothorn province. One classroom was selected and the high school teacher who participated in instructional procedures and considered instructional materials had experience in teaching chemistry for 19 years.

2. Participants during Implementation

The implemented was carried out across 26 learning periods during December 2010 through February 2011 with 36 students of 10^{th} grade at Dhebsirin Pukae school, Saraburi province, Thailand. One classroom with a high school teacher who considered curriculum materials and commented on instructional procedures.

Variables of the study

1. Independent variable

1.1 Teaching by using the developed chemical bonding learning units based on inquiry learning cycle incorporated with information processing theory

2. Dependent variables

2.1 Learning achievement

2.2 Science process skills

2.3 Scientific attitudes

Limitation of the study

There were possible methodological limitations that need to be acknowledged and addressed regarding the present study. This investigation was limited by sampling technique. Convenience sampling was used to select the student participants during the development of instructional materials and pilot study. It means that members of such samples were chosen mainly because they were readily available and willing to be involved. A non-probability sampling technique significantly limits ability to make broader generalizations from findings. However, findings of the pilot study were used to improve the quality of the learning units in terms of time allocation and the appropriateness of instructional sequence. Limitation was not effect to the results of the development of instructional materials and pilot study. The researcher took a role in the teaching process during the implementation phase whereas classroom teacher considered instructional materials and commented on instructional activities.

Definition of terms

The chemical bonding learning units are a set of content, learning experiences and instructional materials that were constructed to promote student's learning to achieve the learning objectives. The learning units incorporated with information processing theory emphasized on instructional design strategies to reduce the working memory demand by reducing the amount of materials presented to students during a sequence of instruction were developed to enhance learning achievement, science process skills, and scientific attitudes. Strategies to reduce working memory overload included presenting the abstract concepts in stepwise fashion, changing the presentation order of the topics, and relating learning materials to prior knowledge were employed. These units were approached using the inquiry learning cycle and drawn on the Thai Basic Education Curriculum B.E. 2551. The learning units consisted of 7 topics: (1) why do atoms bond, (2) ionic bonding, (3) covalent bonding, (4) strength of covalent bonds, (5) molecular geometry and polarity, (6) intermolecular forces, and (7) metallic bonding.

Inquiry learning cycle is the instructional model that is composed of five components:

1. Engagement: The introduction to the lesson that motivates or hooks the students' interest. Students are engaged with a scientific question, event, or phenomenon. This helps students make connections with what they already know, creates dissonance or potential disagreement with their own ideas, and /or motivates them to learn more.

2. Exploration: Students explore concepts and ideas of the lesson through hands-on experiences, formulate and test hypotheses, solve problems, and create explanations for what they observe.

3. Explanation: Students are asked to justify and clarify their ideas. Students analyze and interpret data, synthesize their ideas, build models and clarify concepts and explanations with teachers and other sources of scientific knowledge

4. Elaboration: Students extend their new knowledge and be able to apply what they have learned to new situations.

5. Evaluation: Students, with their teachers, review and assess what they have learned and how they have learned it. Teachers frequently observe students as they apply new concepts and skills to assess students' knowledge and/or skills, looking for evidence that the students have changed their thinking or behavior.

Students' achievement refers to student's ability to remember, understand and apply scientific concepts, and science experimental skills which are the expected learning objectives of the learning units. Students' learning achievement in this study was assessed by using 34 diagnostic multiple-choice test items of Chemical Bonding and Structure Test.

Science process skills refer to the students' basic and integrated skills in process of science. The 9 science process skills are observation, measurement, classification, organizing data and communication, inferring, prediction, formulating hypothesis, identifying and controlling variables, and interpreting data and conclusion were assessed by using the Science Process Skills Test adapted from Enger and Yager (2001).

Scientific attitudes refer to the way in which scientists believe in and conduct their works in order to be successful or to successful solve problems. Scientific Attitude Inventory II (Moore; & Foy. 1997) was used to measure corresponding attitude statements on 6 subscales of scientific attitudes as followings: (1) The nature of the laws and/ or theories of science, (2) The basic of scientific explanation, (3) Characteristics needed to operate in a scientific manner, (4) The type of activity engendered in science, (5) Progress in science, and (6) Science as a career.

Normalized gain is defined as the change in pretest score to the posttest score (posttest - pretest) divided by the maximum possible increase (total score - pretest). This was assumed to be the improvement due to the learning that takes place between the pre- and post-tests.

Conceptual framework of the study

The conceptual framework for this study was developed as a consequence of the literature review based on information processing theory. The learning units were developed to promote and improve the learning achievement of the students, their science process skills and their scientific attitudes. The conceptual framework is shown in FIGURE 1.

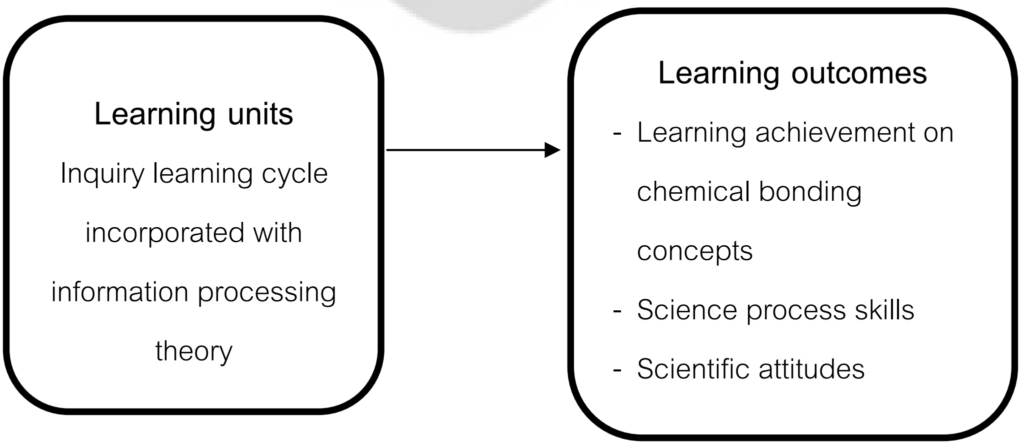


FIGURE 1 CONCEPTUAL FRAMEWORK OF THE STUDY

Research hypotheses

Research hypotheses of this study are as following:

1. The class average normalized gain of students' achievement score in chemical bonding concepts shows the high gain level (<g> ≥ 0.7).
2. Students' science process skills score after the implementation of the learning units is higher than before implementation of learning units with a statistically significant difference at 0.05 level.
3. Students' scientific attitudes after using the learning units are higher than criterion score at high level with a statistically significant difference at .05 level.

CHAPTER 2
REVIEW OF THE LITERATURE

The review of the literature served to inform and develop the theoretical and methodological frameworks for this study. There are 6 sections based on the following areas:

1. Science education in Thailand
2. Information processing theory
3. Constructivism
4. Inquiry learning cycle
5. Teaching and learning chemistry
6. Assessment of students' understanding of concepts.

1. Science education in Thailand

The learning process, as described in the National Education Act B.E. 2542 (1999) and Second National Education Act B.E. 2545 (ONEC. 2003), is based on the capabilities and self-development of all learners. The teaching and learning process aims to enable students to develop at their own pace and to maximize their potential. As a result of the act, the Basic Education Commission of Thailand prescribed a core curriculum known as the Basic Education Curriculum B.E. 2551. According to the act, it was expected that schools will develop their own curriculum based on the Basic Education Curriculum B.E. 2551 (Ministry of Education (MOE). 2002). Unfortunately, the early national curriculum was found to be deficient with criticisms relating to a lack of coherence across the principles, theories, and contents of the curricula (ONEC. 2003). This may result from students lacked of practice of scientific processes. Further these deficiencies may motivate students to memorization scientific information and ignore conceptual understanding. Furthermore it was found that the university entrance examination play an importance and undesirable role in dominating the assessment regime (ONEC. 2001a; 2001b; 2003), to such an extent that teaching and learning tended to focus on coaching students in preparation for university entrance.

The Basic Education Curriculum B.E. 2551(2008) was focused on a revision of core curriculum. Learning was based on constructivism, and teaching was intended to be more learner-centered. In case of science, teaching and learning should focus on students' understanding, science process skills, and scientific attitudes. It is expected that Thai science teachers should reform their teaching practices and focus on students' understanding more than before.

The students should understand basic principles, theories, nature, scope and limitation of science. Students are expected to acquire research, have intellectual skills and be able to apply the scientific process in solving problems (Soydhurum. 2001: 33). However, there are limited opportunities for learners to develop and practice their skills to a satisfactory level. Research on science education in Thailand reveals that different teaching and learning approaches have been developed. It indicated that both content and teaching approach in science have to be improved. Most schools lacked scientific instructional materials which enabled students to construct knowledge by themselves (Soydhurum. 2001:10 -19) and lack of sufficient knowledge and scientific attitude also contributes to the inability of most students to apply scientific knowledge to events and experiences in their daily life (Kaewdang. 1998: 35-47).

2. Information processing theory

The information processing theory approach to the study of cognitive development proposed that the human mind like the computer is a system that processes information through the application of logical rules and strategies. Like the computer, the mind has a limited capacity for the amount and nature of the processing information. Just as the computer can be made into a better information processor by changes its hardware (e.g., motherboard and microchips) and its software (programming), so do students, they can be sophisticated thinkers through changes in their brains and sensory systems (hardware) and the rules and strategies (software) that they learn.

The four main principles of the information-processing approach are (Hetherington; & Parke.1999):

1. Information processing theory holds that thinking is information-processing. When the individual perceives, encodes, represents, and stores information from the environment in his or her mind or retrieves that information, he or she is thinking. Thinking also includes responding to any constraints or limitations on memory processes.

2. The proper focus of study is the role of change mechanism in development. Four critical mechanisms work together to bring about change in children's cognitive skills which are encoding, strategy construction, automatization, and generalization. To solve problems effectively, children must encode critical information about a problem and then use this encoded information and relevant prior knowledge to construct a strategy to deal with the problem

3. Development is driven by self-modification. Like Piaget's theory of cognitive development, the information-processing approach holds that students play an active role in their own development. Through self-modification, the student uses knowledge and strategies that he or she has acquired from earlier problem solution to modify his or her responses to a new situation or problem. In this way, he or she builds newer and more sophisticated responses from prior knowledge.

4. Investigators must perform careful task analysis of the problem situations presented to students. From information processing approach, not only the student's own level of development but the nature of the task itself constraints their performance. Thus a student may possess the basic ability necessary to perform a particular task presented in a simple form, without unnecessary complexities. However, if extra or misleading information is added to the same task, the student may become confused and be unable to perform it.

2.1 The information processing model

As cognitive psychology developed, research provided more detailed understandings of memory. Stage model of information processing (Atkinson; & Shriffrin. 1968) proposed which included a sensory memory, short-term memory (STM), and long-term memory (LTM) as shown in FIGURE 2. According to their model, incoming information was first registered in the sensory store. A limited amount of this information was attended to and passed onto STM; the non-attended information was lost. STM was viewed as a capacity-limited, unitary memory store which temporarily kept information for further processing. Information in STM decayed after two seconds if not rehearsed (Miyake; & Shah. 1999). Rehearsed information was encoded and saved in LTM, an unlimited store that retained information for long periods. Information relevant to a cognitive task could be retrieved from LTM at a later time.

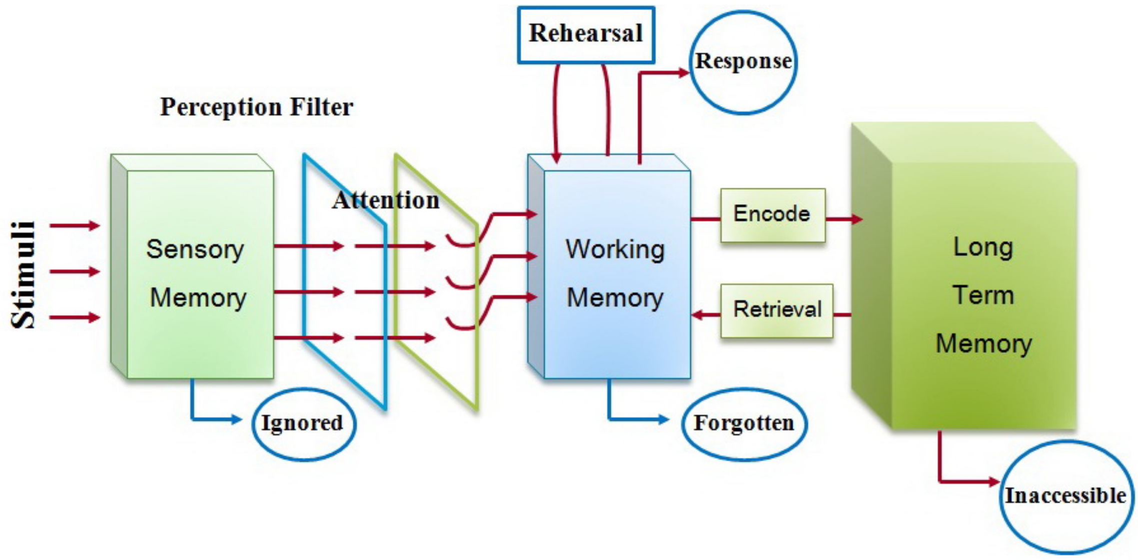


FIGURE 2 INFORMATION PROCESSING BASED ON THE WORK OF ATKINSON AND SHIFFFRIN

Source: Adapted from Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence (Ed.), *The psychology of learning and motivation: Advances in research and theory (Vol. 2) (pp. 89-195).* New York: Academic Press.

Memory researchers recognized that theories of STM could not adequately describe the kind of temporary memory that complex cognitive tasks require (Shah; & Miyake. 1999). Eventually, memory research gave rise to theories in which STM was seen as one component of a larger system known as working memory (WM). Differences in WM models commonly reflect different ideas about the complexity of WM. According to Miyake and Shah (1999), WM models have evolved from a single unit memory store to a system containing multiple cognitive subsystems responsible for different storage and executive control functions. For example, Miller's (1956) finding that immediate memory stored only 7 $\pm$2 "chunks" of information represented the early understanding of WM as a single information store. Baddeley and Hitch's (1974) model of WM as a multiple-component system consisting of a phonological loop, a visuospatial sketch pad, and a central executive started the age of decomposing WM into different components. The same idea is reflected in other WM models that followed. Although researchers differ in their specifications of WM subsystems, most agree that WM includes multiple subsystems working together to activate task-related information, maintain activation, and manipulate information during the performance of cognitive tasks (Miyake; & Shah. 1999).

A majority of researchers agree that LTM is a source of information for WM. For instance, WM consisted of LTM traces activated above threshold (Engle; Kane; & Tuholski. 1999; Engle; Tuholski; Laughlin; & Conway.1999). Ericsson and Delaney (1999) used the term “long-term working memory” to emphasize the close relationship between WM and LTM. Then, it is reasonable to relate the content of WM to LTM since people draw upon knowledge and prior experience stored in LTM to solve problems and understanding phenomena. However, as important as WM in learning and solving new problems, sensory information from the external world must be an important part of the content of WM. Thus, both LTM and the external world are sources of WM content (Kyllonen; & Christal. 1990).

2.2 Working memory, science learning and science achievement

A review of research studies on the relationship between WM, science learning and science achievement revealed that they are positively correlated. For instance, Gathercole et al. (2004) found a strong relationship between working memory capacity (WMC) and science achievement for 14-year-old students. WM was measured by forward and backward digit/letter span tasks and reading dual-tasks. Schools supplied the science achievement levels of each student. The correlation coefficients between WM measures and science achievement ranged from 0.32 (with forward digit span task) to 0.50 (with reading dual-tasks). Danili and Reid (2004) found that 15- 16 year-old students with high and low WMC, measured by backward digit span, performance on chemistry tests had significantly difference. Tsaparlis (2005) examined the correlation between WMC (also measured by backward digit span) and performance on chemistry problem-solving tests through nine independent studies of first-year undergraduate chemistry students. The correlations were ranged between 0.28 and 0.74.

Studies on the association between limited WMC and information load in problem-solving in science were also provided support for the positive relationship between

WM and science achievement. Because WMC has limited amount of information which can be concurrently processed, performance on science problem-solving tasks is expected to drop when the information load exceeds students' WMC (Johnstone; & El-Banna. 1986). Johnstone and El-Banna's (1986) and Opdenacker et al (1990) reported that middle school students and undergraduates gradually decreased their chemistry problem-solving performances when the amount of information to be processed exceeded their WMC (assessed by backward digit span and a figure intersection test). This phenomenon is also consistent with Sweller's (1994) cognitive overload theory, which posits that learning processes will be negatively affected if the cognitive load exceeds the limit of WMC.

The evidence from prior research points to a strong connection between WM and science achievement. Thus, the attention to ways in which research findings on WM should be applied to facilitate science learning.

2.3 Applications of working memory research to facilitate science learning

Prior studies indicated that WMC limits students' performance in science learning (Danili; & Reid. 2004; Johnstone; & Al-Naeme. 1991; Sweller. 1994). Research studies have taken two main approaches to deal with the limit of WMC to help students learn science and gain better conceptual understanding. One is to decrease the working memory load in science learning materials, and the other is to increase students' WMC through specialized training programs.

2.3.1 Decreasing working memory load

According to Sweller's (1994) cognitive load theory, WMC imposes a limit to the amount of information individuals can process in cognitive activities. When the cognitive load exceeds the limit of WMC, learning processes will be affected. Two factors contributing to the amount of cognitive load are the presentation of materials (external cognitive load) and the complexity of learning materials provided to students (internal cognitive load). Thus, to decrease cognitive load, one could decrease external cognitive load by presenting the materials in a way that is easy to understand or by lessening internal cognitive load through reducing the interactivity among elements in the materials.

Studies showed that strategies reducing both external and internal cognitive load of learning materials effectively improved students' science learning. For instance, Danili and Reid (2004) redesigned teaching materials to reduce the amount of information students had to deal with simultaneously based on their finding that WMC affects students' performance in chemistry. Strategies to reduce internal cognitive load included presenting the materials in a more stepwise fashion, changing the presentation order of the materials (from logical order to psychological order), and relating learning materials to prior knowledge. Measures to decrease external cognitive load were using dialogue boxes, pictures, diagrams, and models to help students focus on the main messages and deepen their understanding through multiple coding channels. The redesigned teaching materials also allowed students to spend less time taking notes and focus more on understanding the material. Four middle-school chemistry teachers from four schools participated in their quasi-experimental study. Each teacher taught an experimental class using the redesigned materials and a control class using the original materials. The results showed that the difference in the average improvement between the experimental students (N = 99) and the control students (N = 112) was also statistically significant at .01 level. Students in the experimental group, on average, scored higher on an achievement test based on the content than did the control group.

2.3.2 Improving WMC

There were extensive studies on how to improve memory capacity (Ericsson. 2003; Floyd; & Scogin. 1997; Klingberg; et al. 2005; Yohman; Schaeffer; & Parsons. 1988). These studies were varied the improve target construction and the way in which the participants be trained. Some studies examined how to improve general memory in daily life by teaching memory strategies such as rehearsal, information chunking, visual imagery, and verbal mediation strategies (Turley-Ames; & Whitfield. 2003; Yohman; et al. 1988). Ericsson and co-workers demonstrated that extensive practice on memorizing and training on the use of memory strategies could substantially improve ordinary people's memory, however, the improvement was limited to the special type of information used in the training (Chase; & Ericsson. 1982; Ericsson; & Delaney. 1999; Ericsson; & Kintsch. 1995).

2.3.3 Problems with cognitive load

Cognitive load is a kind of instructional theory that starts from the idea that human working memory is limited with respect to the amount of information it can hold and the number of operations it can perform on that information (Van Gerven; Paas; Jeroven; Van Merrinboer; Hendriks; & Schmidt. 2003). When new information is presented to learners, inexperienced learners generally experience an increased cognitive load (Kalyuga; Chandler; & Sweller. 1999; Sweller. 1994). As this kind of heavy cognitive load works negatively on the mental process to acquire the new information, instructional strategies are needed to facilitate schema construction and automation by reducing working memory load (Van Gog; Ericsson; Rikers; & Paas. 2005). Cognitive load theory describes the different sources of working memory load, related to the complexity of the material (intrinsic cognitive load), the instructional design (extraneous cognitive load), and the amount of mental effort learners invest in learning the materials (germane cognitive load) (Wallen; Plass; & Brucken; 2005).

Strategy for reducing extraneous cognitive load such as visual-auditory worked example simulation which can present visual information with auditory information together is a typical strategy for reducing extraneous cognitive load (Chandler; & Sweller. 1991; 1992; 1996; Ward; & Sweller. 1990). This simulation is based on two features of working memory suggested by Baddeley (1998) that working memory has a limited capacity and may be divided into visual spatial sketchpad and phonological loop. The division of working memory into a visual channel and auditory channel suggests that cognitive load can be reduced when information is divided into visual information and auditory information. Mayer (2001), as a similar viewpoint, suggests dual-channel where visual information and auditory information are processed separately.

Some researchers (Chandler; & Sweller. 1991; 1992; 1996) showed that the simultaneous provision of visual and verbal information was effective. On the other hand, Craig, Gholson, and Driscoll (2002) insisted that provision of a single type of information according to the prior knowledge level of learners could be more effective. In this way, instructional techniques that are highly effective with inexperienced learners can lose their efficiency and even have negative consequences when used with more experienced learners (Kalyuga; Ayres; Chandler; & Sweller. 2003).

Extraneous cognitive load, which can be changed by improving teaching-learning strategy such as data presentation method, learning contents presentation method, and learning strategy, is regarded as the most efficient method for reducing unnecessary cognitive load (Van Merrinboer; & Sweller. 2005). Extraneous cognitive load is also closely related to learners' prior knowledge level. If a learner has a sufficient working memory capacity, he/she would not experience difficulty in solving problems although there is extraneous cognitive load arising from inappropriate instructional design. In the case where a learner has insufficient capacity for working memory, then extraneous cognitive load should be low for successful performance. This suggests that a more effective teaching strategy should be devised, in which extraneous cognitive load can be properly controlled according to the learner's prior knowledge level.

2.3.4 Instruction that reduces the load on working memory

In general, learning activities should be modified in order reduce working memory load. General principles for reducing working memory load in the classroom teaching included (Dehn. 2008, Online):

1. Working memory strategies and mnemonics that are effective with individuals can be taught successfully in the classroom.

2. The comprehension and retention of verbal material will be enhanced if the input is simple, structured, and redundant.

3. Learners will have difficulty remembering information while they are engaged in another processing activity that is demanding their attention.

4. Students with impaired working memory can learn effectively if they have ample exposure to material while demands on working memory are minimal.

5. Teaching practice recommended for children with students who have working memory deficits.

6. More learning occurs when students are allowed sufficient time to process new information when they have enough time to rehearse and apply working memory strategies.

7. Most teaching practices identified as effective or as direct instruction support the storage and capacity limitations of working memory.

Dehn (20008, Online) also suggested specific techniques for reducing working memory load in the classroom teaching described as following:

1. Simple verbalizations: The style of language used in teaching determines how much demand is placed on working memory. All verbal communication e.g. directions, instruction, and explanations should be linguistically simple, brief, and concise, task instructions should be syntactically simple, sentences should be redundant, wording should be precise, and vocabulary should be highly familiar.

2. Simple, isolated procedures: The best approach to managing complexity is to avoid tasks that require secondary processing. For example, asking a student with low working memory capacity to listen attentively to a lecture and take notes at the same time is likely to result in poorly recorded notes, minimal comprehension of the orally presented material, or both. In general, teachers should try to minimize competing inputs, to request only one process or operation at a time, and to help the student focus on one step at a time.

3. Lots of repetition: Directions and instructions should be repeated frequently, and students should be required to repeat information.

4. Allow time for rehearsal and processing: Opportunities for rehearsal, processing, and other strategies during instruction are crucial. Teachers should not only allow enough time for rehearsal, but also teach the strategies and encourage their use.
Also, teachers should remember that the primary goal is to encode the information into long term storage; they should not assume that immediate recall will result in long term encoding.

5. Promote higher level processing: Teachers should promote active reasoning and thinking about the material, rather than just repetition. For example, teachers should promote active manipulation of the material, rather than just having students listen to a presentation.

6. External memory aides: There are numerous external memory aides that reduce working memory load; for example, a number line or notes on step-by-step procedures. Similar to strategy use, a memory aide may itself increase working memory load. Thus, students practice using external aides under low load conditions is important.

7. Quiet learning environment: Background speech is known to reduce verbal working memory span by interfering with the rehearsal function of phonological short

term memory. It is not sound intensity that disrupts working memory processes, but rather phonological similarity.

8. Organized presentations: Presenting related information in an integrated and organized manner can reduce the load on working memory. Organized presentations enhance academic learning because they reduce the processing load on working memory, specifically because they activate and maintain the focus on relevant long term representations, thereby facilitating additions and alterations to those representations.

9. Scaffolding: The practice of scaffolding involves providing the learners with graduated learning supports until the supports are no longer needed.

10. Activating relevant information: Advance organizers facilitate learning by enhancing the effectiveness of working memory encoding and long-term memory organization. Other methods of pulling relevant scheme into the activated pool include: identifying and emphasizing main ideas, providing examples that illustrate connections between ideas, and directly relating the new material to prior knowledge.

11. Reduce unnecessary processing demands: This is especially important when the learner needs to temporarily store information or when the learner needs to encode information into long-term memory.

Furthermore, principles and examples of the information processing approach in classroom (Huitt. 2003, Online) are as followings:

1. Gain the students' attention
   - Use cues to signal when you are ready to begin.
   - Move around the room and use voice inflections.
2. Bring to mind relevant prior learning.
   - Review previous day's lesson.
   - Have a discussion about previously covered content.
3. Point out important information.
   - Provide handouts.
   - Write on the board or use transparencies.
4. Present information in an organized manner.
   - Show a logical sequence to concepts and skills.

- Go from simple to complex when presenting new material.

5. Show students how to categorize (chunk) related information.
   - Present information in categories.
   - Teach inductive reasoning.
6. Provide opportunities for students to elaborate on new information.
   - Connect new information to something already known.
   - Look for similarities and differences among concepts.
7. Show students how to use coding when memorizing lists.
   - Make up silly sentence with first letter of each word in the list.
   - Use mental imagery techniques such as the keyword method.
8. Provide for repetition of learning.
   - State important principles several times in different ways during presentation of information.
   - Have items on each day's lesson from previous lesson.
   - Schedule periodic reviews of previously learned concepts and skills.
9. Provide opportunities for over-learning of fundamental concepts and skills.
   - Use daily drills for arithmetic facts.
   - Play form of trivial pursuit with content related to class.

A major challenge for instructional designers is that meaningful learning can require a heavy amount of essential cognitive processing, but the cognitive resources of the learner's information processing system are severely limited. Therefore, instruction should be designed in ways that minimize any unnecessary working memory load of students.

In summary, working memory load plays an important role in learning science because it provides a mental workspace in which students can hold information while mentally engaged in other relevant activities. Decreasing cognitive load holds the promise of providing students with both knowledge acquisition and application in learning science.

3. Constructivism

Constructivism is a theory about knowledge and learning, attempts to describe how one "comes to know". This theory is based on the work of educational philosopher John Dewey (1938), and educational psychologists Lev Vygotsky, Jean Piaget, and Jerome Bruner. Dewey advocated the idea that learning should pertain to actual life. He also saw the need for the learner to reflect on any personal experience that brought about learning (Educational Broadcasting Corporation (EBC). 2004). Vygotsky (1978) introduced the social aspect of learning into constructivism. He defined the "zone of proximal learning," according to which students solve problems beyond their actual developmental level (but within their level of potential development) under adult guidance or in collaboration with more capable peers. Piaget contended that students came to every learning situation with prior knowledge. Following the thought of Piaget, Bruner (EBC. 2004) postulated that students come into the educational system with their own believes and ideas. He acknowledged that children need assistance with their learning to build on what they have already known. It refers to the notion that knowledge results from mental processes when individual "scheme" interact with the "environment". Cognitive structure thus organizes experiences by allowing the individual to go beyond the information given by connecting those experiences to prior knowledge. Real learning occurs when the learner actively engages in his or her own knowledge construction, integrates the new information into already present schema, associates and interprets this information in a meaningful way. Then, aims of teaching science is to assure that the most fundamental concepts are well represented and connected in the students' mind and that be provided with the necessary tools for student to construct further knowledge upon those core concepts.

An attempt to teach the science content and required to understand can sometimes override the need to teach students how to learn the content themselves (Spencer. 1999). Teachers commonly believe that they can transfer their knowledge to students by explaining and demonstrating their understanding (Skemp. 1976). However, the objective of teaching is to enable students to learn and let students be able to explain and demonstrate their understanding. In the long run, the student who knows how to find out information and how to deal with difficult problems will be better equipped for the workplace than the student who knows only particular facts. Inherent in this simplistic description is the significance of learning the necessary skills for processing ideas, concepts and knowledge. The question of what to teach students is not important when compared to why it is taught and how to emphasize the process of learning. Constructivist approach necessarily puts a great deal of responsibility on the learner, but it is not without direction and guidance from the teacher who takes the role of facilitator (Office of the Education Council (OEC). 2004). Without any doubt constructivism has become one of the most valuable guideline for teaching and learning as well as for research in science education.

3.1 Social constructivism and teaching of science

Social constructivism holds that students learn concepts or construct meaning through their interactions with and interpretations of their world, including essential interactions with others. Knowledge is not something that is simply memorized; it is constructed by the student according to his or her experiences in the world. Students receive information, interpret it, and relate it to other prior knowledge and experiences. As a result, they come to school which concepts related to what they are expected to learn. These prior experiences and conceptions will influence new knowledge that they attempt to acquire. Then, their concepts and theories are not always the same as those developed over the years by expert scientists. Many of them have difficulties for reaching understanding about scientific explanations and sophisticated concepts of science.

The social constructivist theory asserts that students take an active role in constructing meaning. They can not construct meaning by passively absorbing knowledge from a teacher. Accordingly, teaching based on social constructivist theory focuses on the student as an active builder of knowledge in a community of learning. Social constructivist theory has implications for teacher to create the classroom setting, sets up lesson plans, asks questions, reacts to students' ideas, and caries out lessons. According to a constructivist approach, teaching science means that teachers do not teach science as "the search for the truth." Instead, they teach science by actively engaging students in the social process of making sense of experiences. The main features of the social constructivist model of learning (Krajcik; Czerniak; & Berger. 2003: 55) were as follows:

1. Active engagement with phenomena

- Students ask and refine questions related to phenomena.

- Students predict and explain phenomena.

- Students mindfully interact with concrete materials.

2. Use and application of knowledge

- Teachers and students use prior knowledge.

- Students identify and use multiple resources.

- Students plan and carry out investigations.

- Students apply concepts and skills to new situations.

- Students are given time for reflection.

- Students take action to improve their own world.

3. Multiple representations

- Teachers use varied evaluation techniques.

- Students create products or artifacts to represent understanding.

- Students revise products and artifacts.

4. Use of learning communities

- Students use languages as a tool to express knowledge.

- Students express, debate, and come to resolution regarding ideas, concepts, and theories.

- Students debate the viability of evidence.

- Learning is situated in a social context.

- Knowledgeable others help students learn new ideas and skills that they could not learn by their own.

5. Authentic tasks

- Driving questions focus and activities.

- The topic or question is relevant to the students.

- Learning is connected to students' life outside school. Technology tools can help connect learning to life outside the school.

- Science concepts and principles emerge as needed to answer the driving questions.

An important concept for social constructivists is that of scaffolding which is a process of guiding the learner from what is presently known to what is to be known. According to Vygotsky (1978), students' problem solving skills fall into three categories: (1) skills that the student cannot perform, (2) skills that the student may be able to perform, and (3) skills that the student can perform with help.

Scaffolding also allows students to perform tasks that would normally be slightly beyond their ability without the assistance or from the teachers. Appropriate teachers' support may allow students to function at the cutting edge of their individual development. Scaffolding is therefore an important characteristic of constructivist learning and teaching.

3.2 Applications of a zone of proximal development to facilitate learning

The development of understanding occurs as a result of social interaction with more knowledgeable others (MKO) and with peers. MKO can assist students learn new ideas and skills that they could not learn on their own. Vygotsky (1978) developed the construct of the zone of proximal development (ZPD) to represent the difference in performance between what student can accomplish without any assistance and assistance of a more knowledgeable other (Vygotsky. 1978: 85-86). According to Vygotsky's notion of ZPD, the idea of providing timely and relevant support can be a great assistance for students to develop of complex chemistry knowledge and process skills. Vygotsky concluded that the social interaction between students and teachers or other adults is an important aspect of intellectual development because the ZPD allows learners to take part in more cognitively challenging tasks and problem solving than they could doing by their own. Furthermore, students are exposed to overlapping zones, called multiple zone of proximal development, as they learn by interacting with many different people such as the teachers, peers, and community members. Interacting with each other among students can become a support that will enable the students to climb to the next level of learning and understanding. This is one reason that collaborative learning is stressed in constructivist classroom setting.

Accordingly, it can be concluded that social interactions were means to construct knowledge, and that the use of active learning tasks were effective in the learning process. In this study, learning activities can be characterized by active engagement, as inquiry learning, problem solving, and collaboration with others. Thus, teacher is a guide, facilitator, and co-explorer who encourages learners to question, challenge, and formulate their own ideas, opinions, and conclusions.

4. Inquiry learning cycle

4.1 Scientific inquiry and learning cycle

Science standards were further developed that addressed inquiry (National Research Council, NRC. 1996). Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (NRC. 1996: 23).

Scientific inquiry can be described as a cycle of engagement, exploration, explanation, application, and evaluation (Bybee; et al. 1989). The scientific inquiry cycle and the components of questioning, determining and collecting evidence, formulating explanations, connecting scientific knowledge, and communicating explanations were shown in Figure 3.

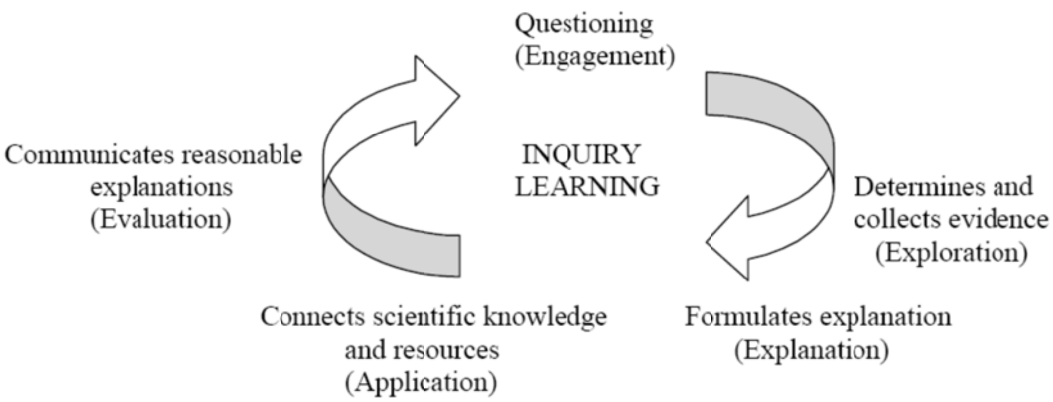


FIGURE 3 SCIENTIFIC INQUIRY CYCLE

Source: Bybee, R. W., Buchwald, C.E., Crissman, S., Heil, D.R., Kuerbis, P.J., Matsumoto, C., & McInerney, J.D. (1989). *Science and technology education for the elementary years: Frameworks for curriculum and instruction.* Colorado Springs: The National Center for Improving Science Education.

The process of scientific inquiry and the teaching strategies utilized are synonymous. The national science teaching standards include inquiry as a central part of science teaching. Teachers of science have to plan, support, encourage and practice the skills of scientific inquiry (NRC. 1996). Teacher guidance and amount of structures provided varies based on the students' needed.

Instructional models have been developed that help teachers organize and sequence inquiry experiences within their classroom (NRC. 2000). Although there is no single method for teaching inquiry, there are five common phases that effective models display which are (NRC. 2000: 35): (1) students are engaged with a scientific question, (2) students explore ideas through hands-on experiences, formulate and test hypotheses, solve problems, and create explanations form observation, (3) students analyze and interpret data, synthesize their ideas, build models and clarify concepts and explanations with teachers and other sources of scientific knowledge, (4) students extend their new understanding and abilities and apply what they have learned to new situations, and (5) students, with their teachers, review and assess what they have learned and how they have learned.

4.2 Learning cycle

The learning cycle is a methodology that provides students with experiences in generating both declarative and procedural knowledge grounded in Piaget's theory of cognitive development (Lawson. 1988). The learning cycle incorporates the Piagetian approach into a methodology of learning. Learning cycle was originally proposed by Robert Karplus and referred actually guided approach to teaching. Three phases of learning cycles (Lawson; Abraham; & Renner. 1989; Musheno; & Lawson. 1999) as follows:

1. Exploration allows students to investigate new materials and/or ideas so that patterns of regularity can be discovered and questions are raised that students then attempt to answer. During exploration, students learn through their own actions to a new situation. Exploration allows students to begin developing declarative and procedural knowledge with the development of their hypothesis creation and testing skills. They explore new materials and new ideas with minimal guidance. The new experience can raise questions or complexities that they cannot resolve with their accustomed ways of thinking.

This can spark debate and analysis of reasons for their ideas. The analysis leads to alternative ways to test ideas though the generation of predictions. The gathering and analysis of ideas may then lead to the rejection of some ideas and retention of other ideas in the cyclic pattern of self-regulation (Lawson. 1995).

2. Term introduction or concept introduction allows the teacher to introduce terms to label the patterns and to explain the newly invented concepts. Terms and concepts are used to refer as the pattern observed during exploration. The terms may be introduced with lectures, assigned readings, or other means. The key is to allow students to sufficiently explore the phenomenon prior to introducing terminology. The teacher orchestrates a discussion period and students share their observations with classmates. This is the time in which the teacher connects student experiences to the target science concept including the identification of scientific vocabulary.

3. Concept application provokes students to seek the patterns elsewhere and to apply the new concepts to additional examples, often employing abstraction or generalization techniques. During concept application, students organize the concept just learned with other related phenomena. The previously learned concepts are extended to new situations and new contexts. Without a variety of applications, the concept's meaning may remain restricted to the examples used at the time it that initially defined and discussed. Without the application phase, many students may fail either to abstract the concepts from its concrete examples or to generalize it to other situations (Lawson. 1995).

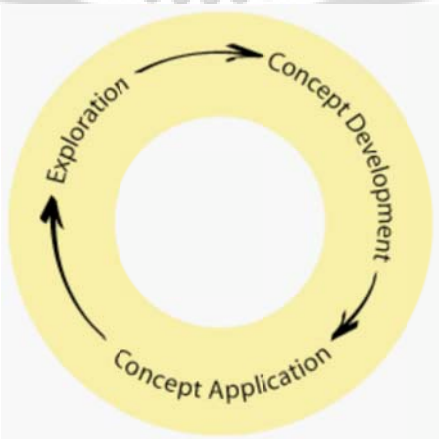


FIGURE 4 THREE PHASES OF LEARNING CYCLE

The learning cycle provides opportunities for students to explore their belief systems, which may result in argumentation, prediction and hypothesis testing, resulting in self-regulation and knowledge construction. Research has supported the effectiveness of the learning cycle in encouraging students to think creatively and critically, as well as in facilitating a better understanding of scientific concepts, developing positive attitudes toward science, improving science process skills, and cultivating advanced reasoning skills (Lawson. 1995: 418–431).

The Biological Science Curriculum Study (BSCS) developed an instructional model called the 5Es. This model extended and elaborated Karplus learning cycle. The 5E instructional model contains five elements: engagement, exploration, explanation, elaboration and evaluation. Each "E" represents part of the process of helping student sequences the learning experiences to construct his or her understanding of concepts (Bybee; et al. 2006): These five components are as following:

1. Engagement: Strategies or activities designed to elicit thoughts or actions by the student that relate directly to the lesson's objective.

2. Exploration: Experiences where students' current understandings are challenged by activities, discussions and currently held concepts to explain experiences.

3. Explanation: Presentations of scientific concepts that change students' explanations to align with scientific explanations.

4. Elaboration: Activities that require the application and use of scientific concepts and vocabulary in new situations.

5. Evaluate: Culminating activity that provides the student and teacher with an opportunity to assess scientific understanding and intellectual abilities.

The BSCS model provides experiences and time for students to recognize the inadequacy of their current ideas, to explore new ways of explaining the world, to reflect on their thinking, and to construct new conceptions of the natural world (Bybee; et al. 2006). To ensure that the materials have the greatest chance of being implemented in the way they were intended and to honor the integrity of the 5Es, the BSCS developed two charts that explicitly show the salient characteristics of each stage of the 5Es as shown in TABLE 1 and TABLE 2. These tables describe in detail what each phase of the instructional model should look like and what it should not look like, from the students' and the teacher's perspective (Bybee; et al. 2006).

TABLE 1 THE BSCS 5E INSTRUCTIONAL MODEL: WHAT THE STUDENT DOES

Stage of the instructional model	The BSCS 5E Instructional Model: What the student does	
	That is consistent with this model	That is inconsistent with this model
Engagement	● Asks questions such as, "Why did this happen?" "What do I already know about this?" "What can I find out about this?" ● Shows interest in the topic	● Asks for the "right" answer ● Offers the "right" answer ● Seeks one solution
Exploration	● Thinks freely, within the limits of the activity ● Tests predictions and hypotheses ● Forms new predictions and hypotheses ● Tries alternatives and discusses them with others ● Records observations and ideas ● Asks related questions ● Suspends judgment	● Lets others do the thinking and exploring (passive involvement) ● "Plays around" indiscriminately with no goal in mind ● Stops with one solution
Explanation	● Explains possible solutions or answers to others ● Listens critically to others' explanations ● Questions others' explanations ● Listens to and tries to comprehend explanations that the teacher offers ● Refers to previous activities ● Uses recorded observations in explanations ● Assesses own understanding	● Proposes explanations without relationship to previous experiences ● Brings up irrelevant experiences and examples ● Accepts explanations without justification ● Does not attend to other plausible explanations

TABLE 1 (continued)

Stage of the instructional model	The BSCS 5E Instructional Model: What the student does	
	That is consistent with this model	That is inconsistent with this model
Elaboration	● Applies new labels, definitions, explanations, and skills in new but similar situations ● Uses previous information to ask questions, propose solutions, make decisions, and design experiments ● Draws reasonable conclusions from evidence ● Records observations and explanations ● Checks for understanding among peers	● Plays around with no goal in mind ● Ignores previous information or evidence ● Draws conclusions without reasonable ● In discussion, uses only those labels that the teacher provided
Evaluation	● Answers open-ended questions by using observations, evidence, and previously accepted explanations ● Demonstrates an understanding or knowledge of the concept or skill ● Evaluates his or her own progress and knowledge ● Asks related questions that would encourage future investigations	● Draws conclusions, not using evidence or previously accepted explanations ● Offers only yes-or-no answers and memorized definitions or explanations as answers ● Fails to express satisfactory explanations in his or her own words

Source: Bybee, R. W.; Taylor, J. A.; Gardner, A.; Van Scotter, P.; Powell, J. C.; Westbrook, A.; & Landes, N. *(2006). The BSCS 5E instructional model: Origins and effectiveness.* Colorado Springs, CO: BSCS.

TABLE 2 THE BSCS 5E INSTRUCTIONAL MODEL: WHAT THE TEACHER DOES

Stage of the instructional model	The BSCS 5E Instructional Model: What the teacher does	
	That is consistent with this model	That is inconsistent with this model
Engagement	● Creates interest ● Generates curiosity ● Raises questions ● Elicits responses that uncover what the students know or think about the concept or topic	● Explains concepts ● Provides definitions and answers ● States conclusions ● Provides closure ● Lectures
Exploration	● Encourages the students to work together without direct instruction from the teacher ● Observes and listens to the students as they interact ● Asks probing questions to redirect the students' investigations when necessary ● Provides time for the students to puzzle through problems ● Acts as a consultant for students ● Creates a "need to know" setting	● Provides answers ● Tells or explains how to work through the problem ● Provides closure ● Directly tells the students that they are wrong ● Gives information or facts that solve the problem ● Leads the students step by step to a solution
Explanation	● Encourages the students to explain concepts and definitions in their own words ● Asks for justification (evidence) and clarification from students ● Formally clarifies definitions, explanations, and new labels when needed ● Uses students' previous experiences as the basis for explaining concepts ● Assesses students' growing understanding	● Accepts explanations that have no justification ● Neglects to solicit the students' explanations ● Introduces unrelated concepts or skills

TABLE 2 (continued)

Stage of the instructional model	The BSCS 5E Instructional Model: What the teacher does	
	That is consistent with this model	That is inconsistent with this model
Elaboration	● Expects the students to use formal labels, definitions, and explanations provided previously ● Encourages the students to apply or extend the concepts and skills in new situations ● Reminds the students of alternate explanations ● Refers the students to existing data and evidence and asks, "What do you already know?" "Why do you think …?" (Strategies from exploration also apply here.)	● Provides definitive answers ● Directly tells the students that they are wrong ● Lectures ● Leads students step by step to a Solution ● Explains how to work through the problem
Evaluation	● Observes the students as they apply new concepts and skills ● Assesses students' knowledge and skills ● Looks for evidence that the students have changed their thinking or behaviors ● Allows students to assess their own learning and group-process skills ● Asks open-ended questions such as, "Why do you think …?" "What evidence do you have?" "What do you know about *x*?" "How would you explain *x*?"	● Tests vocabulary words, terms, and isolated facts ● Introduces new ideas or concepts ● Creates ambiguity ● Promotes open-ended discussion unrelated to the concept or skill

Source: Bybee, R. W.; Taylor, J. A.; Gardner, A.; Van Scotter, P.; Powell, J. C.; Westbrook, A.; & Landes, N. *(2006). The BSCS 5E instructional model: Origins and effectiveness.* Colorado Springs, CO: BSCS.

Some science teachers suggest strategies of using the 5E learning cycle in various kinds of contents. 5E instructional model is a teaching/learning cycle that can promote both inquiry-based approaches and student-centered. It is accepted as an effective instructional strategy. It can be applied to instruct many various kinds of science topics. Summary of effectiveness of BSCS 5E instructional model based teaching (Bybee; et al. 2006) was shown in TABLE 3.

TABLE 3 SUMMARY OF EFFECTIVE OF BSCS INSTRUCTIONAL MODEL BASED TEACHING

Goal of Integrated instructional units	Summary of findings for the BSCS 5E instructional model	Findings from *America's Lab Report* (NRC. 2006: 100)
Mastery of subject matter	Students whose teachers taught with medium or high levels of fidelity to the BSCS 5E instructional model experienced learning gains that were nearly double that of students whose teachers used the model with low levels of fidelity (Coulson. 2002). High school chemistry students in a 5E based course experienced gains in subject matter knowledge that were significantly larger than those in a course where traditional approaches were used (Akar. 2005).	Increases mastery compared with other modes of instruction
Scientific reasoning	Elementary school students showed increases in scientific reasoning as a result of instruction based upon the BSCS 5E Instructional Model (Boddy. 2003).	Aids the development of more-sophisticated aspects
Interest and attitudes toward science	Elementary school teachers who taught science with a 5E approach experienced significant positive changes in attitudes toward science (Tinnin. 2001).	Has greater evidence of increased interest

TABLE 3 (continued)

Goal of Integrated instructional units	Summary of findings for the BSCS 5E instructional model	Findings from *America's Lab Report* (NRC. 2006: 100)
Interest and attitudes toward science (continued)	Elementary school science students taught with a learning cycle–based approach experienced positive changes in attitudes toward science (Boddy. 2003). High school chemistry students in a 5E-based course experienced positive changes in attitudes toward science that were significantly larger than those in a course where traditional approaches were used (Akar. 2003).	Has greater evidence of increased interest

In conclusion, inquiry learning cycle can promote both inquiry-based approaches and student-centered. It is accepted as an effective instructional strategy that was very useful for teaching and learning science. It can be applied to instruct many various kinds of science topics. The inquiry instructional model can be generalized and applied to chemistry curriculum. Additionally, the developed learning units were approached by using the inquiry learning cycle can enhance student learning achievement, science process skills and scientific attitudes.

5. Teaching and learning chemistry

Researches in science education focus on improving students' understanding of scientific phenomena. In order to understand the concepts involved, students must be able to relate concepts to their ideas in meaningful ways. From this point of view, learning is a restructuring of existing ideas rather than merely adding information to existing structure. It is widely accepted that students develops some ideas from out of school context before coming to the classroom. Often these ideas are different from scientific explanations and interact with scientific knowledge presented in the class. Consequently, unintended learning outcomes come out. Therefore one of the aims of science education is to make students acquire scientific knowledge meaningfully.

5.1 Role of representations in chemistry

Chemistry is meaning-based knowledge representations, which are changed and created to reflect the reunification or reconstruction of the theoretical and the experimental. Additionally, representations in chemistry share following three characteristics.

5.1.1 Representations in chemistry are models suitable for specific purposes (Hoffmann; & Laszlo. 1991). Ball-and-stick models represent the physical positions of atoms and molecules, and space-filling models provide information about the size of atoms that is critical for deciding the conformation of organic molecules. Hence, representations embed selected details of the relevant concepts or principles, but permit other details to fade.

5.1.2 The development of representations displays the historical development of theories in this domain. Microscopic representations currently used in chemistry evolve from phenomenological analogies of sensory experiences at the macroscopic level. Because these microscopic representations are historically developed and have been extracted from the observable phenomena, understanding these representations becomes a difficult task. For novices, these representations cannot be understood by personal intuition or perceptions. Consistent with this historical development, Gabel, Samuel and Hunn (1987) indicated that most chemistry concepts have three levels of understanding which are the sensory, particulate, and symbolic levels. Chemists transform the sensory information into chemical processes, explain these processes as atomic and molecular behaviors at the particulate level, and translate atoms and molecules into symbols and formulas. As I will discuss later, this abstract nature of representations is one source of students' learning difficulties.

5.1.3 Representations in chemistry are symbols, signs or elements of chemical language and leading to the world of chemistry (Hoffmann; & Laszlo. 1991; Kozma; et al. 1997; Kozma. 1997). Hoffmann and Laszlo (1991) argued that "a chemical formula is like a word" which composes of both language and chemical representations which share the function of communication. In their ethnographic study at a chemistry laboratory, Kozma, Chin, Russell and Marx (1997) found that chemists used representations to communicate with each other and reconstructed reality and nature. They used various representations for asking questions, stating hypotheses, making claims, drawing inferences, and reaching conclusions. Being familiar with these representations and their usage in chemistry, therefore, is essential for the acquisition of expertise.

As indicated by Kozma (1997) that the use and understanding of a range of representations is not only a significant part of what chemists do. Chemistry education, thus, should promote students to develop representation competence (Kozma; & Russell. 1997) comprising a set of representational skills: the ability to see expressions with different surface features (e.g., changes in color), as representing the same chemical principle or situation, the ability to translate one representation of a chemical concept or situation into another one, and the ability to generate or select an appropriate representations to make explanation, predictions, and justification. Namely, representation competence includes the abilities and skills to use a range of chemical representations to do chemistry inquiry.

Indeed, representations are essential elements of chemistry language. Each type of representation conveys information about some relevant concepts but fade other details. The use of representations in chemistry reflects the theories, findings and discoveries in chemistry. Many chemists use representations to communicate with their colleagues and to do inquiry. The acquisition of the expertise in the chemistry domain would be the development of representation competence. Chemistry education should help students learn how to use representation appropriately. While representations play a critical role in chemistry, however, the literature indicates that many students have difficulty visualizing these representations. Because most students' understanding of chemistry is constrained by the perceptual experiences from daily lives, students tend to stay in the sensory level and are not able to visualize particulate behavior and symbolic representations (Ben-Zvi; Eylon; & Silberstein. 1986; Gabel; et al. 1987).

5.2 Three levels of representation in chemistry

Chemical bonding is a topic in which understanding is developed through diverse models, which, in turn, are built upon a range of physical principles; students are expected to interpret a disparate range of symbolic representations standing for chemical bonds (Taber; & Coll. 2002). According to Johnstone (1991), matter can be represented on three levels, frequently these are referred to as the macroscopic (physical phenomena), microscopic (particles), and the symbolic levels (chemical language and mathematical models).

Following Gabel (1998), Dori and Hameiri (1998) have developed a scheme for multi-dimensional analysis of quantitative problems based on three transformation dimensions between the symbol level and each one of the three representations which are macro, micro, and process. Many students found difficulty to switch their thinking spontaneously between 1) the symbol (chemical formula) and the macro (substance/mass), 2) the symbol to the micro (particles) level, 3) the symbol and the process (chemical reaction) level and vice versa. The findings indicated that students have difficulties to switch their thinking spontaneously between the three representations.

Gabel (1996) claimed that often teachers do not know or realize when to move from one level to another in their teaching. In that way, they do not help students integrate the levels, and each level can be interpreted in more than one way. Thus students become confused rather easily. More recently, Robinson (2003) has suggested that students must first thoroughly understand how to convert a symbol into the meaningful information it represents. Only then will they be able to succeed in dealing with a difficult problem or situation with the quantitative computation.

According to Bodner and Domin (1998), it is very important to distinguish between internal representation, which is the information stored in the brain, and external representation, which is the physical manifestation of this information. Individuals with very different internal representations might write similar external representations. The instructor writes symbols, which represent a physical reality. Very often, students write letters, numbers, and lines, which have no physical meaning to them.

In order to understand chemical bonding concepts, the students have to be familiar with the multiplicity of terms, with the meaning of scientific models, as well as the difference between the macroscopic and the sub-microscopic worlds.

Students' conceptual understanding of chemical representations is an important area of research in chemistry education (Ben-Zvi, Eylon; & Silberstein. 1988; Gabel. 1998). For decades, researchers and chemistry educators have been discussing the three levels of representations in chemistry: macroscopic, microscopic, and symbolic levels (Gabel; Samuel; & Hunn. 1987; Gabel. 1998). Chemical representations at the macroscopic level refer to observable phenomena, such as the change of matter. The microscopic chemistry refers to the nature, arrangement, and motion of molecules used to explain properties of compounds or natural phenomena. Chemistry at the symbolic level refers to the symbolic representations of atoms, molecules, and compounds, such as chemical symbols, formulas, and structures. Empirical studies (Ben-Zvi; Eylon; & Silberstein. 1986; 1987) have shown that learning microscopic and symbolic representations is especially difficult for students because these representations are invisible and abstract while students' understanding of chemistry relies heavily on sensory information.

To help students understand chemistry at the three levels, researchers developed new approaches to teaching chemistry such as adapting teaching strategies based on the conceptual change model, presenting the historical change of a theory, using concrete models, and using technological tools (Gabel. 1998; Krajcik. 1991). According to Kozma and his colleagues (Kozma. 1997; Kozma; Chin; Russell; & Marx.1997; Kozma; et al., 1996) stated that multimedia tools, which integrate the animation of molecular models, video clips of chemical equilibrium, or real time graphics, provide students with opportunities to visualize chemical processes at the microscopic level. They also indicated the use of multiple linked representations helped students understand chemical equilibrium and its related chemical concepts. Additionally, research supports the advantages of manipulating physical models that help students to visualize atoms and molecules and promote long-term understanding (Barnea; & Dori. 1996; Copolo; & Hounshell. 1995; Gabel; & Sherwood. 1980; Talley. 1973). It is aimed at simplifying, illustrating and exploring chemical structure, phenomena and processes in a stepwise fashion. While empirical studies begin to influence of using models of molecules and technological tools in chemistry teaching, however, little is understood about how these tools help student to develop conceptual understanding of chemical structure and bonding.

5.3 Students' learning difficulties

Ben-Zvi, Eylon, and Silberstein's study (1988) explored what level of descriptions students generated (e.g., the macroscopic level, the atomic molecular level, the multi-atomic level), when some chemical symbols and formulas were used, such as Cu(s), H_2O(l), and Cl_2(g). Students' responses indicated that a majority of them confused atoms with molecules. Although most of them generated some macroscopic descriptions of water, i.e., its properties, the atomic-molecular models they used to explain the phenomena were not appropriate. For example, about 20 percent of the students in their study held an additive model of molecules and stated that a water molecule contained a unit of hydrogen gas, H_2. Some students viewed H_2O (l), and Cl_2 (g) as representations of one particle without the conception of atoms or a collection. To them, the use of (l) or (g) could not trigger any descriptions about multitude of molecules. Ben-Zvi, Eylon, and Silberstein's study (1986; 1988) also found that even though most students were able to recognize these chemical symbols as hydrogen or chlorine, they relied on their intuitive mental models of atoms and molecules to make explanations or descriptions about these representations. Many students, even after studying chemistry, do not understand the role of a formula; some think that formulas are merely abbreviations for names rather than a short way to represent composition or structure and others hold the misconception that a formula is an abbreviation for a mixture.

Importantly, Kozma and Russell (1997) stated that most students have difficulties interpreting chemical equations, because their understanding is constrained by the surface features of representations. When they see an equation, such as C(s) + O_2(g)$\longrightarrow$$CO_2$(g), they interpret it as a composition of letters, numbers and lines rather than a process of bond formation and breaking. The technique of balancing chemical equations makes them picture chemical equations as mathematical puzzles (Ben-Zvi; et al. 1987), and they can even work algorithmic without having a conceptual understanding of the phenomena. Thus, while chemists see symbols and letters as molecules and the arrow as the direction of reaction, many students are not able to visualize these representations.

In addition to the difficulty of interpreting representations, Keig and Rubba's study (1993) showed that large numbers of students were unable to make translation among formula, electron configuration, and ball-and-stick models.

The literature suggests that two aspects of chemical representations cause these difficulties. Firstly, representations, especially symbolic and molecular ones, are abstract (Ben-Zvi, Eylon; & Silberstein. 1988). It has been known that meaningful learning is built on a relevant set of concepts already held by the student. Therefore, to make these representations understandable and meaningful for students, instruction and chemistry curriculum should give students opportunities to build conceptual connections between these abstract molecular symbols and collective behaviors of molecules. Secondly, students' ability to visualize representations is correlated to their understanding of the underlying concepts (Keig; & Rubba. 1993). Thus, translation between representations is an information processing task, requiring understanding of the underlying concept to the extent that the individual can interpret the information provided by the initial representation and infer the details required to construct the target representation (Keig; & Rubba. 1993).

According to Lesh, Post and Behr (1987) illustrated the information processing character of translation among representations, and the role of concept knowledge in the translation process. Each student's knowledge of representations in terms of atoms and molecules provides a foundation for translation of representations. This foundation is more like a network for the cognitive application of connections or relationships between these concepts.

Consequently, making conceptual connections between representations and developing understanding of underlying concepts are important for students to learn chemistry.

In summary, chemistry is not a subject that can be taught in isolation -- teacher and teaching resources including molecular models and representations play a significant role in providing explanations of the abstract concepts. Because teaching chemistry is dependent on the use of chemical representations, the relationship between the various types of models and representations were considered.

5.4 Instructional design based on information processing theory

Saiyud Uraisakul (2000) developed the course of Introduction of Soils Science in the topic of "Water and Soil Conservation" based on information processing approach. The randomized control group pretest posttest design was used to examine the ability of problem solving scores. The treatment group was 25 vocational students at Pranakhornsriayuthaya Huntra Campus. They were taught by information processing approach. The results of this study showed that after the study, the development of problem solving ability of the treatment group was higher than before with statistically significance at 0.01 level.

Tasker and Dalton (2006) examined the student attributes affecting the development of students' mental models when VisChem animations were used. The constructivist VisChem learning design integrating the audiovisual information-processing model incorporated with combination of evidence-based models, cognitive load theory, and dual-coding theory, was used to probe students' mental models of a substance or reaction at the molecular level before showing animations portraying the phenomenon. The research was conducted research under factors that affect a student's ability to form scientifically acceptable mental models of chemical substances and processes at the molecular level after exposure to VisChem animations. This study examined the changes in mental models of first-year chemistry students (N = 48) following a semester of teaching that emphasized molecular visualization using the animations. The study used a pre-test/post-test design with follow-up interviews. A transfer-test was also administered after the post-test, and prior to interviews. This study demonstrated that showing animations to students, with opportunities for them to practice drawing representations of the molecular world, significantly increased the number of scientifically acceptable key features in students' representations of chemical phenomena at the end of the semester. Students developed more vivid mental imagery of these phenomena and had greater confidence in their images. Evidence from interviews with 14 students revealed that changes were largely attributed to having viewed VisChem animations. There was also an indication that some students had been able to transfer their ideas from animations to new situations, as evidenced by a statistically-significant correlation between the post-test and transfer test, and comments in interviews.

Costu et al. (2007) attempted to facilitate students' conceptual change on boiling by implementing appropriately designed teaching activities. The authors worked with 42 university students enrolled in introductory chemistry courses. The results indicated that the designed teaching strategy was an effective means of reducing the number of alternative conceptions students held about the boiling concept. However, it was found that some students maintained their alternative conceptions throughout the study, number of students' belief that bubbles in boiling water contain air decreased from pretest to posttest, finally this belief increased considerably in a retention post-test.

Slavakalyuga, Chandler and Sweller (1999) investigated alternatives to split-attention instructional designs with two experiments. It was assumed that because a learner has a limited working memory capacity, any increase in cognitive resources required to process split-attention materials decreases resources available for learning. Using computer-based instructional material consisting of diagrams and text, Experiment 1 attempted to improve split-attention effects by increasing effective working memory size by presenting the text in auditory form. Auditory presentation of text proved superior to visual-only presentation but not when the text was presented in both auditory and visual forms. In that case, the visual form was redundant and imposed a cognitive load that interfered with learning. Experiment 2 improved split-attention effects by using color coding to reduce cognitive load inducing search for diagrammatic referents in the text. Mental load rating scales provided evidence in both experiments that alternatives to split-attention instructional designs were effective due to reductions in cognitive load.

From an analysis of a learning model based on the theory of information processing, Vianna, Sleet, and Johnstone (2009) developed laboratory courses for improving the specific procedures to minimize the load on students' working memory. The study was also concerned with the value of mini-projects in enhancing meaningful learning of the knowledge and skills underpinning the set experiments. A three-year study of a first year undergraduate chemistry laboratory course at a Scottish university has been carried out. The results indicated that the load on students working space should be reduced by appropriate changes to the written instructions and the laboratory organization and by the introduction of prelab-work and prelab-training in laboratory techniques. It was concluded from research conducted over the three years period that the developed laboratory courses was effective both in reducing the load on students' working spaces and in improving their attitudes to the laboratory course.

Dechsri, Jones and Heikkinen (1997) applied visual information aids consisting of pictures and diagrams integrated with text to the design of a chemistry laboratory manual for 83 university students. Results showed that the manual incorporating visual information processing characteristics helped students gain significantly higher scores on measures of achievement and psychomotor skills, and also stimulated students to develop more favorable attitudes toward the laboratory activities. Visual information-processing assistance provided by pictures and diagrams integrated with text in chemistry laboratory manuals can reduce the information load passing through students' working memories and can help them gain more from their laboratory experiences.

From research reviewed, curriculum materials design based on information processing theory would help students to gain better in learning achievement, attitude, and process skills. Designing the curriculum materials to reduce the amount of information that students had to deal with simultaneously and based on their working memory capacity was highly interested. Therefore, the strategies to reduce working memory load were employed for instructional design based on theory of information processing. These strategies included re-structuring multi-step tasks into separate independent steps, presenting pictures and diagrams integrated with text, relating learning materials to prior knowledge, and reducing the amount of material to be stored e.g., shortening sentences to be written, or number of items to be remembered.

6. Educational assessment

Assessment is a process of information collection in the contexts of instruction that was used to examine students' knowledge, skills, and abilities. National Science Education Standards of the U.S. has suggested 3 major aspects of science assessment. These outcomes consist of conceptual understanding in science, ability to perform scientific inquiry and understandings about inquiry.

As student's inquiry is a multifaceted activity, 5 aspects to assess the abilities of students in inquiry suggested by NRC included: (1) identifying a worthwhile and researchable question, (2) planning the investigation, (3) executing the research plan, (4) drafting the research report and (5) assessing individual student achievement (NRC. 1999: 98-100). In addition, the NRC suggests methods of assessment that can be used such as paper and pencil testing, performance testing, interviews, portfolios, performances, observing programs

6.1 Domain in Assessments

According to Bloom et al. (1979: 7), a useful framework for classifying learning outcomes, the notion of educational goals can be assessed in three major domains:

6.1.1 Cognitive domain

The cognitive domain (Bloom. 1956) involves knowledge and the development of intellectual skills. This includes the recall or recognition of specific facts, procedural patterns, and concepts that serve in the development of intellectual abilities and skills. There are 6 major categories, which are listed in order below (Clark. 2010), starting from the simplest behavior to the most complex. The categories can be thought of as degrees of difficulties. That is, the first ones must normally be mastered before the next ones can take place.

1. Knowledge: Recall data or information.

2. Comprehension: Understand the meaning, translation, interpolation, and interpretation of instructions and problems. State a problem in one's own words.

3. Application: Use a concept in a new situation or unprompted use of an abstraction. Applies what was learned in the classroom into novel situations in the work place.

4. Analysis: Separates material or concepts into component parts so that its organizational structure may be understood. Distinguishes between facts and inferences.

5. Synthesis: Builds a structure or pattern from diverse elements. Put parts together to form a whole, with emphasis on creating a new meaning or structure.

6. Evaluation: Make judgments based on criteria and standards.

Lorin Anderson, a former student of Bloom, revisited the cognitive domain in the learning taxonomy in the mid-nineties and made some changes (Clark. 2010), with perhaps the two most prominent ones being, (1) changing the names in the 6 categories from noun to verb forms and (2) slightly rearranging them (Pohl. 2000). This new taxonomy reflects a more active form of thinking and is perhaps more accurate as following:

1. Remembering: Retrieve relevant knowledge form long-term memory.

2. Understanding: Construct meaning from instructional messages, including oral, written, and graphic communication.

3. Applying: Carry out or use a procedure in a given situation.

4. Analyzing: Break material into its constituent parts and determine how the parts relates to one another and to an overall structure or purpose.

5. Evaluating: Make judgments based on criteria and standards.

6. Creating: Put elements together to form a coherent or functional whole; reorganize elements into a new pattern or structure.

6.1.2 Affective domain

The affective domain (Krathwohl; Bloom; & Masia. 1973) includes the manner in which we deal with things emotionally, such as feelings, values, appreciation, enthusiasms, motivations, and attitudes. The five major categories are listed from the simplest behavior to the most complex:

1. Receiving phenomena: Awareness, willingness to hear, selected attention.

2. Responding to phenomena: Active participation on the part of the learners. Attends and reacts to a particular phenomenon. Learning outcomes may emphasize compliance in responding, willingness to respond, or satisfaction in responding (motivation).

3. Valuing: The worth or value a person attaches to a particular object, phenomenon, or behavior. This ranges from simple acceptance to the more complex state of commitment. Valuing is based on the internalization of a set of specified values, while clues to these values are expressed in the learner's overt behavior and are often identifiable.

4. Organization: Organizes values into priorities by contrasting different values, resolving conflicts between them, and creating a unique value system. The emphasis is on comparing, relating, and synthesizing values.

5. Internalizing values (characterization): Has a value system that controls their behavior. The behavior is pervasive, consistent, predictable, and most importantly, characteristic of the learner. Instructional objectives are concerned with the student's general patterns of adjustment (personal, social, emotional).

6.1.3 Psychomotor domain

The psychomotor domain (Simpson. 1972) includes physical movement, coordination, and use of the motor-skill areas. Development of these skills requires practice and is measured in terms of speed, precision, distance, procedures, or techniques in execution. The 7 major categories are listed from the simplest behavior to the most complex:

1. Perception: The ability to use sensory cues to guide motor activity. This ranges from sensory stimulation, through cue selection, to translation.

2. Set: Readiness to act. It includes mental, physical, and emotional sets. These three sets are dispositions that predetermine a person's response to different situations (sometimes called mindsets).

3. Guided response: The early stages in learning a complex skill that includes imitation and trial and error. Adequacy of performance is achieved by practicing.

4. Mechanism: This is the intermediate stage in learning a complex skill. Learned responses have become habitual and the movements can be performed with some confidence and proficiency.

5. Complex overt response: The skillful performance of motor acts that involve complex movement patterns. Proficiency is indicated by a quick, accurate, and highly coordinated performance, requiring a minimum of energy. This category includes performing without hesitation, and automatic performance. For example, players are often utter sounds of satisfaction or expletives as soon as they hit a tennis ball or throw a football, because they can tell by the feel of the act what the result will produce.

6. Adaptation: Skills are well developed and the individual can modify movement patterns to fit special requirements.

7. Origination: Creating new movement patterns to fit a particular situation or specific problem. Learning outcomes emphasize creativity based upon highly developed skills.

In addition, Robert Gagné had classified behaviors to assess specific for science teaching and learning including five kinds of capabilities: intellectual skills, cognitive strategies, verbal information, attitudes, and motor skills. The Gagné taxonomy is perhaps the most popular of the many learning taxonomies in the field of instructional design. Its popularity can be attributed best for its ability to clearly distinguish between abstract and concrete definitions of learning (Seels; & Glasgow. 1990) as followings:

1. Motor skill refers to bodily movements involving muscular activity.

2. Attitude is an internal state which affects an individual's choice of action toward some object, person, or event.

3. Verbal information includes labels and facts and bodies of knowledge.

3.1 Labels and facts refer to naming or making a verbal response to a specific input. The response may be naming or citing a fact or set of facts. The response may be vocal or written.

3.2 Bodies of knowledge refer to recalling a large body of interconnected facts.

4. Cognitive strategy is an internal process by which the learner controls his/her own ways of thinking and learning.

5. Intellectual skills include discrimination, concrete concept, rule using and problem solving. These are the 4 levels within the intellectual skills domain that Gagné identified as his taxonomy.

5.1 Discrimination is making different responses to the different members of a particular class. Seeing the essential differences between inputs and responding differently to each.

5.2 Concrete concept is responding in a single way to all members of a particular class of observable events. Seeing the essential similarity among a class of objects, people, or events, which calls for a single response.

5.3 Rule using is applying a rule to a given situation or condition by responding to a class of inputs with a class of actions. Relating two or more simpler concepts in the particular manner of a rule. A rule states the relationship among concepts. Examples: It is helpful to think of rules or principles as "if-then" statements. "If a task is a procedure, then use flowcharting to analyze the task." "If you can convert a statement into an 'if-then' statement, then it is a rule or principle."

5.4 Problem solving is combining lower level rules to solve problems in a situation never encountered by the person solving the problem. It may involve generating new rules which receive trial and error use until the one that solves the problem is found.

6.2 Science process skills

The other important dimension of science in addition to science knowledge is processes of doing science. The processes of doing science are the science process skills that scientists use in the process of doing science. Since science is about asking questions and finding answers to questions, these are actually the same skills that we all use in our daily lives as we try to figure out everyday questions. When we teach students to use these skills in science, we are also teaching them skills that they will use in the future in every area of their experiences.

Science process skills are skill-based approaches of practical work that include hands-on activities, scientific inquiries or experiments. Science process skills consist of basic and integrated science process skills (Enger; & Yager. 2001: 4). Basic science process skills which are: (1) observing, (2) using space and time relationship, (3) classifying, grouping and organizing, (4) using numbers and quantifying, (5) measuring, (6) communicating and (7) inferring. Integrated science process skills which are: 1) predicting, 2) identifying and controlling variable, 3) interpreting data, 4) formulating hypotheses, 5) defining operationally, and 6) experimenting.

6.2.1 Basic science process skills (Wideen. 1975: 82) included 6 processes which are:

1. Observing - using the senses to gather information about an object or event.

2. Inferring - making an "educated guess" about an object or event based on previously gathered data or information.

3. Measuring - using both standard and non-standard measures or estimates to describe the dimensions of an object or event.

4. Communicating - using words or graphic symbols to describe an action, object, or event.

5. Classifying - grouping or ordering objects or events into categories based on properties or criteria.

6. Predicting - stating the outcome of a future event based on a pattern of evidence.

6.2.2 Integrated science process skills (AAAS. 2001: online) included 8 processes which are:

1) Making models: constructing mental, verbal, or physical representations of ideas, objects, or event to clarify explanations or demonstrate relationships.

2) Defining operationally: creating a definition by describing what is done and observed.

3) Collecting data: gathering and recoding information about observations and measurements in a systematic way.

4) Interpreting data: organizing, analyzing, and synthesizing data using tables, graphs, and diagrams to locate patterns that lead to the construction of inferences, predictions, or hypotheses.

6) Identifying and controlling variables: manipulating one factor to investigate the outcome of an event while other factors are held constant.

7) Formulating hypotheses: making educated guesses based on evidence that can be tested through experimentation.

8) Experimenting: designing one's own experiment to test a hypothesis using procedures to obtain reliable data.

6.3 Scientific attitude

Scientific attitude has come to be known as a way in which scientist believe in and conduct their work (Simpson; Koballa; &Olive. 1994: 211). A scientific attitude is a disposition or demonstration of feelings and/or thoughts. Studies of the actions of scientists have led to lists of scientific attitudes such as displayed below. Some attitudes such as honesty would be expected in any human endeavor, but other attitudes such as tolerance of uncertainty are more characteristic of scientists.

Several reasons have been given for the need to study student science attitudes. Numerous studies have concluded that a positive relationship exists between attitude and achievement (Shrigley; Koballa; & Simpson.1988; Talton; & Simpson.1987). Schibeci and Riley (1986) found evidence of a causal link between attitude and achievement, while another influential study (Shrigley; Koballa; & Simpson.1988) concluded that although attitude may be a valuable predictor of achievement, the relationship between the two is probably correlation. Furthermore, it is important to study attitudes because positive attitudes result in increased enrollment in science courses, and influence science achievement and interest in scientific careers (Smail. 1993). In addition, students with positive attitudes towards learning science are more likely to have intentions to engage in future learning behaviors (Norwich; & Duncan. 1990: 312-321).

Some of the researchers stated that, students' achievements in science affected their attitudes by investigating relationships between students' attitudes towards science and science achievements (Germann. 1988; Simpson; & Oliver. 1990). According to these findings, the nature of science education markedly affects students' attitudes towards science and attitudes have the feature of being one of the most important variables in determining students' achievements. In addition, several studies found that scientific attitudes were positively correlated with science achievement and participation in advanced science courses (Simpson; & Oliver. 1990; Lee; & Burkam. 1996; Papanastasiou; & Zembylas. 2004).

The Scientific Attitude Inventory I (SAI I) was designed by Richard Moore in 1969 to use for the measurement of biology and physical science students' attitudes toward science at the high school level. It has been used extensively throughout the world, and a revised version of the Scientific Attitude Inventory II was developed and field tested since 1997. The SAI II used a five-response Likert Scale with 40 items (Moore; & Foy. 1997) to measure corresponding attitude statements on 6 subscales of scientific attitudes: (1) The nature of the laws and/ or theories of science, (2) The basic of scientific explanation, (3) Characteristics needed to operate in scientific manner, (4) The type of activity engendered in science, (5) Progress in science, and (6) Science as a career.

The SAI II was scored by assigning point values to subscale of the attitude items. The point values for the positive items were assigned as follows: strongly agree = 5 point values, mildly agree = 4 point values, neutral/undecided = 3 point values, mildly disagree = 2 point values, and strongly disagree = 1 point value. The point values for the negative items were assigned as follows: strongly agree = 1 point value, mildly agree = 2 point values, neutral/undecided = 3 point values, mildly disagree = 4 point values, and strongly disagree = 5 point values. The range of scores for the entire SAI II is 40 to 200 (Moore; & Foy. 1997: 330-331).

A split-half reliability coefficient for SAI II was computed for the entire group of 557 respondents. Application of the Spearman Brown correction of split-half to the correlation coefficient yields a reliability coefficient of 0.80. Cronbach's alpha reliability coefficient is 0.781 for this group.

The results of an administration of the SAI II to 557 students indicated that the scales of the instrument can distinguish between those who have more positive attitudes toward science and those who have less positive attitudes as determined by the total score on the SAI II (Moore; & Foy. 1997: 330-331). The t-test comparison of the high and low scores is evident in that the various subscales contribute positively to the total score of the instrument. Coupled with judgments that the items of the instrument are related to the scientific attitudes it is supposed to assess, validity is claimed for the SAI II.

From review of the related literature, this research developed chemical bonding learning units incorporated with information processing theory by examining the effectiveness on students' learning outcomes which achievement, science process skills, and scientific attitudes were included. The learning units were approached by using the inquiry learning cycle which fits. The curriculum materials were designed to reduce the amount of information that students had to deal with simultaneously and based on their working memory capacity.

6.4 Diagnostic assessment

Diagnostic assessment helps to identify specific learning strengths and needs. Diagnostic assessments provide instructors with information about student's prior knowledge and misconceptions before beginning a learning activity. They also provide a baseline for understanding how much learning has taken place after the learning activity is completed. Instructors usually build concepts sequentially throughout a course. Most important for diagnostic assessment is that teachers be clear about what they expect to do in their science teaching and know what qualities they hope to bring out in their students.

The assessment of students' understanding of scientific concepts has been interested to researcher and teacher. In an effort to recognize and change teaching approaches teachers can begin by simply investigating students' science concepts. This is necessary to be aware of students' alternative points of view, to reveal the way in which students think and what they understand about scientific concepts.

6.4.1 The importance of diagnostic instrument in science learning

The nature and extent of students' understanding of scientific concepts and phenomena are key components of any science curriculum. Two-tier multiple choice diagnostic instruments have been reported in the science education research literature and suggested that it appears to provide a feasible approach for evaluating students' understanding and for identifying alternative conceptions and misunderstandings of the various topic such as chemical bonding, covalent bonding, and photosynthesis (Duit; & Treagust. 2003; Treagust. 1995; Treagust; et al. 2001). In order to evaluate students' understanding of scientific concepts, appropriate assessment instruments have to be readily available for use by teachers.

Research data collected over three decades has shown that the majority of students come to science classes with pre-instructional knowledge or beliefs about the phenomena and concepts to be taught and many students develop only a limited understanding of science concepts following instruction (Duit; & Treagust. 2003). In addition, large body of research literature on students' understanding of science concepts attempted to provide interventions has been categorized, synthesized and summarized (Duit. 2004; Duit; & Treagust. 2003; Taber. 2001).

In order for science teachers' pedagogy to be more effective, diagnostic formative assessment methods are needed since research suggests that current assessment procedures distort and narrow instruction, misrepresent the nature of the subject, and underscore inequities in access to education (Wolf; et al. 1991). Furthermore, current assessment procedures are claimed to not provide valid measures of what students know and to provide no opportunity for students and teachers to be involved in discussions about the work being assessed (Black; & Wiliam. 1998). Wolf et al. (1991) claimed that a change in this direction of in-class formative assessment might enable teachers to develop sophisticated clinical judgments about students' understanding of significant ideas and processes and encourage educators to discuss, rather than simply measure, educational progress. One such successful approach is embedded assessment where the teachers are able to incorporate a wide variety of formative assessment procedures within their teaching (Treagust; et al. 2001). These alternative forms of assessment are different to those generally used by science teachers in that standard tests are largely paper-and-pencil collections of individual items with single correct answers presented without a surrounding context. However, the difficulty with most effective methods mentioned above is that they are very time consuming and rarely practical for busy classroom teachers to create.

Teachers have several methods for discovering student conceptions. Methods used to determine students' understanding of concepts include concept mapping (Novak. 1996), interviews (Carr. 1996) and multiple-choice diagnostic instruments (Treagust. 1995). In this study, a two-tier multiple-choice instrument was selected.

6.4.2 The development of two-tier multiple choice diagnostic instrument

There are 3 general aspects for developing the two-tier multiple choice instrument items: 1) the content is defined by the identification of propositional content knowledge statements of the topic to be taught and the development of the propositional statements; 2) information about students' conceptions is obtained by having students provide free response explanations to their answers; and 3) the development and revision of the two-tier multiple-choice diagnostic items.

6.4.3 Characteristics of two-tier multiple choice diagnostic instrument

The achievement score was assessed by using a two-tier multiple choice diagnostic test items. The first tier consists of a content question having usually two to four possible choices. The second tier of each item contains a set of four possible reasons for the answer of the first part. The reasons consist of the designated correct answer, together with identified students' conceptions and/or misconceptions. Students' answers to each item are considered to be correct only if both the correct choice and correct reason are given.

In this research study, the first tier of each item consisted of a content question having two, three, or four choices; the second tier of each item contained four possible reasons for the answers of the first tier, which included the correct answer and three alternative reasons involving alternative conceptions. Some questions were adapted from literature (Peterson; et al. 1989; Tan; et al.1999; Treagust. 1995) for used to examine students' prior knowledge about chemistry concepts involved in chemical bonding and structure.

6.5 Normalized gain

Hake defines the normalized gain (or gain score) on the Force Concept Inventory (FCI) test to be the average increase in students' scores on the FCI divided by the average increase that would have resulted if all students had perfect scores on the post-instruction test. He used the normalized gain as an important tool for the characterization of conceptual improvement in physics courses (Hake. 1998). After analyzing results from more than 6,000 students, Hake found that introductory physics course that can be characterized as traditional in teaching style get low normalized gains of 0.23±0.04, a quite narrow range in spite of the wide range of student initial abilities. By contrast, the medium normalized gains earned interactive engagement (IE) courses are in the range 0.48 ± 0.14 with a statistically significant difference. Hake examined a number of possible explanations for these results, and concludes that the teaching methods employed in the IE courses make the difference.

The normalized gain is calculated from the score on a pre-test administered before instruction and a post-test administered after instruction. The statistic has been used in many published works since Hake's paper (1998). Normalized gain (<g>) was defined as following:

<g> = (posttest - pretest) / (total score - pretest)

where angle brackets <.. . .> mean an average over all students in a course.

Notice: Students' scores were interpreted based on these following criteria:

1) if <g> ≥ 0.70, the result was interpreted as high gain level

2) if 0.30 ≤ <g> ≤ 0.69, the result was interpreted as medium gain level

3) if <g> ≤ 0.29, the result was interpreted as low gain level

In investigating the effect of implementing the learning units on student learning achievement regarding the concept of chemical bonding, in this study, class average normalized gain of each topic of chemical bonding was examined. The change in conceptual understanding from the beginning of the course of instruction to the end was described by class average normalized gain as following:

$$<g> = (\%posttest - \% pretest) / (100\% - \% pretest)$$

In this study, class average normalized gain of students' achievement scores were compared with a setting criterion score at high gain level. The normalized gain measures and compares the students in relation to the level of performance they will be expected to achieve. The criterion-reference measurement considers how students' test scores would be interpreted. Thus, students' performances are compared with the specific criterion they are expected to achieve. More specifically, students' achievement scores are compared with the normalized gain.

CHAPTER 3
RESEARCH METHODOLOGY

This study was concerned with the development of chemical bonding learning units incorporated with information processing theory for high school. In this chapter, the research methodology is outlined and detailed in as following:

1. Design
2. Instruments
3. Data collection
4. Data analysis

1. Design

The design for the development of the learning units on chemical bonding for high school students were based on five main phases: studying basic information, developing learning units, conducting a pilot study, implementing the research study, and evaluating learning units. These stages are described with more details as follows:

1.1 Basic information study

1.1.1 Studying related documents

This step involved studying and analyzing related documents to develop a new approach for teaching the concept of bonding. The documents included and covered the National Science Curriculum Standards, problematic aspects from traditional teaching approach, designing strategies for developing teaching materials, information processing theory, and educational assessment.

1.1.2 Focusing area of the study

The aim in designing the learning units was to minimize learning situations where a high working memory was demanded. To achieve the purpose, the learning units were approached using the inquiry learning cycle. The learning units were designed under information processing theory with emphasis on instructional design strategies to reduce the working memory demand by restructuring multi step tasks into separate independent steps, presenting pictures and diagrams integrated with text, relating learning materials to prior knowledge, and reducing the amount of material to be stored (e.g., shortening sentences to be written, or number of items to be remembered). The instructional materials were based the standard science 3.1, sub-strand 3: matters and properties of matters. The selected content was based on the National Science Curriculum Standards.

> Standard Sc3.1: Understanding of properties of substances; relationship between properties of substances and structures and binding forces between particles; having investigative process for seeking knowledge and scientific reasoning; and communicating acquired knowledge that could be applied for useful purposes (Ministry of Education. 2002: 15).

1.2 Learning units' development

The learning units was designed and developed according to the information gathered from previous stage. The following main steps were employed for designing the learning units.

1.2.1 Establishing the scope and sequence

The fundamental step in planning was establishing the scope and sequence plan which contained the overview of the sequence of 7 main topics with sub-topics of each is shown in TABLE 4 and duration of proposed learning units is shown in TABLE 5. Concepts flow and learning objectives targeted in the learning units were outlined from the completed scope and sequence.

An overview of goals and objectives, content, and recommended activities for developing the learning units is showed as follows.

TABLE 4 AN OVERVIEW OF COMPETENCY GOALS FOR LEARNING UNITS

COMPETENCY GOAL 1: The development of abilities necessary to do and understand scientific inquiry.

Goals	Content	Recommended Activities
1.1 Design, conduct and analyze investigations to answer questions related to chemical bonding concepts. • Identify questions and suggest hypotheses. • Identify variables. • Use a control when appropriate. • Select and use appropriate measurement tools. • Collect and organize data in tables, charts and graphs. • Analyze and interpret data. • Explain observations. • Make inferences and predictions. • Explain the relationship between evidence and explanation. • Identify how scientists share findings.	This goal and these objectives are an integral part of each of the other goals. In order to measure and investigate scientific phenomena, students must be given the opportunity to design and conduct their own investigations in a safe laboratory. The students should use questions and models to formulate the relationship identified in their investigations and then report and share those finding with others Students should be able to: • Identify questions and suggest hypotheses. • Identify variables. • Use a control when appropriate. • Select and use appropriate measurement tools. • Collect and organize data in tables, charts and graphs. • Analyze and interpret data. • Explain observations. • Make inferences and predictions. • Use questions and models to determine the relationships between variables in investigations. • Identify how scientists share findings.	• Effort should be made in each topic to provide students opportunities to acquire and practice science process skills. • Students should be given numerous opportunities to design and conduct experiments within the context of the entire course.

TABLE 4 (continued)

COMPETENCY GOAL 2: Construct the understanding of structure and properties of matter.		
Goals	Content	Recommended Activities
2.1 Investigate and analyze data, discuss and explain bonding in metals and ionic compounds as related to chemical and physical properties.	Students should be able to: • Describe how ions are formed and which arrangements are stable. • Appropriately use the term cation as a positively charged ion and anion as negatively charged ion. • Predict ionic charges for representative elements based on valence electrons. • Describe formation of ionic bond and lattice structure due to electrostatic attraction. • Determine that a bond is predominately ionic by the location of the elements in the periodic table (metals combined with nonmetals) and by electronegativity differences. • Explain how ionic bonding in compounds determines their characteristics: high melting and boiling point, brittle, and high electrical conductivity in molten state or in aqueous solution.	• Classify types of bonding based on properties of substance • Formation of an ionic bond and lattice structure • Reaction of ionic compounds in water • Lattice energies • Reaction of ionic compounds • Nomenclature of ionic compounds
	• Describe metallic bonds: metal ions and electron sea model. • Explain how metallic bonding determines the characteristics of metals: high melting and boiling point, high conductivity, malleability, ductility, and luster.	• Metal ions and electron sea model.

TABLE 4 (continued)

COMPETENCY GOAL 2: Construct the understanding of structure and properties of matter.		
Goals	Content	Recommended Activities
2.2 Investigate and analyze data, discuss and explain covalent bonding in molecules as related to molecular geometry and chemical and physical properties.	Students should be able to:	
	• Apply the concept that sharing electrons form a covalent molecule for stable arrangement.	• Formation and nature of the covalent bond
	• Determine that a bond is predominately covalent by the location of the elements in the periodic table (nonmetals combined with nonmetals) and by electronegativity differences.	• Types of covalent bonds, Lewis structure, and nomenclature • Electronegativity and bond types
	• Explain how covalent bonding in compounds determines their characteristics: low melting and boiling point, poor electrical conductivity, and polarity, etc.	
	• Know number of bonding diatomic molecules as single, double, or triple bonds (e.g. F_2, O_2, and N_2).	• Formation of the covalent bond in hydrogen molecule
	• Describe carbon bonds as either single, double or triple bonds.	
	• Apply the relationship between bond energy and bond length of single, double, and triple bonds.	• Comparisons of relative strengths of covalent bonds
	• Draw Lewis dot structures for simple covalent molecule.	
	• Apply Valence Shell Electron Pair Repulsion model (VSEPR) for molecular geometries and bond angles.	• VSEPR model and molecular geometries

TABLE 4 (continued)

COMPETENCY GOAL 2: Construct the understanding of structure and properties of matter.		
Goals	Content	Recommended Activities
2.2 (continued)	• Describe bond polarity. Polar/non-polar molecules and relate polarity to solubility • Describe unique properties of macromolecules and network structures: water (ice), graphite/diamond/bucky ball • Describe intermolecular forces for molecular compounds (H-bond, dipole-dipole attractions, and London dispersion forces) • Relative strengths of intermolecular forces.	• Comparisons of polarity of molecule • Describing bond polarity, polar/non-polar molecules with "like dissolves like" • Molecular and intermolecular forces • Describe macromolecules and network solids • Describe intermolecular forces for molecular compounds

Seven main topics in the learning units were showed in TABLE 5. These topics were analyzed into sub-topics which were grouped and arranged to organize content for entire learning units.

TABLE 5 TOPICS AND TEACHING PERIODS OF THE LEARNING UNITS

Learning units	Sub-topics	Periods (50 min/ period)
1	1. Why do atoms bond	
	1.1 Why do atoms bond	1
2	2. Ionic Bonding	
	2.1 Formation of an ionic bond and lattice structure	2
	2.2 Reaction of ionic compounds in water	2
	2.3 Nomenclature of ionic compound	1

TABLE 5 (continued)

Learning units	Sub-topics	Periods (50 min/ period)
3	3. Covalent bonding	
	3.1 Formation and nature of the covalent bond	2
	3.2 Types of covalent bonds, Lewis structure, and nomenclature	2
4	4. Strength of covalent bonds	
	4.1 Bond length, bond energy and relative bond strength	2
5	5. Molecular geometry and polarity	
	5.1 VSEPR model and molecular shape	2
	5.2 Electronegativity and bond types	2
	5.3 Polarity of molecule	2
6	6. Intermolecular forces	
	6.1 Intermolecular forces in common molecules	2
	6.2 Properties of covalent network structure	1
7	7. Metallic bonding	
	7.1 Metals and properties of metals	2
	Total	23

1.2.2 Gathering evidences of learning

In the initial stage of the planning process, the expected results or intended learning outcomes requiring evidence of learning to be observed through the learning, teaching and assessment processes were identified. The concepts flow representing the expected processes of scientific concepts was outlined and constructed from TABLE 4. For designing the learning units, the learning objectives were identified and concepts flow was presented in TABLE 6.

TABLE 6 THE OUTLINE OF LEARNING OBJECTIVES AND CONCEPT FLOW

Topic	Concepts flow	Objectives
1. Why do atoms bond	1. Substances in every state are composed of a number of particles including atoms, molecules or ions which interact with each other. 2. The force that holds atoms together is called a chemical bond. Chemical bond may form by two atoms sharing electron with each other or the electrostatic attraction between positive ions and negative ions.	1. Define chemical bonding and explain how chemical bonding occurs.
2. Ionic Bonding 2.1 Nature of ionic compounds	3. Ionic bond is a very strong bond and a lot of energy is needed to break ionic compounds having high melting points and boiling points. 4. Ionic compounds tend to dissolve in water. In the process of dissolving (also called dissolution), water molecules extract ions from the lattice. As a result, ions are solvated with water molecules. 5. Ionic compounds are brittle. This property is due to the powerful attractive forces that hold the ions in specific positions throughout the crystal. Moving the ions out of the position, ions of like charges are brought next to each other and the repulsions crack the sample suddenly. 6. Ions are charged particles, but ionic compounds can only conduct electricity if their ions are free to move. So ionic compounds do not conduct electricity when they are solid, but they do conduct electricity when they are dissolved in water or when they are melted.	2. Explain how ionic bonding in compounds determines their properties: high melting point, high boiling point, brittle, and high electrical conductivity in aqueous solution. 3. Describe what happens when ionic compounds dissolve in water.

TABLE 6 (continued)

Topic	Concepts flow	Objectives
2.2 Formation of ionic bond and lattice structure	7. A positive ion forms when an atom lose one or more valence electrons. An atom that has a great attraction for electrons may form a negative ion by gaining electrons. 8. Ionic bonds result from electrostatic attraction between oppositely charged ions. These ions are formed by the complete transfer of electrons from one atom to another, typically to achieve a noble-gas configuration. 9. The oppositely charge ions are arranged in a regular repeating pattern to form giant ionic lattices.	4. Describe how ions are formed and which arrangements are stable. 5. Predict ionic charges for representative elements based on valence electrons. 6. Describe ionic bond as electrostatic attraction. 7. Describe the structure of ionic compound. 8. Determine that a bond is predominately ionic by the location of the atoms on the periodic table or when ΔEN > 1.7.
2.3 Reaction of ionic compound	10. When two difference solutions are mixed, a new product of ionic compound may or may not be generate, even though particles of the substances collide with each other. If the product is formed a precipitate will occur.	9. Predict what happen when two solutions mixed together.
2.4 Nomenclature of ionic compounds	11. The simplest ratio of the ions represented in an ionic compound is called a formula unit. The net charge of the formula unit is electrically neutral. Positive ions and negative ions exist together in a ratio determined by the number of electrons transferred from the metal to the nonmetal. 12. Ionic compounds are named by start with naming positive ion and negative ion.	10. Discuss the rules used in formulated and naming ionic compounds. 11. Identify the names from their formulas.

TABLE 6 (continued)

Topic	Concepts flow	Objectives
2.5 Lattice energy	13. When chemical reaction proceeded, energy is either absorbed or released. The reaction which energy absorbed is called endothermic reaction whereas energy released is called exothermic reaction. 14. Lattice Energy is a result of the electrostatic attractions among ions. Its magnitude depends on several factors, including ionic charge, ionic size, and arrangement of particles in the solid.	12. Describe the process of forming an ionic bond. 13. Discuss the energy involved in the formation of ionic lattice. 14. Relate the lattice energy and the formation of ions.
3. Covalent Bonding 3.1 Formation and nature of the covalent bond	15. Covalent bonding takes place when the atoms share electrons making each atom isoelectronic with noble gas configuration. 16. A hydrogen molecule is formed when two hydrogen share electron to each other. Each atom attracts one pair of shared electrons. Thus, two electrons shared by two hydrogen nuclei belong to each atom equally.	15. Apply the concept that sharing electrons form a covalent compound that is a stable (inert gas) arrangement. 16. Explain the formation of a covalent bond in a hydrogen molecule.
3.2 Single, multiple and coordinate covalent bonds	17. In forming a multiple covalent bond, atoms attain a noble-gas configuration (or octet rule) by sharing more than one pair of electrons between two atoms. 18. A coordinate covalent bond is a bond formed when both electrons of the bond are donated by only one atom.	17. Describe how the diatomic elements have single, double, or triple bonds (For example: F_2, O_2, N_2).
3.3 Structural formulas and Lewis structure	19. In the Lewis structure, valence electrons are presented as dots. The covalent bond is represented by bonding pair of electrons. An electron pair that is not involved in bonding is called a lone pair or nonbonding pair electron.	18. Draw Lewis dot structures for simple compounds with one central atom.

TABLE 6 (continued)

Topic	Concepts flow	Objectives
3.3 (continued)	20. A resonance structure is one of two or more Lewis structures for a single molecule that cannot be represented accurately by only one Lewis structure.	19. Explain why resonances occur, and identify resonance structures.
3.4 Octet rule and its exceptions	21. The number of valence electrons of an element is associated with the number of shared electron pairs needed to complete the octet and this number gives a clue as to how many covalent bonds can form. 22. There are two cases of exceptions to the octet rule considered: molecules in which the central atom has valence electron less than an octet and more than an octet.	20. Apply the octet rules to atoms that bond covalently. 21. Explain exceptions of the octet rule, and identify molecules in which these exceptions occur.
3.5 Nomenclature	23. Binary molecular compounds are named by using prefixes to indicate the number of atoms of each atom that are present in the formula. The second element is named using the root of the element and adding the suffix *–ide.*	22. Identify the names of binary molecular compounds from their formulas.
4. Strength of covalent bonds 4.1 Bond length, bond energy and relative bond strength	24. Covalent bond strength is determined by the energy required to break the bond. 24. Bond length is the average distance between two covalently bonded atoms. Bond energy is the quantity of energy required to break one mole of chemical bonds in a gaseous species. The strength of a chemical bond can be predicted by comparing the quantity of bond energies.	23. Apply the relationship between bond energy and bond length of single, double, and triple bonds.
5. Molecular geometry and polarity 5.1 VSEPR model and molecular shape	26. Valence shell electron pair repulsion model can be used to predict the three-dimensional shape of a molecule. Electron pairs repel each other and determine both the shape of and bond angels in a molecule.	24. Predict the shape of and the bond angles in a simple molecule.

TABLE 6 (continued)

Topic	Concepts flow	Objectives
5.1 (continued)	27. The central atom's valence electrons and electron(s) from bonded atoms are combined as valence electrons around central atom. The combined valence electrons are grouped as bonding and nonbonding electrons mostly are unshared pair electron or lone pair electron. The repulsions among electron groups lead to molecular geometry. 28. Electron groups repel each other as far as possible. Thus, the best geometry is the one that minimizes all electron repulsions in the molecule.	25. Apply Valence Shell Electron Pair Repulsion model for molecular geometries, and bond angles.
5.2 Electronegativity and bond type	29. Electronegativity (EN) is the relative ability of a bonded atom to attract the shared electrons. The EN difference between two bonded atoms is used to determine the type of bond that most likely occurs.	26. Describe how EN is used to determine bond type.
5.3 Polar covalent bonds	30. Polar bonds occur when electrons are not shared equally, resulting in an unequal distribution of charge and the formation of a dipole. 31. The three dimensional arrangement of polar bonds in molecule determines the overall polarity of molecule.	27. Describe bond polarity. 28. Compare and contrast polar and non-polar covalent bonds and polar and non-polar molecules.
5.4 Molecular shapes and Polarity	32. Polarity of molecules based on EN difference, VSEPR model, and bonds dipole moment.	29. Relate the polarity of molecules with the molecular shapes and the properties of a substance.

TABLE 6 (continued)

Topic	Concepts flow	Objectives
6. Intermolecular forces 6.1 Intermolecular forces in common molecules	33. Intermolecular forces are much weaker than covalent bonds. Three types of intermolecular attractive forces are: dipole-dipole forces, London dispersion forces and hydrogen bonding forces. These attractive forces determine properties of covalent compounds. 34. A hydrogen bond is the intermolecular attraction occurring when a hydrogen atom is bonded to a strong electronegative atom. 35. Dipole moment occurs in any polar covalent bond due to an unequal sharing of the electron pair between two atoms.	30. Describe intermolecular forces for molecular compounds. 31. Use drawings to represent each type of intermolecular attraction and give an example.
6.2 Properties of covalent network structure	36. Molecular solids consist of molecules held together by intermolecular forces (dipole-dipole forces, London dispersion forces, and hydrogen bonds). 37. Covalent network solids consist of atoms held together in large networks or chains by covalent bonds. These solids are much harder and have higher melting points than common covalent molecules.	32. Describe Molecular solids and network solids: water (ice), graphite and diamond.
7. Metallic bonding 7.1 Metals and properties of metals	38. The electron sea model proposes that all the metal atoms in the metallic solid contribute their valence electron to form the sea of electrons. 39. A metallic bond is the attraction between a metallic cation with its delocalized electrons. 40. The physical properties of metals can be explained by metallic bond. Metals have moderately high melting points and high boiling point. Metals are malleable, can be hammered into a thin sheet. Metals are ductile, can be drawn into wire. The movement of mobile electrons around positive metallic cations makes metals being good conductors.	33. Describe metallic bonds: metal ions and sea of electrons 34. Explain how metallic bonding determines the characteristics of metals: high melting point, high boiling point, high conductivity, malleability, ductility, and luster.

1.2.3 Designing the learning units

The developed learning units were included in the teacher guidebook and the student guidebook to provide necessary information on concepts and provide information regarding learning resources and instructional materials necessary for student investigations. Procedures for developing these instructional materials were as following:

1.2.3.1 Selecting instructional strategies used in the learning units and designing instructional materials

To ensure the greatest opportunity of learning, carefully selected and arranged activities were constructed to give the desired learning outcomes for students. All necessary information was included and the lesson plan was properly organized to achieve the lesson objective. Consequently, strategies to reduce cognitive load included re-structuring multi-step tasks into separate independent steps, presenting pictures and diagrams integrated with text, relating learning materials to prior knowledge, and reducing the amount of material to be stored (e.g., shortening sentences to be written, or number of items to be remembered) were selected.

Dimensional analysis or task analysis (Pascual-Leone. 1978; Niaz. 1987; 1988; 1989) was utilized for developing the draft learning units. Task analysis is summarized as follows:

1) General figurative model (GFM) refers recalling the idealized objects or scientific general facts that inform the problem in question, inform in the sense that the problem is the particular case or concretization of the idealized objects or principles.

2) Specific figurative model (SFM) involves concretization or specification, that is, adaptation of the general figurative model so that it more closely reflects the concrete solution of the actual problem.

3) Operation usually represents application to the specific figurative model that is needed to obtain the results and is prescribed by the subject's general and specific operative models, according to the problem domain in question.

The task analysis was outlined to organize strategies to reduce working memory loading during the presentation of the sequence of activity for constructing the draft of the learning unit. The task analysis also was used for providing 'thought' steps that student have to deal with in the cognitive tasks. The task analysis of learning units provided the guideline to organize activities in the learning units shown in TABLE 7.

TABLE 7 TASK ANALYSIS OF LEARNING UNITS

Activity/ Content	Strategies	Student' thought steps				
		Prior knowledge	General figurative model (GFM)	Specific figurative model (SFM)	Operation	Thought steps
1.1 Present diagrams integrated with text about ability to conduct electricity of water, solid salt, salt solution, and sugar solution.	Reduce external load working memory: 1. Imagery : Presenting pictures integrated with text	1. Knowledge about conductivity of substance.	2. Explore ability to conduct electricity of ionic solids and sugar when these are dissolved in water		3. Predict the results and answer questions	3
1.2 Compare melting and boiling points can be used to investigate students' classifying types of bonding based on property.	Reduce external load working memory: 1. Highlighting physical properties of substance	1. Comparing physical properties such as melting point, boiling point, electrical conductivity	2. Explore physical properties of salt, sugar, hydrogen gas, and metal copper.	3. Conclude how bonding in compounds determines some of their characteristics : low melting point, low boiling point, poor electrical conductivity	4. Classify types of bonding based on their properties	4

TABLE 7 (continued)

Activity/ Content	Strategies	Student' thought steps				
		Prior knowledge	General figurative model (GFM)	Specific figurative model (SFM)	Operation	Thought steps
2.1 Present sequences of diagram integrated with text about process of formation of ions and ionic lattice	Reduce external load working memory: 1. Imagery: Presenting diagram integrated with text	1. Knowledge about chemical reaction	2. Explore sequences of diagram integrated with text about process of formation of ions and ionic lattice		3. Predict what happens when sodium metal and chlorine gas react to form salts	3
2.2 Present multi steps of lattice formation encourage student to link the macroscopic, symbolic and microscopic representations	Reduce external load working memory: 1. Highlighting steps of lattice formation in a more stepwise fashion and present only essential messages. 2. Using animation	1. Knowledge about endothermic and exothermic reaction	2. Explore steps of lattice formation by linking the macroscopic and symbolic representations	3. Link the macroscopic and microscopic levels that system released energy when electron transfer from metal to nonmetal to form ions.	4. Conclude that attraction occurs between ions and ionic lattice from steps of lattice formation	4

TABLE 7 (continued)

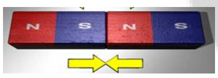
Activity/ Content	Strategies	Student' thought steps: Prior knowledge	Student' thought steps: General figurative model (GFM)	Student' thought steps: Specific figurative model (SFM)	Student' thought steps: Operation	Thought steps
3.1 Demonstrate the attraction and repulsion between the pole of magnet' analogy as following:    Ask student to give explanation.	Reduce external load working memory: 1. Encouraging students to focus on the essential message	1. The north pole of a magnet will be attracted to the south pole of another magnet	2. Observe the attraction and repulsion between the pole of magnets	3. Predict what happens	4. Conclude from observation and give the answer	4
3.2 Present diagrams of attraction and repulsion between electron and nucleus in hydrogen molecule. Ask student to compare the figure with magnet' analogy	Reduce external load working memory: 1. Using analogy	1. Knowledge about attraction and repulsion of magnet	2. Explore diagrams of attraction and repulsion between electron and nucleus in hydrogen molecule	3. Link the idea of how atoms bond to concepts of attraction and repulsion between electron and nucleus	4. Predict what happens and link new concepts to prior knowledge	4

TABLE 7 (continued)

Activity/ Content	Strategies	Student' thought steps				Thought steps
		Prior knowledge	General figurative model (GFM)	Specific figurative model(SFM)	Operation	
3.3 Present diagram of formation of hydrogen molecule (H_2) and ask student where position has the highest potential energy. To extend the concept of the formation and nature of the covalent bond further, a video animation about covalent bonding is introduced	1. Present diagrams 2. Using animations and video	1.Knowledge about potential energy	2. Explore diagrams of attraction and repulsion between electron and nucleus of two hydrogen atom	3. Link the concepts of the lowest potential energy of system to concepts of electrostatic attraction and repulsion between electron and nucleus	4. Conclude that systems tend toward configuration that has the lowest potential energy	4

TABLE 7 (continued)

Activity/ Content	Strategies	Student' thought steps				Thought steps
		Prior knowledge	General figurative model (GFM)	Specific figurative model(SFM)	Operation	
4.1 Allow student to visualize the relationship between bond length and bond energy for simple molecules and examine the geometries of ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), and benzene (C_6H_6).	Reduce external load working memory: 1. Motion pictures and dynamic models generated from computer programs are introduced carefully, to make representations of molecular symbols and collective behaviors of molecules	1. Knowledge about geometric shapes and Lewis structure	2. Observe and record the bond lengths of single, double and triple bonds appeared on computer screen	3. Visualize geometric shapes of ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), and benzene (C_6H_6).	4. Compare bond length and bond energy and generate relationship between them. 5. Make predictions of the bond strength of the saturated versus unsaturated hydrocarbons.	5

TABLE 7 (continued)

Activity/ Content	Strategies	Student' thought steps				Thought steps
		Prior knowledge	General figurative model (GFM)	Specific figurative model(SFM)	Operation	
5.1 To demonstrate the geometries for two to six electron pairs, and to find out how electron pair clouds surrounding the central atom are oriented with respect to one another. The position taken naturally by two to six balloons tied together at the center is shown.	Reduce external load working memory: Re-structuring material into multi-step tasks	1. Knowledge about geometric shapes	2. Balloons naturally arrange themselves so that they are as far from one another as possible	3. Visualize what shapes looks like to get conclusion.	4. Predict or indicate the shape of molecule	4

TABLE 7 (continued)

Activity/ Content	Strategies	Student' thought steps				
		Prior knowledge	General figurative model (GFM)	Specific figurative model(SFM)	Operation	Thought steps
5.2 Explore molecular structure and build models of some simple molecules such as CH_4, NH_3 and H_2O.	Reduce external load working memory by relating instructional materials to prior knowledge and experiencing concrete and dynamic models. Simple models of molecule were created by using balloons and styrofoam balls and dynamic molecular models were also explored	1. Geometric shapes according to balloon analogy	2. Visualize molecular models (CH_4, NH_3 and H_2O) on display screen	3. Link the idea of how atoms bond to construct knowledge and concepts	4. Predict and construct the molecules according to their shapes	4

The learning units were developed by using the outline of learning objectives and concept flow mentioned in TABLE 6 and task analysis as mentioned in TABLE 7 as a guideline. In developing the learning units, all instructional materials were designed to reduce students' working memory load by re-structuring multi-step tasks into separate independent steps, presenting pictures and diagrams integrated with text, relating learning materials to prior knowledge, and reducing the amount of material to be stored (e.g., shortening sentences to be written, or number of items to be remembered).

The instructional materials employed several features in seeking to make the material more accessible to those with lower working memory space. Thus, learning would be made easier if less is taught and less was demanded on working memory space. This inquiry was not done to students without direction but the materials were taught in a more stepwise fashion, with less wordiness, using small workbook as guides. The goal was to reduce the working memory demand by reducing the amount of materials which has to be processed by students. The goal was also to reduce the peripheral information that would act as noise for those who can insufficiently separate an item or the message from its context.

The learning units had the following features:

1) The working memory demand was reduced by presenting the material in a more stepwise fashion;

2) Dialogue boxes were used to encourage students to focus on the essential message;

3) Pictures, animations, analogies and diagrams were introduced carefully, always seeking to reduce information load to reduce 'noise' or extraneous load;

4) Molecular models were used so that students are able to use both verbal and imaginary coding and encourage them to link the symbolic and other representation aspects (microscopic and macroscopic) of the teaching material;

5) The order of presentation of the concepts (or detailed sequences and concepts flow) was changed in some cases. This was only done when it offered a reduction of working memory demand;

6) The goal was to reduce the need for note-taking, allowing more attention to be paid to the new material. By reducing note-taking, demand on working memory space was being reduced;

7) Great attention was taken to build on prior knowledge and provide opportunities for students to link new concepts to concepts already grasped from previous learning units.

1.2.3.2 Developing the student guidebook

From analyzing the learning standards in Thailand's Basic Education Curriculum B.E. 2551(2008), and then specific goals, objectives and contents focusing on chemical bonding and students' abilities necessary to do and understand scientific inquiry, the learning objectives of each learning units were established. The concept flow was constructed to represent the expected processes of learning the scientific concepts. This concept flow was also used to design the learning activities in student guidebook. After the concept flow had been determined, instructional strategies for designing each learning unit was selected. For developing the learning units, 7 main topics including why do atoms bond, ionic bonding, covalent bonding, strength of covalent bonds, molecular geometry and polarity, intermolecular forces, and metallic bonding. In constructing the learning units, a structure for presenting the sequences of learning activities were outlined. The contents and learning activities of the student guidebook were developed and derived from the learning objectives and concepts flow (see TABLE 6) and the task analysis (see TABLE 7). The student guidebook consisted of seven learning units including the contents, and science activities were organized and summarized as presents in TABLE 8.

TABLE 8 THE CONTENTS AND ACTIVITIES OF THE STUDENT GUIDEBOOK

Learning units	Sub-topics	Activities
1. Why do atoms bond?	1. Why do atoms bond	1. Justify types of bonding based on properties of matter
2. Ionic Bonding	2. Formation of an ionic bond and lattice structure 3. Reaction of ionic compounds 4. Nomenclature of ionic compounds	2. Formation of an ionic bond and lattice structure 3. Reaction of ionic compounds 4. Names and formulas
3. Covalent bonding	5. Formation and nature of the covalent bond 6. Types of covalent bonds, Lewis structure, and nomenclature	5. Formation and nature of the covalent bond 6. Types of covalent bonds, Lewis structure, and nomenclature
4. Strength of covalent bonds	7. Bond length, bond energy and relative bond strength	7. Bond length and relative bond strength in covalent molecules
5. Molecular geometry and polarity	8. VSEPR model and molecular shape 9. Electronegativity and bond types 10. Polarity of molecule	8. VSEPR model and molecular shape 9. Electronegativity and bond types 10. Comparisons of polarity of molecule
6. Intermolecular forces	11. Intermolecular forces in common molecules 12. Properties of covalent network structure	11. Intermolecular forces in common molecules 12. Properties of covalent network structure
7. Metallic bonding	13. Metals and properties of metals	13. Metals and properties of metals

1.2.3.2 Developing the teacher guidebook

Lesson plans in each learning unit appeared in teacher guidebook were written by applying organized activities according to the results mentioned above. The learning units originally consisted of 13 lesson plans covering the main 7 concepts of chemical bonding and structure. The entire learning units have 13 instructional plans lasting 23 periods. The summary of the learning units was describes in TABLE 9.

TABLE 9 THE DETAILS OF THE TEACHER GUIDEBOOK

Learning units	Sub-topics	Lesson Plans	Periods (50 minutes)
1. Why do atoms bond	1. Why do atoms bond	1	1
2. Ionic Bonding	2. Formation of an ionic bond and lattice structure	2	2
	3. Reaction of ionic compounds	3	2
	4. Nomenclature of ionic compounds	4	1
3. Covalent bonding	5. Formation and nature of the covalent bond	5	2
	6. Types of covalent bonds, Lewis structure, and nomenclature	6	2
4. Strength of covalent bonds	7. Bond length, bond energy and relative bond strength	7	2
5. Molecular geometry and polarity	8. VSEPR model and molecular shape	8	2
	9. Electronegativity and bond types	9	2
	10. Polarity of molecule	10	2
6. Intermolecular forces	11. Intermolecular forces in common molecules	11	2
	12. Properties of covalent network structure	12	1
7. Metallic bonding	13. Metals and properties of metals	13	2

1.2.3.2 Developing of research instruments and evaluation tools

The assessment tools were developed and verified for quality in order for gathering following learning outcomes: learning achievement, science process skills, and scientific attitudes. The details of construction the research instruments and evaluation forms for collecting data were described in the section of research instruments.

1.2.3.3 Evaluating the learning units by experts

The effectiveness of the learning units was assessed by 3 experts: a chemistry teacher, a curriculum developer, and a chemistry professor. The learning units were evaluated regarding the appropriateness and the congruence of the components of each learning unit.

The evaluation involved the appropriateness of the student and teacher guidebooks, lesson plans, and the curriculum materials. The IOC evaluation of the learning units involved the internal congruence of the learning unit elements such as the congruence (1) between the course description and the goals of the learning units, (2) between the goals and the content of the learning unit, and (3) between the content and the instructional strategies.

Processes of constructing the evaluation forms on the appropriateness and the congruence of the learning units were described further in the section of research instruments.

1.3 Conducting a pilot study

The learning units was tried out in the pilot study to check congruence of the learning units and lesson plans to see if they were well fit together. The purpose of this step was to gain information for improving the quality of the learning units in terms of time allocation and the appropriateness of the instructional sequence. The pilot study helped researcher and co-teacher to familiar with the teaching strategies and all materials before implementation stage was carried out. This stage helped to reveal the problems that may happen during implementing the final draft. Time allocation for doing the activities was adjusted and the results from pilot study were utilized for revising the learning units.

A pilot study was carried out during October to November, 2010 in the second semester of the 2010 academic year with 40 students of 10^{th} grade at Somdej Phra Yanna Sangworn school, Yasothorn province. One classroom of high school students was selected and chemistry teacher who participated in instructional procedures and considered instructional materials had experience in teaching chemistry for 19 years.

The role of participating teacher was introduced before the conducting pilot study. In this pilot study, preparing on the appropriate use of the learning units before the implementation was discussed with participating teacher for implementing the learning units as planned. Participating teacher was required to follow the sequence and following strategies, which were mentioned in each learning unit and acted as a facilitator to encourage students to be actively participating in the learning process. If there was a need, the participating teacher assisted students to meet learning objectives. While students were studying in their groups, participating teacher encouraged them to participate a group working, and guided them appropriately to prevent swerve from learning objectives by using guiding questions. Moreover, participating teacher provided: (1) Guidelines for using the learning units in classrooms and (2) Learning resources and instructional media including the molecular models (e.g. ball and stick plastic models, concrete models, styrofoam balls and balloons), video animation, slide presentations, equipment, chemicals or curriculum materials needed for students' investigation.

Individual student and groups were also required to follow the sequence of instruction, which were prepared them to guide the construction of knowledge and understanding. The students' roles in an appropriate direction were also introduced before the implementation. In this study, the student role was introduced as follows: (1) Students underwent training on the basic experienced skills of how to use student guidebook effectively and informed about chapter outline and guidelines for using the learning units, (2) Students were informed about how to do the investigation in learning activities and informed about macroscopic, molecular views of a process and the chemical equation to maximize understanding, (3) Students' groups were required to activate their prior knowledge related to chemical bonding concepts at the beginning of the instruction. The student would be to actively participate in the learning process. If there was a need, the student might be asked to generate some questions that associate with learning activities. While students were studying in their groups, student encouraged team members to participate a group working, and helped each other appropriately to reach the learning objectives by using their skills and experiences, and (4) The individual student acted as an active learner and sometimes as an audience or questioner to support effective learning during implementing the learning units.

Time allocation, instructional strategies and sequence, and assessment instruments were considered to revise according to pilot results.

1.4 Implementing the research study

The research study was implemented across 26 learning periods during December 2010 through February 2011 with 36 students of 10^{th} grade at Dhebsirin Pukae School, Saraburi province, Thailand. In this study, the researcher took a greater leading role in the teaching process during the implementation phase.

The role of researcher as teacher and role of individual student were introduced before the implementing. In this study, the roles of teacher acted by researcher were as follow:

1) Preparing the guideline for using the learning units.

2) Preparing the assessment tools in each classroom activity.

3) Providing learning resources and instructional media including the molecular models (e.g. ball and stick plastic models, concrete models, styrofoam balls and balloons), video animation, slide presentations, equipment, chemicals or curriculum materials needed for students' investigation.

4) Observing and collecting student' opinions related to the instruction.

5) Preparing on the appropriate use of the learning units before the implementation.

6) Considering misconceptions related to chemical bonding identified in the literature and the application procedures of learning activities.

7) Introducing the instructional sequence and strategies, which were provided by the learning units.

The role of classroom teacher in approaching the learning units was different from a traditional approach. In this study, the teacher acted as a facilitator and spectator to support effective learning. The teacher should encourage students to be actively participating in the learning process. During the time that teacher monitored the learning process, observed students in each group (or individuals) and assessed ongoing processing during the lesson by asking some questions such as “What are you doing?” “Why are you doing that?” “How will it help you understanding the subject?” “Why are you researching it?” If there was a need, the teacher would assist them to meet learning objectives. While students were studying in their groups, teacher encouraged them to participate a group working, and guided them appropriately to prevent swerve from learning objectives by using some guiding questions.

Individual student and groups were also required to follow the sequence of instruction, which were prepared them to guide the construction of knowledge and schema acquisition. The students’ roles in an appropriate manner were also discussed and introduced before the implementation. In this implementation, the role of the student was as outlined in the pilot phase. Here increased emphasis was given to the following aspects: (1) Training on the basic experienced skills of how to use student guidebook effectively and informed about chapter outline, guidelines for using the learning units, and informed about macroscopic, molecular views of a process and the chemical equation to maximize understanding, (2) Investigating the learning activities, (3) Actively participating in the learning process and encouraging team members to participate a group working, and using their skills and experiences to help each other appropriately for achieving the learning objectives, and (4) Being an active learner and a questioner to support effective inquiry learning during implementing the learning units.

1.5 Learning units’ evaluation

After the implementation finished, the effectiveness on students’ learning outcomes which include achievement, science process skills, and scientific attitudes were examined for testing all hypotheses purposed. The results of investigating the students’ learning outcomes were used to indicate the effectiveness of the learning units by comparing the class average normalized gain of students’ achievement score with the criterion at high gain level, comparing science process skills score between pretest and posttest, and comparing students’ scientific attitudes with the criterion at high level.

2. Instruments

2.1 The learning units

The chemical bonding learning units are a set of content, learning experiences and instructional materials that were constructed to reduce working memory overload and promote student's learning achievement, science process skills, and scientific attitudes. These learning units were approached by using the inquiry learning cycle and drawn on the Thai Basic Education Curriculum B.E. 2551. As mentioned in section of design, the learning units incorporated with information processing theory emphasized on instructional design strategies to reduce the working memory demand by reducing the amount of materials presented to students during a sequence of instruction. The learning units consisted of aims, expected learning outcomes, principles, course description, contents and concepts, instructional strategies, curriculum materials, instructional media, and assessments.

The curriculum materials which were developed in this study included teacher and student guidebooks. The curriculum materials included: (1) the curriculum alignment, (2) the guidelines for using the learning units in classrooms, and (3) the lesson plans, learning activities, worksheets, handouts, and assessments. The learning activities in the lesson plans were developed based on the integration of the inquiry learning cycle incorporated with information processing theory. The instructional media included: (1) the molecular models (e.g. concrete model, styrofoam ball with toothpick, balloon, ball and stick plastic model, and video animation), and (2) power point presentations and slides created by researcher.

2.2 Assessment instruments

The assessment instruments were developed for gathering the learning outcomes which were students' achievement score, science process skills and scientific attitudes. The details of constructing the assessment instrument for collecting each data were described as follows:

2.2.1 The achievement test on chemical bonding and structure

The achievement test was developed by the researcher based on examining textbooks, expected learning outcomes form the chemical bonding units and related concepts, and the literature related to students' alternative conceptions or misconceptions of chemical bonding concepts. The achievement test, called the Chemical Bonding and Structure Test (CBST) was a two tier multiple choice question. The first tier consisted of a content question having 2, 3, or 4 choices and the second tier contained 4 possible reasons which included the correct answer and three alternative reasons involving alternative conceptions. Each item was considered to be correctly answered if a student correctly responded to both parts of the item (Peterson; et al. 1989); (Tan; et al.1999); (Treagust. 1995). The CBST was adapted from literature and used to examine students' prior knowledge about chemistry concepts involved in chemical bonding and structure.

For assessing of the students' learning achievement, the students' cognitive domain was categorized by using of Bloom's taxonomy of educational objectives (Anderson; et al. 2001: 28). The test was given as pre- and post-test of the implementation stage. Content validity and reliability in the development of the test were determined. Constructions of the test items comprised a seven-step process as followings:

1) Reviewing previous relevant studies focused on the construction of the achievement test and the relevant documents.

2) The curriculum goals, learning outcomes, and content were identified by using the categories of the cognitive dimension of a revision of Bloom's taxonomy of educational objective (Anderson; et al. 2001:68-69).

3) After analyzing the learning objectives by creating a table of specifications, an achievement test on chemical bonding were written. The achievement test consisted of 58 multiple-choice questions covering 7 main concepts derived from textbooks and literature review which are: why do atoms bond (3 items), ionic bonding (16 items), covalent bonding (10 items), strength of covalent bonds (6 items), molecular geometry and polarity (10 items), intermolecular forces (10 items) and metallic bonding (3 items). The instrument was constructed by researcher and prepared in the Thai version.

4) Evaluating content validity by the three experts: chemistry teachers, chemistry professor and curriculum developer. The experts were evaluated the achievement test on the Index of Item Objective Congruence (IOC) between test items and learning outcomes in the IOC evaluation form. The IOC was higher than 0.60. After analyzing the

data obtained from the IOC evaluation form, the test was improved and revised according to the experts' suggestions on wording and correctness of the test.

5) The item difficulty (p), item discrimination (r) and reliability (KR-20) were determined by trying out with 58 students of 11th grade at Lukhamhan Warichamrab school during the second semester of the 2010 academic year.

6) Each test item was analyzed after trying out to determine the item difficulty (p), item discrimination (r) and reliability (KR-20) of the test.

7) The item which had the difficulty (p) level between 0.20 – 0.80 and the discrimination (r) between 0.20 – 1.00 were selected for use in the students' learning achievement test for learning units implementation stage.

2.2.2 The Science Process Skills Test (SPST)

The SPST was used to identify the student ability in the use of science process skills. This instrument was designed to measure 9 science process skills, which are observation, measurement, classification, organizing data and communication, inferring, prediction, formulating hypothesis, identifying and controlling variables, and interpreting data and conclusion. The instrument was included 33 multiple-choice test items and it was adapted from the Mason City Schools, Mason City, Iowa (Enger; & Yager. 2001). All skills demonstrated students' competency in each particular behaviors. The test items engaged students in well-known situations which required their appropriate process skill to answer each question. Index of Item Objective Congruence (IOC) of the test items was evaluated by the 3 experts is higher than 0.50.This test was administered to 56 students of 11th grade at Somdej Phra Yanna Sangworn school and 59 grade 11 students from Muangbua Wittaya school for determining the reliability (Cronbach's Alpha) and the appropriateness of time needed to complete the test.

2.2.3 The Scientific Attitudes Inventory II (SAI II)

The Scientific Attitude Inventory (SAI I) was designed by Richard W. Moore in 1969 to use for the measurement of biology and physical science students' attitudes toward science at the high school level. It has been used extensively throughout the world, and it continues to use and a revision was made. A revised version of the Scientific Attitude

Inventory II (SAI II) used a five-response Likert scale with 40 items (Moore; & Foy. 1997) to measure attitude corresponding on 6 subscales of SAI II shown in TABLE 10.

TABLE 10 POSITIVE AND NEGATIVE ATTITUDE CORRESPONDING ON 6 SUBSCALES OF SCIENTIFIC ATTITUDES INVENTORY II

Six subscales	Corresponding	
	Positive	Negative
1. The nature of the laws and/ or theories of science	Changeable truths	Unchangeable truths
2. The basic of scientific explanation	Observation	Authority
3. Characteristics needed to operate in scientific manner	Group thinking	Independent of thought
4. The type of activity engendered in science	Idea generating	Technology developing
5. Progress in science	Dependent on public understanding	No need for public understanding
6. Science as a career	Interesting and rewarding	Dull and uninteresting

Students' scientific attitudes were evaluated using 40 statement items on Likert-scale. Data from trying out the SAI II with a classroom of 59 students of 11^{th} grade at Muangbua Wittaya School was used to find out the appropriateness of time that students need to complete the test and the reliability of the test.

2.3. The evaluation forms of learning units

The evaluation forms were developed by the researcher for evaluating the appropriateness and the consistency of the draft by employing the following 4 steps:

2.3.1 Studying the documents related to constructing the evaluation forms of learning units.

2.3.2 Determining the statements for evaluating the components of the draft of learning units.

2.3.3 Writing the evaluation form which was consisted of 6 parts as follows.

1) The experts' personal information section.

2) Evaluation of the appropriateness for the student guidebook.

3) Evaluation of the appropriateness for the lesson plans and teacher guidebook.

4) Evaluation of the appropriateness for the overall learning units.

A five-point rating scale questionnaire was utilized for ranging of the appropriateness level in each evaluation form. The five-point rating scale questionnaire was ranged the level of the appropriateness as follows:

The appropriateness level	Scale value (points)
Very high level	5
High level	4
Moderate level	3
Low level	2
Very low level	1

5. Evaluation of the consistency for the draft of learning units' components.

A five-point rating scale questionnaire was utilized for ranging of the consistency level in each evaluation form. The three-point rating scale questionnaire was ranged the level of the appropriateness as follows:

The consistency level	Scale value (points)
Consistent	+1
Unsure	0
Inconsistent	-1

6. A blank space area provided for the experts to add opinions, comments and suggestions for improving the draft of learning units.

2.3.4 Checking the content validity and wording of the evaluation form by three experts. Each evaluation form was revised regarding the comments and suggestions from the experts.

3. Data collection

The implemented was done across 26 learning periods during December 2010 through February 2011 with 36 students of 10^{th} grade at Dhebsirin Pukae school, Saraburi province, Thailand.

Quantitative data including students' learning outcomes were obtained from various kinds of research instruments at different times as shown in TABLE 11.

TABLE 11 RESEARCH INSTRUMENTS AND DATA COLLECTION PERIODS

Research Instruments	Implementation	
	Before	After
1. The Chemical Bonding and Structure Test (CBST)	√	√
2. The Science Process Skills Test (SPST)	√	√
3. The Scientific Attitude Inventory: a revision (SAI II)	-	√

In this implementation, participating students took the pre-test of learning achievement and science process skills test before instruction. Students' responses to curriculum materials that student had encountered during their studies, this entailed a thorough examination of student guidebook, topic test, and student responds on worksheets were gathered during the course of instruction. The participating teacher participated in instructional procedures, considered instructional materials, and gave comments in each learning units. Finally, the participating students took the post-test of learning achievement, science process skills test, and scientific attitudes after completion of all learning units.

This study incorporated both qualitative and quantitative data. The quantitative research examined the differences between pre and post-test of the achievement score and science process skills of 10^{th} grade students, whereas the content analysis has been conducted to obtained the of qualitative findings investigated in this study. The qualitative data gathering from student' reflective journal, follow-up test question and response in worksheet were used for supporting the interpretation of the quantitative findings.

4. Data analysis

4.1 Analysis of quantitative data

In this section, the effectiveness of the learning units was determined by examining learning outcomes: achievement test, science process skills test, and scientific attitudes. The quantitative data analyzed by statistical methods and the summary of qualitative data were used to support the discussion of the results from learning outcomes that represent the effectiveness of the learning units.

After the implementation, achievement score, science process skills, and scientific attitudes were analyzed for evaluating the effectiveness of the learning units. The statistics used in this research study were as follows:

4.1.1 Basic statistics

The basic statistics such as mean, standard deviation, frequency, and percentage were used to analyze the score on students' learning outcomes including achievement score, science process skills, and scientific attitudes.

4.1.2 Statistics for assessing the learning units

The developed learning materials in this research study were analyzed as follows:

4.1.2.1 The Index of Item Objective Congruence (IOC)

The IOC was used to evaluate the draft learning units, achievement test, and science process skills test. Each response from the questionnaire of three level rating scales was weighed by the experts as follows:

The consistency level	Scale value (points)
Consistent	+ 1
Unsure	0
Inconsistent	- 1

The data of IOC evaluation form were analyzed to find the IOC using the following formula:

$$IOC = \frac{\sum R}{N}$$

IOC	means	Index of Item Objective Congruence
$\sum$ R	means	summation of experts' opinion marks
N	means	number of experts

4.1.2.2 The appropriateness evaluation

In the evaluation form on appropriateness of the draft learning units, each statement was ranged score for level of appropriateness as following:

The appropriateness level	Scale value (points)
Very high level	5
High level	4
Moderate level	3
Low level	2
Very low level	1

The data from the draft evaluation form were analyzed by calculating the mean scores and assigned weightings as follows:

Mean scores	Appropriateness level
4.50-5.00	Very high
3.50-4.49	High
2.50-3.49	Moderate
1.50-2.49	Low
1.00-1.49	Very low

4.1.2.3 The item difficulty (p)

Analyzing the test items difficulty (p) of the achievement test was used the formula as follows:

$$P = \frac{R}{N}$$

P means the item difficulty

R means the number of students who answered the item correctly

N means the total number of students who answered the item

4.1.2.4 The item discrimination (D)

Analyzing the test items of discrimination (D) of the achievement test was calculated by using the formula as follows:

$$D = \frac{R_U - R_L}{N}$$

D means the item discrimination

R_U means the total number of students in the upper group

R_L means the total number of students in the lower group

N means the total number of student in the upper group and the lower group

4.1.2.5 The reliability of the research instruments

In this study, reliability of the achievement test and the science process skills was examined by using Kuder-Richardson Formula 20 (KR-20) and reliability of the scientific attitudes for Likert scales was examined by using Cronbach's alpha coefficient.

4.1.2.6 The normalized gain

Normalized gain was calculated by using the score on a pre-test administered before instruction and a post-test administered after instruction. The statistic has been used in many published works since Hake's research study (1998). Hake defined normalized gain as the average actual gain (posttest - pretest) for a course and define average normalized gain for a course as:

<g> = (posttest - pretest) / (total score - pretest)

Normalized gain measured the improvement of the posttest score relative to the pretest score compared with the maximum amount of improvement that could have achieved. In this study, the normalized gain was determined from following formulas:

<g> = (%posttest - % pretest) / (100% - % pretest)

Notice: Students' scores were interpreted as following criteria:

1. If <g> ≥ 0.70, the result was interpreted as high gain level.

2. If 0.30 ≤ <g> ≤ 0.69, the result was interpreted as medium gain level.

3. If <g> ≤ 0.29, the result was interpreted as low gain level.

In this study, students' achievement scores were interpreted based on setting criteria as mentioned earlier. The criterion-reference measurement considers how students' test scores would be interpreted. Thus, students' performances were compared with the specific criterion they were expected to achieve. More specifically, students' achievement scores were compared with the normalized gain at high gain level.

4.1.3 Statistics for testing research hypotheses

The statistics for answering research hypotheses in this study were analyzed as follows:

4.1.3.1 Testing the first hypotheses

One sample t-test at the 0.05 level of significance was used to compare class average normalized gain of learning achievement with the criterion (<g> ≥ 0.70).

Paired samples t-test at the 0.05 level of significance was used to compare mean of pre-test and post-test scores to find out whether significant difference in learning achievement score exists.

4.1.3.2 Testing the second hypotheses

Paired samples t-test at the 0.05 level of significance was used to compare mean of pre-test and post-test scores to find out whether significant difference in science process skills exists.

4.1.3.3 Testing the third hypotheses

One sample t-test at the 0.05 level of significance was used to compare mean of post-test scores of the students' scientific attitudes with the criterion score at high level of attitude (3.51).

4.2. Analysis of qualitative data

The content analysis of qualitative data has been conducted according to the themes established during the research implementation. According to this, the qualitative findings on the number of student responses obtained from student' reflective journal were calculated and the proportion for given response is reported as percentage.

Qualitative data from analysis of the curriculum materials and the follow-up test questions during implementation were analyzed by allocating student responses into categories: sound understanding (SU), partial understanding (PU), partial understanding with alternative conception (PUAC), specific alternative conception (SA), and no explanation (NE). The use of such classification criteria for student responses provides the researchers with an opportunity to compare students' understanding. These criteria also provided an opportunity to classify students' responses and make interpretations about their level of understanding.

CHAPTER 4
FINDINGS

This chapter presents the findings of a study that has evaluated the effectiveness of the learning units on chemical bonding incorporated with information processing theory for high school students. The goals of this study were to assist students to enhance their achievement score, science process skills, and scientific attitudes. The findings reported in this chapter are presented in 4 sections:

1. The findings of the preparatory stage
2. The implementation of the learning units
3. Other findings from the study
4. A summary of the research results

1. The findings of the preparatory stage

In this preparatory stage, chemical bonding learning units incorporated with information processing theory were designed to minimize learning situations with concerning students' working memory demand. The chemical bonding learning units are a set of content, learning experiences and instructional materials including student and teacher guidebooks. For developing the learning units, 7 main topics were drawn from the standard science 3.1, sub-strand 3: matters and properties of matters. These seven learning units consisted of (1) why do atoms bond; (2) ionic bonding; (3) covalent bonding; (4) strength of covalent bonds; (5) molecular geometry and polarity; (6) intermolecular forces; and (7) metallic bonding. After the task analysis was outlined to organize strategies to reduce working memory loading for use in the sequence of activity for constructing the learning units, these units were developed. Then, three experts evaluated the learning units on appropriateness and congruence. This section presents the results of determining the appropriateness and congruence of the learning units, evaluating assessment instrument for collecting data, and conducting pilot study respectively.

1.1 Determining the appropriateness and validity of the learning units

The chemical bonding learning units were evaluated on appropriateness, and congruence by 3 experts: chemistry teacher, curriculum developer, and chemistry professor. The learning units were evaluated regarding the appropriateness and the congruence of the components of learning units. The evaluation for appropriateness covered the student and teacher guidebooks. The evaluation of the learning units involved the congruence of the learning unit components such as (1) the course description and the goals of the learning units, (2) the goals and the content of the learning units, and (3) the content and the learning activities.

The results of evaluation on appropriateness of the student and teacher guidebooks according to the experts' opinion are presented in TABLE 12 and TABLE 13 respectively.

TABLE 12 EVALUATION ON THE APPROPRIATENESS OF THE STUDENT GUIDEBOOK

List of evaluation		Mean, standard deviation, and level of appropriateness of learning units						
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
1. The sequences of activities were appropriate for preparation on the learning process and stated clearly	$\bar{X}$	4.33	4.33	4.33	4.00	4.33	4.33	4.33
	S.D.	0.47	0.47	0.47	0.82	0.47	0.47	0.47
	level	high	high	high	high	high	high	high
2. The worksheets for each lesson were appropriate and suitable for sequence of learning activity	$\bar{X}$	4.00	4.00	4.00	4.33	4.00	4.33	4.00
	S.D.	0.00	0.00	0.00	0.00	0.82	0.47	0.82
	level	high	high	high	high	high	high	high
3. The concepts and contents of each lesson were appropriate for scientific explanation	$\bar{X}$	4.00	4.00	4.00	4.33	4.33	4.00	4.33
	S.D.	0.00	0.00	0.00	0.00	0.47	0.82	0.47
	level	high	high	high	high	high	high	high

TABLE 13 EVALUATION ON THE APPROPRIATENESS OF TEACHER GUIDEBOOK

List of evaluation		Mean, standard deviation, and level of appropriateness of learning units						
		Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
1. The goals of learning unit were appropriate for high school students	$\bar{X}$	4.33	4.33	4.33	4.00	4.33	4.33	4.33
	S.D.	0.47	0.47	0.47	0.82	0.47	0.47	0.47
	level	high	high	high	high	high	high	high
2. The instructional activity was appropriate for preparation students to achieve the goals of learning outcomes	$\bar{X}$	4.33	4.00	4.00	4.33	4.00	4.33	4.33
	S.D.	0.47	0.00	0.00	0.47	0.82	0.47	0.47
	level	high	high	high	high	high	high	high
3. The sequences of activities were appropriate for preparation on the teaching-learning process	$\bar{X}$	4.33	4.00	4.00	4.33	4.00	4.00	4.00
	S.D.	0.47	0.00	0.00	0.47	0.82	0.82	0.82
	level	high	high	high	high	high	high	high
4. Time allocation in the learning unit was appropriate for learning of students	$\bar{X}$	4.33	4.00	4.00	4.00	4.00	4.33	4.00
	S.D.	0.47	0.47	0.00	0.82	0.47	0.47	0.82
	level	high	high	high	high	high	high	high
5. The concepts and contents were appropriate for high school students	$\bar{X}$	4.33	3.67	4.00	4.33	4.33	4.00	4.00
	S.D.	0.47	0.47	0.00	0.47	0.82	0.82	0.82
	level	high	high	high	high	high	high	high
6. The contents of each learning unit covered the main ideas that high school students need to achieve	$\bar{X}$	4.33	4.00	4.00	4.00	4.00	4.00	4.00
	S.D.	0.47	0.00	0.00	0.82	0.82	0.82	0.82
	level	high	high	high	high	high	high	high
7. Curriculum materials, worksheet and assessment tools necessary for student investigations were appropriate for preparation students to achieve the goals of learning outcomes	$\bar{X}$	4.00	4.00	4.00	4.00	4.00	4.00	4.33
	S.D.	0.00	0.00	0.47	0.82	0.82	0.82	0.47
	level	high	high	high	high	high	high	high

As shown in TABLE 12 and TABLE 13, the results of the overall lists of evaluation on appropriateness of student and teacher guidebooks showed mean score ranges from 4.00 - 4.33 indicating that the learning units were highly appropriate in all areas of evaluation (score 3.51 - 4.50 = the high level of appropriate).

The results of evaluating the congruence of the components of the learning units are presented in TABLE 14.

TABLE 14 EVALUATION ON THE CONGRUENCE OF THE COMPONENTS OF THE LEARNING UNITS

The item consideration	Index of Objective Congruence (N=3)						
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
1. The goals of leaning units consistent with the indicators of national science curriculum standards	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2. The content of leaning units with the goals of the leaning units	1.00	1.00	1.00	1.00	1.00	1.00	1.00
3. The learning activity with the goals of each leaning unit and intended learning outcomes	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4. The learning activity with the inquiry learning cycle incorporated with information processing theory	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5. The instructional materials with the learning activity and assessment following the goals of each leaning unit	1.00	1.00	1.00	1.00	1.00	1.00	1.00

The results of this evaluation covering congruence across various aspects of the learning units were highly congruence in all items under consideration (IOC = 1.00). This means the components in the learning unit were highly congruence with each other (the IOC equal or higher than 0.60 = highly congruence).

Additionally, in this study, the developed learning units were improved quality, appropriateness, and congruence based on the comments and evaluations provided by the experts' opinion. As well as the learning units, other research instruments were made ready for use in the further steps in this research study. Details of these instruments are as following:

1.2 Evaluating the assessment instruments

The assessment instruments were developed for investigating learning outcomes, which were students' achievement score, science process skills and scientific attitudes. The assessment instruments were called Chemical Bonding and Structure Test (CBST), Science Process Skills Test (SPST), and Scientific Attitude Inventory II (SAI II). Details of evaluating these instruments were as following:

1.2.1 The Chemical Bonding and Structure Test (CBST)

The CBST originally consisted of 58 items of multiple-choice questions assessed following 7 main topics: why do atoms bond (3 items), ionic bonding (16 items), covalent bonding (10 items), strength of covalent bonds (6 items), molecular geometry and polarity (10 items), intermolecular forces (10 items) and metallic bonding (3 items). This test was evaluated the IOC of test items and learning outcomes by experts. The IOC was higher than 0.60. The item difficulty (p), item discrimination (r) and reliability were determined by trying out the 58 items of the CBST with 58 grade 11 students at Lukhamhan Warichamrab School during the second semester of the 2010 academic year.

After the CBST was tried out, it consisted of 34 test questions. TABLE 15 present numbers of test items after trying out the CBST instrument which consisted of 34 items. These of 31 items were considered acceptable without the need for further revision of the test items. These of three items (items 1, 19, and 27) were adjusted for preserving the structure of CBST diagnostic instrument. Items 1 and 27 were revised by increasing difficulty and item 19 was revised by decreasing difficulty. The difficulty indices ranged from 0.29 to 0.76 providing a wide range of difficulty in the items and discrimination indices ranged from 0.21 to 0.63. The reliability of the test analyzed by KR-20 was 0.757. Quality of each test item of the CBST was presented in Appendix B.

TABLE 15 THE RESULTS AFTER TRYING OUT THE ACHIEVEMENT TEST

Areas Evaluated	Objectives	Learning periods (50 minutes)	Numbers of items
1. Why do atoms bond	1	2	1
2. Ionic bonding	2-5	7	10
3. Covalent bonding	6-10	4	6
4. Strength of covalent bonds	11-13	2	3
5. Molecular geometry and polarity	14-15	6	7
6. Intermolecular forces	16-17	3	4
7. Metallic bonding	18	2	3
Total	18	26	34

1.2.2 The Science Process Skills Test (SPST)

The science process skills test included 33 test items, accompanied by a list of appropriate indicators to assess following science process skills: observation, measurement, classification, organizing data and communication, inferring, prediction, formulating hypothesis, identifying and controlling variables, and interpreting data and conclusion. The IOC of each test item evaluated by the 3 experts was ranged from 0.67 - 1.00. After trying out the test with 115 grade 11 students (56 students of 11^{th} grade at at Somdej Phra Yanna Sangworn school and 59 students of 11^{th} grade at Muangbua Wittaya school), the reliability of the SPST analyzed by Cronbach's Alpha was 0.778.

1.2.3 The Scientific Attitude Inventory II (SAI II)

Students' scientific attitudes were evaluated using 40 statement items on Likert scale of the Scientific Attitudes Inventory II (SAI II). After trying out the SAI II with 59 students of 11^{th} grade at Muangbua Wittaya school, the reliability of the SPST analyzed by Cronbach's Alpha was 0.605.

1.3 Conducting pilot study

The pilot study aims to check congruence of the learning units and lesson plans to see if all instructional materials including student guidebook, teacher guidebook, and assessment instruments necessary for student investigations were appropriate for preparing the students to achieve the goals of each learning unit. The pilot study also helped researcher and participating teacher to become familiar with the teaching strategies and identify any problems that may occur before carrying out the implementation by using the learning units. After each instruction, researcher and participating teacher discussed the outcome of classroom events in order to revise the lesson plans, student guidebook and teacher guidebook. The results of the pilot study were used to revise the learning units.

Results of the pilot study were used to improve the quality of the learning units in terms of time allocation and the appropriateness of instructional sequence for revising the learning units before conducting the implementation study. After the instruction, the learning achievement score of the students were collected as the learning outcomes of the instruction.

The learning achievement score of the students was assessed by the CBST consisting of 34 test items. The achievement pre-test and post-test scores were collected and analyzed. The results of comparison of the pre-test and post-test achievement mean score are showed in TABLE 16.

TABLE 16 THE COMPARISON OF THE ACHIEVEMENT MEAN SCORE OF THE STUDENTS BEFORE AND AFTER USING THE LEARNING UNITS

Score	N	$\bar{X}$	S.D.	Mean of Difference	t
Pretest	40	2.62	1.61	5.73	10.03*
Posttest	40	8.35	3.05		

$t_{(0.05;\ df\ 39)} = 2.0227$

The results showed that the students' achievement mean score after learning using the learning units was higher than that before at the 0.05 level of significance. Generally, this indicated that the students who learned through the learning units had a significant improvement in their learning achievement on chemical bonding concepts.

1.4 Revising the learning units

The results of the pilot study related to learning units revealed some problems of the instructional process. The revision to improve the learning units which done as followings:

1.4.1 Presenting macro-to-micro views on student's worksheet were integrated within the beginning of information to help students visualized the macro-to-micro representations. Some pictures and wording in the instructional material especially graphic pictures were changed and edit to Thai version. The language was simplified. Pictures were edited or enlarged and description adjusted to avoid this confusion that the students had.

1.4.2 The student exercises at the end of units were added so that students were able to review the main concepts they have learnt. The answer sheets with answers were added to the teacher's guide so that the teacher be able to examine student's answers and gives feedback to the students if necessary.

1.4.3 For student handout of unit 2: Formation of ionic bond and lattice structure, new color diagrams of molecular view integrated with text and descriptions were added to help student understand the relationship between diagrams and steps of lattice formation.

1.4.4 The precipitation reaction of silver chloride activity was revised in style for presentation. The discussion questions of some activities were shortened. Some of the replicated diagrams were eliminated but still retained target purpose of illustrating the microscopic views to help students visualize chemical phenomena. The procedures and time allocation of some activities were reduced into a short laboratory demonstration and data was provided for analysis and discussion instead of doing real experiment. As a result, the instructional sequences and procedures were reorganized for implementation stage to ensure that the students should follow all process of instruction in all sections of this learning unit.

1.4.5 The style for presenting some activities e.g. naming ionic compound was rewritten and some activities e.g. ionic bonding jigsaw activity were assigned to complete the learning activity at home and bring the results to discuss with other students in class to manage the time allocation. Questions were added to improve the learning activity.

1.4.6 For learning unit 3: Lewis dot structure activity, new section of drawing line structure was placed before the section of drawing Lewis dot structure to help student become familiar with various types of structural representations. Throughout this unit, the background color and the position of ball-and-stick models were modified to make molecular geometry vividly clear.

1.4.7 For learning unit 5, discussion questions of the lesson plan 9 (Electronegativity and bond types) were shortened. The first section of electronegativity and bond types was also eliminated but the concept of classifying the types of bond according to the differences in electronegativity of nearby atoms was retained. Consequently, the time allocation for the students was adjusted appropriately without any affect the overall structure of the learning units.

1.4.8 For learning unit 6: Intermolecular forces, the content of intermolecular forces was shortened and summarized only the key concepts including London dispersion, hydrogen bonding, and dipole-dipole interaction. The question section was modified and placed after each key concept.

Accordingly, entire lesson plans consisted of 13 lesson plans lasting 26 periods and covering the main seven concepts of chemical bonding and structure. Time needed by students to complete activities was adjusted for some lesson plans. The time adjustment according to the results of the pilot study is shown in TABLE17.

TABLE 17 THE SUMMARY OF REVISED LEARNING PERIODS IN THE LESSON PLANS IN TEACHER GUIDEBOOK AFTER PILOT STUDY

Learning unit	Lesson plan	Learning period (50 minutes)	
		Before revised	After revised
1. Why do atoms bond	1. Why do atoms bond	1	1
2. Ionic Bonding	2. Formation of an ionic bond and lattice structure	2	2
	3. Reaction of ionic compounds	2	3
	4. Nomenclature of ionic bonding	1	2
3. Covalent bonding	5. Formation and nature of the covalent bond	2	2
	6. Types of covalent bonds, Lewis structure, and nomenclature	2	2
4. Strength of covalent bonds	7. Bond length, bond energy and strength trends	2	3
5. Molecular geometry and polarity	8. VSEPR model and molecular shape	2	3
	9. Electronegativity and bond types	2	1
	10. Polarity of molecule	2	2
6. Intermolecular forces	11. Intermolecular forces in common molecules	2	2
	12. Properties of covalent network structure	1	1
7. Metallic bonding	13. Metal and properties of metals	2	2
Total		23	26

The information gathered from the pilot study was used to revise not only the appropriateness of time allocation for doing the activities but also the wording and sequence and procedure to avoid any ambiguity in the student guidebook. Before the implementation was launched, the learning units, instructional materials, teacher guidebook and student guidebook were revised and adjusted according to the information gathered from real problems that were found during the course of instruction in the pilot study.

2. The implementation of the learning units

The implemented was conducted across 26 learning periods during December 2010 through February 2011 with 43 students of 10th grade at Dhebsirin Pukae school, Saraburi province, Thailand. One classroom with a high school teacher who participated in instructional procedures and considered instructional materials was selected. The researcher took a greater leading role in the teaching process during the implementation phase and participant teacher considered instructional materials and commented on instructional activities. The implementation involved the finalized material of the learning units being used with a sample group of selected high school students. The student's learning outcomes including learning achievement, science process skills, and scientific attitudes were collected by using the following instruments: the Chemical Bonding and Structure Test (CBST), the Science Process Skills Test (SPST), and the Scientific Attitude Inventory II (SAI II). The results from analyzing the quantitative data were used to test the following research hypotheses:

2.1 Testing the first hypothesis

The first hypothesis stated that the class average normalized gain of students' achievement score of chemical bonding concepts shows the high gain level ($<g> \geq 0.7$).

The achievement score from administering the achievement pre-test and post-test was analyzed to determine students' class average normalized gain. Students' class average normalized gain in each topic of chemical bonding is presented in TABLE 18.

TABLE 18 STUDENTS' CLASS AVERAGE NORMALIZED GAIN FROM ADMINISTRATING THE ACHIEVEMENT PRETEST AND POSTTEST

Topics	Number of items	Pre-test		Post-test		<g>
		%Pretest	S.D.	%posttest	S.D.	
Why do atoms bond	1	0.00	0.00	75.00	12.20	0.75
Ionic bonding	10	9.25	16.54	59.50	13.17	0.55
Covalent bonding	6	6.67	9.70	57.92	9.28	0.55
Strength of covalent bonds	3	25.83	19.42	40.00	6.61	0.19
Molecular geometry and polarity	7	17.14	18.95	34.29	15.92	0.21
Intermolecular force	4	16.25	29.26	50.00	13.39	0.40
Metallic bonding	3	1.67	2.89	40.00	12.50	0.39
Total	34	13.07	5.09	55.47	13.99	0.49

As show above, the topic of why do atoms bond showed the class average normalized gain at high level. The following topics: (1) ionic bonding, (2) covalent bonding, (3) intermolecular force, and (4) metallic bonding showed the class average normalized gain at medium level. The following topics: strength of covalent bonds, (2) molecular geometry and polarity showed the class average normalized gain at low level.

The comparison of the normalized gain after using the learning units with criterion referenced score was statistically performed using one sample t-test at 0.05 level of significance. According to post-test score of main study group, the criterion-referenced score was established at high gain level (0.70). The t-test for one sample statistics was used in order to test whether the normalized gain was higher than the criterion score. The results of analysis are presented in TABLE 19.

TABLE 19 THE COMPARISON OF NORMALIZED GAIN OF THE STUDENTS IN THE IMPLEMENTATION WITH THE CRITERION SCORE AT HIGH GAIN LEVEL

Statistic test	N	Criterion score	$\bar{X}$	S.D.	t
Posttest	36	0.70	0.49	0.16	7.86

$t_{(0.05;\ df=39)} = 2.0227$

The result of the class average normalized gain after using the learning units was not achieved at the established criterion at the high gain level.

When the criterion-referenced score was established at medium gain level (range from 0.60 to 0.30), t-test for one sample statistics was used in order to indicate which normalized gain score that the students were achieved. The results are presented in TABLE 20.

TABLE 20 THE COMPARISON OF NORMALIZED GAIN OF THE STUDENTS WITH THE CRITERION SCORE AT MEDIUM GAIN LEVEL

Statistic test	N	Criterion score	$\bar{X}$	S.D.	t
Posttest	36	0.60	0.49	0.16	4.19
Posttest	36	0.50	0.49	0.16	0.52
Posttest	36	0.40	0.49	0.16	3.15^{*}
Posttest	36	0.30	0.49	0.16	6.81^{*}

$t_{(0.05;\ df=39)} = 2.0227$

The result indicated that the students' normalized gain was higher than the criterion score at medium gain level ($\langle g \rangle > 0.4$).

TABLE 21 presents the comparison of the students' achievement scores before and after using the learning units.

TABLE 21 THE COMPARISON OF THE STUDENTS ACHIEVEMENT PRETEST AND POSTTEST SCORES OF 7 MAIN TOPICS OF CHEMICAL BONDING

Topic	Achievement score	N	$\bar{X}$	S.D	Mean of difference	t
Why do atoms bond	Pre-test	36	0.00	0.00	0.83	13.23*
	Post-test	36	0.83	0.38		
Ionic bonding	Pre-test	36	1.03	0.74	5.58	17.47*
	Post-test	36	6.61	1.84		
Covalent bonding	Pre-test	36	0.44	0.65	3.42	12.87*
	Post-test	36	3.86	1.40		
Strength of covalent bonds	Pre-test	36	0.86	0.64	0.47	3.23*
	Post-test	36	1.33	0.72		
Molecular geometry and polarity	Pre-test	36	1.33	1.07	1.33	4.51*
	Post-test	36	2.67	1.49		
Intermolecular force	Pre-test	36	0.72	0.57	1.50	7.94*
	Post-test	36	2.22	0.96		
Metallic bonding	Pre-test	36	0.06	0.23	1.28	8.69*
	Post-test	36	1.33	0.86		
Total	Pre-test	36	4.44	1.73	14.42	16.99*
	Post-test	36	18.86	4.76		

$t_{(0.05;\ df\ 39)} = 2.0227$

As shown above, the results showed that the students' achievement mean score in all concepts after learning using the learning units was higher than before at the 0.05 level. This indicated that students who learned through the learning units had a significant improvement on the conceptual understanding of chemical bonding. These results provided evidence to show that the learning units were effective in enhancing students’ conceptual understanding of bonding concepts.

TABLE 22 presents the results of students' percent correct response to the CBST items after implementing the learning units.

TABLE 22 STUDENTS' PERCENT CORRECT RESPONSES TO THE ACHIEVEMENT POST-TEST

Topics	Number of items	First tier		Both tiers	
		%Correct	S.D.	%Correct	S.D.
Why do atoms bond	1	85.00	13.82	75.00	12.20
Ionic bonding	10	79.00	5.30	59.50	13.17
Covalent bonding	6	74.17	7.07	57.92	9.28
Strength of covalent bonds	3	66.67	1.77	40.00	6.61
Molecular geometry and polarity	7	67.50	19.45	34.29	15.92
Intermolecular force	4	80.00	10.61	50.00	13.39
Metallic bonding	3	80.83	1.77	40.00	12.50
Total	34	75.15	9.57	49.93	16.22

The data in TABLE 22 showed that 75.15% of the students responded correctly to all items at the tier 1 level, whereas only 49.93% responded correctly at both tiers. While considering the correct response data in both tiers on TABLE 22, it was found that the topics, for which the mean values equal 50% or higher, were why do atom bond, ionic bonding, covalent bonding, and intermolecular force. The topics, for which the mean values less than 50%, were molecular geometry and polarity, the strength of covalent bonds, and metallic bonding. The scores of the top three topics suggested that students had relatively better understanding of these concepts than in the others. Whereas molecular geometry and polarity with the lowest percentage suggested that students were lacking in their understanding in this section. According to the results, student's selection of an incorrect content choice and /or incorrect reason choice indicated their existence of alternative conceptions of chemical bonding and structure.

In summary, findings from analyses of quantitative data provide evidence to show that the learning unit would be effective in enhancing students' conceptual understanding of bonding concepts. The learning units had a significant improvement on students' achievement score and the results of paired samples t-test indicated that the students' achievement mean score after learning using the learning units was higher than before at the 0.05 level. Even though the class average normalized gain did not achieve at the high gain level, the class average normalized gain of students' achievement was higher than the criterion score at medium gain level (<g> > 0.4).

2.2 Testing the second hypothesis

The comparison of the students' science process skills before and after using the learning units was examined to test the second hypotheses, which show in TABLE 23. The second hypotheses stated that students' science process skills score after the implementation of the learning units is higher than before implementation of learning units with a statistically significant difference at 0.05 level.

TABLE 23 THE COMPARISON OF THE NINE SCIENCE PROCESS SKILLS SCORE BEFORE AND AFTER USING THE LEARNING UNITS

Science process skills	Score	N	$\bar{X}$	S.D	Mean of Difference	t
1. Observation	Pre-test	36	1.08	0.60	0.03	0.57
	Post-test	36	1.06	0.63		
2. Measurement	Pre-test	36	2.14	0.68	0.22	1.49
	Post-test	36	2.36	0.76		
3. Classification	Pre-test	36	2.22	0.72	0.06	0.40
	Post-test	36	2.28	0.70		
4.Organizing data and communication	Pre-test	36	2.14	0.83	0.50	3.55*
	Post-test	36	2.64	0.93		

TABLE 23 (continued)

Science process skills	Score	N	$\bar{X}$	S.D	Mean of Difference	t
5. Inferring	Pre-test	36	2.53	0.65	0.53	3.26*
	Post-test	36	3.06	0.79		
6. Prediction	Pre-test	36	2.56	0.77	0.39	2.58*
	Post-test	36	2.94	0.79		
7. Formulating hypothesis	Pre-test	36	2.28	0.82	0.61	3.41*
	Post-test	36	2.89	0.92		
8. Identifying and controlling variables	Pre-test	36	1.50	0.74	0.14	0.93
	Post-test	36	1.64	0.76		
9. Interpreting data and conclusion	Pre-test	36	2.14	0.68	0.25	1.55
	Post-test	36	2.39	0.87		
Total	Pre-test	36	18.58	3.05	1.61	3.30*
	Post-test	36	20.19	3.11		

$t_{(0.05;\ df\ 35)} = 2.0301$

As shown in TABLE 23, the post-test mean scores for the following 8 skills: measurement, classification, organizing data and communication, inferring, prediction, formulating hypothesis, identifying and controlling variables, and interpreting data and conclusion are higher than the pre-test mean score. Surprisingly, the posttest mean scores of observation skills is the only one that was lower than pretest. Beside that there were science process skills which were: organizing data and communication, inferring, prediction, and formulating hypotheses, the posttest mean scores were higher than the pretest mean scores at the 0.05 level. This means that the students who learned through the learning units had a significant improvement on most of science process skills.

In summary, the findings from the analyses of quantitative data provide, in general, evidence to show that the learning units were effective in enhancing the science process skills of students. The use of the learning units produced a significant improvement in students' science process skills and the results of paired samples t-test indicated that students' science process skills mean score after using the learning units was higher than before at the 0.05 level of significance. This means that the learning units helped the students to improve their science process skills.

2.3 Testing the third hypothesis

The third hypothesis stated that students' scientific attitudes after using the learning units are higher than criterion score at high level with a statistically significant difference at .05 level. In this study, students' scientific attitudes were evaluated using the Scientific Attitude Inventory II (SAI II) with 40 statement items on Likert-scale. These 6 subscales of the SAI II posttest are: (1) The nature of the laws and/ or theories of science, (2) The basic of scientific explanation, (3) Characteristics needed to operate in scientific manner, (4) The type of activity engendered in science,(6) Progress in science, and (6) Science as a career. The comparison of these 6 subscales after using the learning units with criterion score (3.51) was statistically performed using one sample t-test at 0.05 level of significance presented in TABLE 24.

TABLE 24 THE COMPARISON OF THE STUDENTS' SCIENTIFIC ATTITUDES AFTER USING THE LEARNING UNITS WITH CRITERION SCORE

Statistic test	N	Criterion score	$\bar{X}$	S.D.	t
Subscale 1	36	3.51	3.55	0.68	0.37
Subscale 2	36	3.51	3.18	0.38	5.23
Subscale 3	36	3.51	3.45	0.58	0.64
Subscale 4	36	3.51	3.26	0.44	3.47
Subscale 5	36	3.51	3.76	0.89	1.68
Subscale 6	36	3.51	3.33	0.48	2.30
Entire scale	36	3.51	3.42	0.43	1.26

$t_{(0.05;\ df\ 35)} = 2.0301$

The results of the scientific attitudes scales indicated that the average point value for entire SAI II subscales was found to be neutral to mildly agree ($\overline{X}$=3.42). The average point value for entire SAI II subscales was not significantly higher than the criterion score (3.51) at the 0.05 level. This means that the students who learned through the learning units did not show improvement in their scientific attitudes at a high level.

3. Other findings from the study

The content analysis of qualitative data has been conducted according to the themes established during the implementation of the learning units. Five minute after using each learning unit, a reflective journal was used for collecting data about students' impression and other concerns and suggestions. According to content analysis, the frequency of student responses obtained from students' reflective journal were counted and the proportion for a given response is reported as percentage. The opinions of the students after using the learning units are summarized in TABLE 25.

TABLE 25 OPINIONS OF STUDENTS TOWARD THE LEARNING UNITS IMPLEMENTATION

Students' opinion	Frequency	Percentage
1. Impression about learning activity provided by the learning units		
- Doing hands-on activities	20	50.0
- Preferring visualized models and instructional media	20	50.0
- Preferring activities in student guidebook	5	12.5
<u>Reason</u>		
- Doing activities by themselves	14	35.0
- Fun and interesting	7	17.5
- Easy to understand	15	37.5
- Applying knowledge	2	5.0
- Relaxing and enjoy	5	12.5
- Gaining better understanding	8	20.0

TABLE 25 (continued)

Students' opinion	Frequency	Percentage
2. Which section in particular did you find easy to learn?		
- Ionic bonding	22	55.0
- Covalent bonding	18	45.0
- Molecular shape and polarity of molecule	8	20.0
- Intermolecular force	2	5.0
- Strength of covalent bond	4	10.0
- Metallic bond	7	17.5
<u>Reason</u>		
- I learn best with variety of visualized models	2	5.0
- Doing various activities	9	22.5
- Enjoy	2	5.0
3. Which section in particular did you find difficult to learn?		
- Nature of covalent bond		
1) Resonance structure	9	22.5
2) Octet rule and oxidation number	8	10
3) Lewis dot structure	9	22.5
- Molecular shape and polarity of molecule		
1) Molecular structure	4	10.0
2) Predicting bond angle	5	12.5
3) Predicting polar and non-polar molecule	2	5
- Formation of ionic bond and lattice structure	6	15.0
- Reaction of ionic compound in water	4	10.0
- Name and formulas	2	5.0
- Strength of covalent bond (Bond energy)	2	5.0
- Intermolecular forces	2	5.0

TABLE 25 (continued)

Students' opinion	Frequency	Percentage
4. Suggestion for improving instruction		
- Having more time	6	17.5
- Adding more animations, cartoons and pictures	5	12.5
- Adding more laboratory experiments	4	10.0
- Teaching a bit more slowly	2	5.0
- Being a strict teacher	2	5.0
- Adding more quiz questions at the end of each learning unit	2	5.0

These are some examples of student opinion toward implementation of the learning units. The results obtained from student' reflective journal after using the learning units revealed that:

1. The students found that learning activities were very interesting and these helped them to understand chemical bonding concepts. Some students have stated their opinion like this: "I like the balloons analogy for molecular shape activity because molecular structure was made from colorful balloons which make this activity interesting.", "Rearrangement of molecular structure activity is a very fun activity for me. I have seen molecular shape arrangement from balloon analogy. I have learned various types of molecular geometry and how arrangement of balloons works"

2. The students were impressed with the learning activity. They were very exciting about various kinds of visualized models, graphic diagrams and Styrofoam molecules. Some students have stated their opinion like this: "I have learnt how to determine the formula of ionic compounds from Ionic Bonding Jigsaw Activity.", "Using balloons and Styrofoam models as the instructional materials make me easily understand.", "I prefer the prediction of molecular shape activity using balloons and Styrofoam models."

3. Students found that chemical bonding concepts were more accessible and easier to understand than using the textbook. Some students have stated their opinion like this: "This activity (Molecular shape activity) helped me understand more about

molecules.", "I like activities that the teacher uses in the classroom. These activities help me understand better."

4. Even though most of the students enjoy the programmed learning activities, suggestions for improving instruction toward implementation of the learning units were stated like this: "I like activities that the teacher uses in the classroom. These activities help me understand better.", "I would like to have more time.", "Teacher should add more animations and cartoons.", "I would like to have competition activities.", "More activities and laboratory experiments should be added."

Qualitative data from analysis of the follow-up test questions during implementation were analyzed by allocating student responses into categories. The test questions were used to examine knowledge of chemical bonding. The results of students' responses toward the follow-up test questions are summarized below.

1. The learning unit helped the student gain a better understanding of ionic bonding. Students' responses indicated that all students selected correct choices and 78.5% of students provided the correct explanation which 31% classifying as sound understanding and 47.5% classifying as partial understanding. Most of these students (62.5%) believed that strong ionic bonding formed through the electrostatic attraction of oppositely charge ions, resulting in a crystal lattice with high boiling and melting points. However, there may be the specific alternative conception that sodium chloride exists as a crystal consisting of covalently bonded sodium and chlorine atoms (22.5%).

2. Forty five percent of students mentioned in the reflective journal that covalent bonding concepts including resonance structure and Lewis dot structure were difficult for them.

3. Students' responses toward the question testing the concept of intermolecular force were as follows: (1) 30% of students' responses provided correct reason with complete explanation whereas the higher percentage (53.5%) showed understanding of the concept, but made a statement, which demonstrated alternative conception category, (2) the lower percentage (10%) demonstrated sound understanding category whereas the higher percentage (45%) provided incorrect explanations and generated some specific alternative conceptions.

4. A summary of the research findings

In this study, the chemical bonding learning units incorporated with information processing theory were developed and implemented in classrooms of high school students. Students' learning outcomes were collected using assessment instruments for testing the research hypotheses. Findings are summarized as following:

4.1 The findings of the preparatory stage

4.1.1 The results of the overall lists of evaluation on appropriateness of student and teacher guidebooks showed mean score ranges between 4.00 and 4.33 indicating that the learning units were highly appropriate in all areas of evaluation. The results of IOC evaluation covering congruence across various aspects of the learning units were congruence in all items under consideration (IOC = 1.00).

4.1.2 After learning using the learning units, students' achievement score of pilot study group was higher than that before at the 0.05 level of significance. The findings from the analyses of quantitative data from administrating the achievement test showed that the learning unit would be effective in enhancing the achievement of chemical bonding concepts.

4.2 The implementation of the learning units

4.2.1 The students' class average normalized gain achieved at medium gain level ($\langle g \rangle = 0.49$).

4.2.2 The students' achievement mean score after learning using the learning units was higher than before at the 0.05 level. This revealed that students who learned through the learning units had a significant improvement on the conceptual understanding of chemical bonding in all concepts.

4.2.3 The students' science process skills mean score after using the learning units was higher than before at the 0.05 level of significance. The findings from the analyses of quantitative data provide, in general, evidence to show that the learning units are effective to enhance students' science process skills.

4.2.4 The results of the scientific attitudes scales after using the learning units indicated the average point value for entire SAI II subscales was not significantly higher than the criterion score at the 0.05 level.

CHAPTER 5

CONCLUSIONS, DISCUSSIONS AND RECOMMENDATIONS

In this chapter, the main purpose, research hypotheses, the methodology and results are concluded with the findings of this research study presented within the context of the aims of the study as outlined as follows.

1. Purposes of the study

The purposes of this study were outlined as follows:

1. To develop the learning units on chemical bonding incorporated with information processing theory for high school students.

2. To examine the effectiveness of the learning units by assessing students' learning achievement score, science process skills, and scientific attitudes.

2. Research hypotheses

The hypotheses of this study were as follows:

1. The class average normalized gain of students' achievement score in chemical bonding concepts shows the high gain level ($<g> \geq 0.7$).

2. Students' science process skills score after the implementation of the learning units is higher than before implementation of learning units with a statistically significant difference at 0.05 level.

3. Students' scientific attitudes after using the learning units are higher than criterion score at high level with a statistically significant difference at .05 level.

3. Participants

3.1 Participants during pilot study

A pilot study was carried out across 23 learning periods during October to November, 2010 with 40 students of 10^{th} grade at Somdej Phra Yanna Sangworn school, Yasothorn province. One classroom was selected from three classrooms and a high school teacher who participated in instructional procedures and considered instructional materials had 19 years' experience in teaching chemistry subject.

3.2 Participants during Implementation

The implemented was carried out across 26 learning periods during December 2010 through February 2011 with 36 grade 10 students at Dhebsirin Pukae school, Saraburi province, Thailand. One classroom with a high school teacher who considered curriculum materials and commented on instructional procedures.

4. Research instruments

This section presents the overviews of the research instruments including the learning units, the Chemical Bonding and Structure Test (CBST), the Science Process Skills Test (SPST), and the Scientific Attitude Inventory II (SAI II). Details of these research instruments were as following:

4.1 The learning units

The learning units were developed using the inquiry learning cycle incorporated with information processing theory to minimize difficulties in learning situations where working memory capacity of the students were problematic. The learning units consisted of aims, expected learning outcomes, principles, course description contents and concepts, lesson plans, instructional strategies, and assessment.

The curriculum materials aligned with the developed learning units based on sub-strand 3: matter and properties and standard science 3.1. The selected contents were based on national science curriculum standards. The chemical bonding learning units were designed for implementing across seven main topics which were (1) why do atoms bond; (2) ionic bonding; (3) covalent bonding; (4) strength of covalent bonds; (5) molecular geometry and polarity; (6) intermolecular forces; and (7) metallic bonding.

4.2 Assessment instruments for data collection

The research instruments for collecting data were briefly described as followings:

4.2.1 The Chemical Bonding and Structure Test (CBST)

The CBST diagnostic instrument consisted of 34 two-tier multiple choice questions covering seven main concepts including why do atoms bond (1 item), ionic bonding (10 items), covalent bonding (6 items), strength of covalent bonds (3 items), molecular geometry and polarity (7 items), intermolecular forces (4 items) and metallic bonding (3 items). The difficulty indices ranged from 0.29 to 0.76 providing a wide range of difficulty in the items. Discrimination indices ranged from 0.21 to 0.63. The reliability of the CBST analyzed by KR-20 was 0.757.

4.2.2 The Science Process Skills Test (SPST)

The SPST included 33 multiple-choice test items for assessing 9 science process skills: observation, measurement, classification, organizing data and communication, inferring, prediction, formulating hypothesis, identifying and controlling variables, and interpreting data and conclusion. The reliability of the SPST analyzed by Cronbach's Alpha was 0.778.

4.2.3 The Scientific Attitudes Inventory II (SAI II)

Students' scientific attitudes were evaluated using 40 statement items on Likert-scale. The reliability of the SPST analyzed by Cronbach's Alpha was 0.605.

5. Research methodology

Three stages of research procedures to develop the high school chemistry learning units on chemical bonding incorporated with information processing theory were described as follows:

5.1 Developing the learning units

The first phase began with the analysis of the learning standards in Thailand's Basic Education Curriculum B.E. 2551(2008), and then specific goals, objectives and contents focusing on chemical bonding and students' abilities necessary to do and understand scientific inquiry were analyzed and the learning objectives of each learning units were established. The concept flow was constructed to represent the expected processes of learning the scientific concepts. This concept flow was also used to design the learning activities and instructional plans. After the concept flow had been determined, instructional strategies for designing the learning units were selected. For developing the learning units, 7 main topics were drawn from the standard science 3.1. These topics consisted of (1) why do atoms bond; (2) ionic bonding; (3) covalent bonding; (4) strength of covalent bonds; (5) molecular geometry and polarity; (6) intermolecular forces; and (7) metallic bonding.

The learning units including teacher guidebook, student guidebook and instructional materials were developed and evaluated by the experts who are chemistry professor, high school teacher and curriculum developers in order to verify quality. The draft of the developed learning units was evaluated regarding the appropriateness and the consistency of the components of learning units.

5.2 Developing assessment tools

The research tools were developed for investigating learning outcomes which were students' conceptual understanding of chemical bonding concepts, students' achievement score, science process skills and scientific attitudes. The following sections describe the details of constructing the research tools for collecting each data.

5.2.1 Chemical Bonding and Structure Test (CBST)

The achievement test was developed to assess whether the students achieve the expected goals of the learning units. The CBST consisted of 34 two-tier multiple choice questions covering seven main topics mentioned earlier. The achievement test was developed to assess whether the students achieve the expected goals of the learning units. The method used for gathering content related evidence of validity was based on the expert's justification. The item difficulty (p), item discrimination (r) and reliability were determined by trying out with 58 students of 11th grade at Lukhamhan Warichamrab school during the second semester of the 2010 academic year.

5.2.2 Science Process Skills Test (SPST)

The Science Process Skills Test (SPST) was designed to measure nine science process skills, which are observation, measurement, classification, organizing data and communication, inferring, prediction, formulating hypothesis, identifying and controlling variables, and interpreting data and conclusion. The instrument was comprised of 33 multiple-choice test items and it was adapted from the Mason City schools, Mason City, Iowa (Enger; & Yager. 2001). The IOC of each test item was evaluated by the three experts and found to be higher than 0.60. This test was administered to 56 students of 11th grade at Somdej Phra Yanna Sangworn school and 59 grade 11 students from Muangbua Wittaya school to determine reliability of the test and the appropriateness of time needed to complete the test.

5.2.3 The Scientific Attitude Inventory II

Students' scientific attitudes were evaluated using 40 statement items on Likert-scale. Data from trialing the SAI II with a classroom of 59 students of 11^{th} grade at Muangbua Wittaya school was used to determine the appropriate allocation of time that students need to complete the test and the reliability of the test was also determined (0.605).

5.3 The pilot study

The learning units were tried out in the pilot study to check congruence of the learning units and lesson plans to see if they were well fitted. The purpose of this step was to gain information for improving the quality of the learning units in terms of time allocation and the appropriateness of the instructional sequence. The pilot study helped researcher to become familiar with the teaching strategies and all materials before implementation stage was carried out. This stage helped to highlight any problems that may otherwise occur during implementing the final program. Time allocation for doing the activities was adjusted and the results from pilot study were utilized in revising the learning units.

5.4 Implementation

5.4.1 Conducting the implementation

The implementation was undertaken 26 learning periods during December 2010 through February 2011 in the second semester of the 2010 academic year with 36 students of 10^{th} grade at Dhebsirin Pukae school, Saraburi province, Thailand. One classroom with a high school teacher who participated in instructional procedures and considered curriculum materials was selected. The researcher took a greater leading role in the teaching process during the implementation phase. The implementation involved the finalized material of the learning units being used with a sample group of selected high school students. The research instruments included learning units, achievement test, science process skills test, and Scientific Attitude Inventory II. The student's learning outcomes including learning achievement, science process skills, and scientific attitudes were collected for testing the research hypotheses. The student's learning outcomes were analyzed to evaluate the effectiveness of the learning units.

5.4.2 Testing the research hypotheses

The statistics for answering the first research hypotheses in this study were analyzed as follows:

5.4.2.1 Normalized gain: In investigating the difference in the normalized gain, the effect of implementing the learning units on student learning achievement regarding the seven main concept of chemical bonding was examined to answer the first research hypothesis.

5.4.2.2 t-test for paired sample: The t-test of significance was performed using the results from learning achievement score and science process skills score before and after implementing the learning units. The students' achievement score and science process skills score were tested with t-test for paired sample comparing between pretest and posttest for each assessment tool. The t-test paired sample was performed to find out: (1) whether significant difference in achievement score exists between pretest and posttest; (2) whether significant difference in science process skills exists between pretest and posttest.

5.4.2.3 One sample t-test: One sample t-test statistic was used to compare the student's mean score and the criterion score whether or not there was a significant difference between them. This method examined whether the student's mean score was significantly higher than the criterion score. The mean scores from the students' scientific attitudes were compared with the established criterion score.

5.4.2.4 Descriptive statistics: The basic statistics such as mean, standard deviation, and percentage were used to analyze the score on students' learning outcomes including achievement score, science process skills, and scientific attitudes.

5.4.3 Analyzing of qualitative data

The content analysis of qualitative data has been conducted according to the themes established during the implementation of the learning units. A reflective journal was used for collecting data about students' opinion and other concerns and suggestions after using the learning units. According to this, the frequency of student responses obtained from student' reflective journal were counted and the proportion for a given response is reported as percentage. Qualitative data from analysis of the follow-up test questions during implementation were analyzed by allocating student responses into one of the following categories: sound understanding (SU), partial understanding (PU), partial understanding with alternative conception (PUAC), specific alternative conceptions (SA), and no explanation (NE). The use of such classification criteria for student responses provided the researchers with an opportunity to compare students' understanding. These criteria also provided an opportunity to classify students' responses and make interpretations about their level of understanding. The follow-up test questions were also used to examine students' knowledge of chemical bonding.

6. Conclusion of research findings

The findings reported in this section are concluded in 4 sections: (1) the appropriateness and validity of the learning units, (2) the evaluation of the assessment instruments, (3) the results of pilot study, and (4) the results of the implementation of the learning units.

6.1 The appropriateness and validity of the learning units

The developed chemical bonding learning units including teacher guidebook and student guidebook were evaluated for quality on appropriateness and congruence by three experts. The evaluation for appropriateness covered the student guidebook, teacher guidebook, lesson plans, and overall curriculum materials including worksheets and exercises. The evaluation for congruence of the learning units involved the internal consistency of the learning unit elements such as (1) between the course description and the goals of the learning units, (2) between the goals and the content of the learning units, and (3) between the content and the learning activities. The results of the overall lists of evaluation on appropriateness of student and teacher guidebooks showed mean score ranges between 4.00 and 4.33 (within a possible range of 1.0-5.0) indicating that the learning units were highly appropriate in all areas of evaluation. The results of the IOC evaluation covering congruence across various aspects of the learning units were congruence in all items under consideration (IOC = 1.00). This means the components in the learning units were highly congruence.

6.2 The evaluation of the assessment instruments

The assessment instruments were as following:

6.2.1 Chemical Bonding and Structure Test

Fifty eight items of CBST diagnostic instrument were evaluated by three experts on the IOC between test items and learning outcomes. All items were selected to be tried out for determining the items difficulty (p), the items discrimination index (r) and reliability of the test. After trying out with 58 students of 11^{th} grade, the CBST consisted of 34 two-tier multiple choice questions covering 7 main concepts including why do atoms bond (1 item), ionic bonding (10 items), covalent bonding (6 items), strength of covalent bonds (3 items), molecular geometry and polarity (7 items), intermolecular forces (4 items) and metallic bonding (3 items). The difficulty indices ranged from 0.29 to 0.76 providing a wide range of difficulty in the items. Discrimination indices ranged from 0.21 to 0.63. The reliability of the CBST analyzed by KR-20 was 0.824.

6.2.2 Science Process Skills Test

The science process skills test included 33 multiple-choice test items, accompanied by a list of appropriate indicators for assessing 9 science process skills, which are observation, measurement, classification, organizing data and communication, inferring, prediction, formulating hypothesis, identifying and controlling variables, and interpreting data and conclusion. The IOC of the test items evaluated by the three experts was higher than the criterion (IOC ranged from 0.67 -1.00). Data from trying out the test with 56 students of 11^{th} grade at Somdej Prayarnasangworn school and 59 students of 11^{th} grade at Muangbua Wittaya school were used to determine the appropriate amount of time that they needed to complete the test. The reliability of the SPST analyzed by Cronbach's Alpha was 0.778.

6.2.3 Scientific Attitude Inventory II (SAI II)

A five-response Likert scale with 40 items of SAI II was used for measurement of scientific attitudes at the high school level. After trying out the SAI II with 59 students of 11^{th} grade at Muangbua Wittaya school, the reliability of the SPST analyzed by Cronbach's Alpha was 0.605.

6.3 Results of pilot study

The learning units were tried out with 40 students of 10^{th} grade at Somdej Phra Yanna Sangworn school during October to November, 2010. The learning units used as a part of chemistry, core science course, were conducted across 26 learning periods with a full scale of instruction in the classroom. Results of the pilot study were used to improve the quality of the learning units in terms of time allocation and the appropriateness of instructional sequence for revising the learning units before conducting the implementation study

The learning achievement score of the students was assessed by the CBST consisting of 34 test items. The achievement pre-test and post-test scores were collected as the learning outcomes of the instruction and were analyzed using paired samples t-test. The results showed that the students' achievement mean score after learning using the learning units was higher than that before at the 0.05 level of significance. This indicated that the students who learned through the learning units had a significant improvement in their conceptual understanding of chemical bonding.

6.4 Results of the implementation of the learning units

The main study for this stage was conducted across 26 learning periods during December 2010 through February 2011 with 43 students of 10^{th} grade at Dhebsirin Pukae school, Saraburi province, Thailand. The revised learning units were implemented across 26 learning periods. The implementation involved the finalized material of the learning units being used with a sample group of selected high school students. The student's learning outcomes including learning achievement, science process skills, and scientific attitudes were collected to test the research hypotheses. The results from analyzing the quantitative data were used to test the research hypotheses:

6.4.1 The results of testing the first hypotheses

6.4.1.1 Testing the first hypotheses

The first hypotheses stated that the class average normalized gain of students' achievement score of chemical bonding concepts shows the high gain level ($\langle g \rangle \geq 0.7$). The achievement score from administering the CBST was analyzed to determine students' class average normalized gain. The results of students' achievement on chemical bonding indicated that the class average normalized gain shows the medium gain level (<g> = 0.49). Thus, the class average normalized gain did not achieve at the established criterion at high gain level.

6.4.1.2 The comparison of the students' achievement scores before and after using the learning units

The achievement score from administering the CBST revealed that the students' achievement mean score after learning using the learning units was higher than before at the 0.05 level. The results indicated that the learning units were effective to enhance students' conceptual understanding of chemical bonding concepts.

6.4.2 The results of testing the second hypotheses

The second hypotheses stated that students' science process skills score after the implementation of the learning units is higher than before implementation of learning units with a statistically significant difference at 0.05 level.

The comparison of the students' science process skills before and after using the learning units was examined to test the second hypothesis. The results indicated that the students' science process skills mean score after learning using the learning units was higher than before at the 0.05 level. The results of post-test mean scores for the following science process skills: measurement, classification, organizing data and communication, prediction, formulating hypothesis, identifying and controlling variables, and interpreting data and conclusion are higher than they were for the pre-test but the results of posttest mean scores of observation is the only one that was lower than pretest.

6.4.3 The results of testing the third hypotheses

The third hypotheses stated that students' scientific attitudes after using the learning units are higher than criterion score at high level with a statistically significant difference at .05 level.

The results of the scientific attitudes scales indicated that the average point value for entire SAI II subscales was found to be neutral to mildly agree ($\overline{X}$=3.42). The average point value for entire SAI II subscales was not significantly higher than the criterion score (3.51) at the 0.05 level. This means that the students who learned through the learning units did not show improvement in their scientific attitudes to achieve at a high level.

6.4.4 Other findings from the study

The content analysis of qualitative data has been conducted according to the themes established during the implementation of the learning units. The findings obtained are summarized as follows.

6.4.4.1 The students' opinion in reflective journal

The content analysis of qualitative data has been conducted according to the themes established during the implementation of the learning units. At the end of the class of instruction, a reflective journal was used for collecting data about students' impression and other concerns and suggestions after using the learning units. The results obtained from student' reflective journal after using the learning units revealed that:

1. The students found that learning activities were very interesting and these helped them to understand chemical bonding concepts.

2. The students were impressed with the learning activity. They were very exciting about various kinds of visualized models, graphic diagrams and Styrofoam molecules.

3. Students found that chemical bonding concepts were more accessible and easier to understand than using the textbook.

4. Even though most of the students enjoy the programmed learning activities, suggestions for improving instruction toward implementation of the learning units were addressed.

6.4.2 The follow-up test questions

Qualitative data from analysis of the follow-up test questions during implementation were analyzed by allocating student responses into categories. The test questions were used to examine knowledge of chemical bonding. The results of students' responses toward the follow-up test questions are summarized as following:

1. The learning unit helped the student gain a better understanding of ionic bonding,

2. Students mentioned in the reflective journal that covalent bonding concepts including resonance structure and Lewis dot structure were difficult for them,

3. There were only 30% of students' responses toward the question testing the concept of intermolecular force provided correct reason with complete explanation whereas the higher percentage showed understanding of the concept, but made a statement, which demonstrated alternative conception category. The very lower percentage of students' responses demonstrated sound understanding category whereas the higher percentage provided incorrect explanations and generated some specific alternative conceptions.

7. Discussions

This study was concerned with the research and development of high school chemical bonding learning units incorporated with information processing theory. The goals of this study were to assist students to enhance their achievement score, science process skills, and scientific attitudes. In this section, discussion on the effectiveness of the learning units is outlined in as followings:

7.1 General discussion

In regard to the inquiry approach, students were allowed to focus on the learning process of group working. Findings show that the learning units incorporated with information processing theory were effective in enhancing students' conceptual understanding of chemical bonding concepts, which is consistent with the findings of Verilette (2000: 236) who found that middle-grade students participated in the intervention program which instructed through learning cycle in 5 weeks gained significantly higher post-test scores than pre-test scores. Effective curricular components included appropriate content, as designated by national standards and state-mandated instructional objectives for Georgia, and the inquiry teaching procedure were incorporated in the intervention program. Students' science achievement was higher following participation in the science intervention program. Haury (1993) found that students who participated in the inquiry approach gained higher cognitive learning outcomes. According to inquiry approach, students had an opportunity to learn knowledge, apply, and link their new knowledge to gain better understanding from involvement in this learning. This was consistent with Akar (2005) who reported that high school chemistry students in an inquiry cycle course experienced gains in subject matter and knowledge that were significantly higher than those in a course where traditional approaches were used. Teaching using the learning cycle approach provides experiences for students to recognize the inadequacy of their current ideas, to explore new ways of explaining the world, to reflect on their thinking, and to construct new conceptions from prior knowledge.

In this research implementation, it was emphasized that the students and teacher should understand their roles in inquiry activities. Increased appreciation of their roles enhanced student learning. Students frequently pay attention to the learning activities provided by the learning units and exchange their ideas with others during participating in a group. These actions are particularly common during hands-on activities in science classroom. The participating teacher' opinions were given comments on instructional activities and instructional materials after completing the implementation indicated that classroom management of inquiry cycle activities can help students to activate their prior knowledge and interest in learning activities.

7.2 Results of course materials using in classroom

To assist concrete-operational students who experienced difficulty in visualizing or conceptualizing atoms, molecules and molecular models, the researcher emphasized that macroscopic properties were covered before an attempt was made to study microscopic properties. In the introductory week, for instance, microscopic and macroscopic aspects in chemistry such as molecular models, styrofoam model, and interactive media were visualized and addressed in some aspects and the microscopic properties that students should have encountered in grade 10 were reviewed during the introductory week. It was founded that many of students had little or no prior experience of practical work in visualizing molecular models. It has been suggested that students were given more time during hands-on sessions.

In this study, course materials of unit 2 (ionic bonding jigsaw activity) dealt with writing of chemical formulas and a set of ion cards to use for writing of chemical formulas were used extensively in this section. Sequences of diagram integrated with text about process of formation of ions to form ionic compound were explored and external load on working memory were reduced by highlighting steps of lattice formation in multi-step approach and presenting only essential messages. Animation was used to encourage student to link the macroscopic, symbolic and microscopic representations of ionic bonding concepts. This approach was similar to Dechsri, Jones and Heikkinen (1997) using visual information processing assistance provided by pictures and diagrams integrated with text in chemistry laboratory manuals can reduce the information load passing through the working memories of the students and can help them gain more from their laboratory experiences.

In learning unit 3, students carried out hands-on experiments with molecular models and balloons to visualize molecular structure and create models of some simple molecules such as CH_4, NH_3 and H_2O. Students used styrofoam balls and toothpicks to create a model of each type of molecule. External load working memory was reduced by using balloon analogy and metaphor. Students used this hands-on activity to help them to visualize the relationship between bond angles and shapes of molecules by examining through geometries of CH_4, NH_3 and H_2O. Students used these geometries to observe the effect of lone pairs on bond angles and predict the molecular shapes of other similar compounds. Course material in learning unit 4 dealt with the strength of covalent bond including bond length, bond energy and relative bond strength. Students visualized the relationship between bond length and bond energy and examined the geometries of ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), and benzene (C_6H_6). These visual models were used very effectively in this section. In unit 5 students carried out hands-on experiment with balloons to observe the geometries of simple molecules. These sessions were either experimental in nature, with students doing their own experiments, or consisted of opportunities for the students to use molecular models. These course materials emphasized on hands-on activities because many researchers have shown that hands-on activities incorporating inquiry based science teaching to science instruction can improve science process skills (Staver; & Small.1990; Turpin; & Cage. 2004). Additionally laboratories have been recognized for their potential to facilitate the learning of science concepts and process skills (Hofstein; & Lunetta. 2004). The results of the qualitative findings in this research were consistent with these literature reported results. It can be confidently implied that students experienced these hands-on sessions as helpful to enhance learning.

7.3 Discussion about the learning achievement

After using the learning units indicated that the class average normalized gain was not achieved at the criterion score at the high gain level. According to this study, the achievement was assessed by using a two-tier multiple choice diagnostic test items. The first tier consists of a content question and the second tier contains a set of four possible reasons for the answer given to the first part. The effect of reasoning ability on students' learning achievement was reported by many researchers in chemistry and physics classes at the high school level (Kraijik; & Haney. 1987; Staver; & Halsted. 1985). Furthermore, studies of Niaz (1996) and Kwon and Lawson (2000: 57) revealed a relationship between scientific reasoning ability and ability to gain conceptual knowledge. Following researchers found the same relationship (Lawson; & Worsnop. 1992; Westbrook; & Marek. 1992). Thus, this factor resulted in process of scientific explanation.

The use of the learning units produced a significant improvement in students' achievement score and the findings indicated that the medium gain level was achieved. This was consistent with Hake (1980) who proposed that the medium normalized gains earned by interactive engagement courses are in the range 0.48 ± 0.14 with a statistically significant difference. Hake (1998) concluded that the teaching methods employed in the interactive engagement courses make a difference and he stated that there was no high average gain found in any course. The similar findings from the analyses of the normalized gain led this researcher to imply that improvement on students' understanding of chemical bonding concepts was due to implement the learning units incorporated with information processing theory.

From analyzing the students' achievement on chemical bonding, the topics, for which the post-test score less than 50%, were molecular geometry and polarity and the strength of covalent bonds. These results indicated that many students have not understood the concepts of (1) molecular geometry and polarity and (2) the strength of covalent bonds. The results were consistent with the findings from analysis of students' class average normalized gain in both topics which showed low gain level. The correct responses for molecular geometry and polarity with the lowest percentage of post-test mean score and low gain level suggested that students were lacking in their understanding in this topic.

The findings provide evidence to indicate that, despite the fact that chemical bonding was carefully introduced to high school students; it is possible that some of students have not developed the appropriate conceptual understanding of some particular topics i.e. strength of covalent bond, and molecular geometry and polarity and students frequently retain their existing views even following further instruction (Driver; & Oldham.1986).

It has been found that many students can answer correctly at first tier, but the number drops dramatically when both tiers are considered. It may be the result of rote learning of scientific information without making connections between the various pieces of information provided. In some case, with its limitation of time, breaking down the tasks into separate steps may not work well in some particular concepts such as molecular shape and polarity of molecule. Even though the material was presented in such a way that working memory demand is minimized, many students were not abled to link these separate steps to previous knowledge in a meaningful way. This leads many students to generate alternative conceptions and some of high school students used the correct information in one question and they missed out the use of the same information in another question, which appears to support compartmentalized learning.

7.4 Discussion about science process skills

The SPST was employed for assessing 9 science process skills. The findings from the analyses of quantitative data provided, in general, evidence to show that the learning units were effective in enhancing the science process skills of students. This means that student science process skills, as measured by the SPST, were enhanced through participation in the developed chemical bonding learning units.

According to the findings, the learning activities incorporated with information processing when used in instruction through inquiry learning cycle showed that students gained significantly higher post-test scores than pre-test scores on science process skills. This result is consistent with Turpin and Cage (2004) who found in their study that activity-based methods had effects on some science process skills. This study was consistent with the findings of Walter and Soyibo (2001) who discussed the change in the science programs that were mainly based on hands-on activities done in laboratories. Such programs were based on basic science process skills and integrated science process skills. Their study suggested that the middle grade students in the schools following the new program were more successful than those who were in the schools adopting traditional teaching methods. To explain this consistency, hands-on activities were major factors to enhance their science process skills. In addition, many studies have shown that hands-on activities incorporating inquiry based science teaching to science instruction will improve science process skills (Staver; & Small.1990; Turpin; & Cage. 2004). Further laboratories have long been recognized for their potential to facilitate the learning of science concepts and skills (Hofstein; & Lunetta. 2004; Bilgin (2006) also found that when hands-on learning activities were used together with cooperative learning approach, the 8^{th} grade students were more successful in science process skills than the control group students following the traditional methods.

When the questions assessing each skill of pre-test and post-test were investigated, the results indicated that the students were found not to be applying science process skills thoroughly. According to these findings, the skills in which the students were least successful were identifying and controlling the variables. The reason behind this can be explained as chemical bonding concepts are essentially theoretical based and there were limit numbers of experiment in the learning units. Therefore, students lacked opportunities to practice this skill to reach a satisfactory level. Butts et al. (1997) reported that students needed more practices to be done in laboratories to improve their science process skill. Surprisingly, the questions related to the skills on observation were slightly decreased. The reason for this can be explained by the fact that students needed more practice in laboratories to improve these skills to reach a satisfactory level.

7.5 Discussion about students' scientific attitudes

Regarding students' scientific attitudes, the results indicated that students did not show improvement to achieve at high level and the average point value was found to be moderate level ($\overline{X}$ =3.42). This finding suggests that students' attitudes can not be improved over a short implementation period. According to the findings, students conducted few activities and did not have enough time on developing more positive attitudes which required more time and a sustained effort. Similarly, Century (2002) investigated the impact of alternative and traditional assessment on students' attitudes and found no significant difference between alternative and traditional groups in their attitudes. Consistency may be related to the issue of separating assessment from teaching and learning procedures which prevent them from being actively engaged in classroom.

In qualitative aspect, however, the results of the content analysis of students' reflective journal demonstrated that on average, students had a positive view of scientific attitudes and that this may change to be more positive over the longer period of time. The results obtained from student' reflective journal, for example, after using the learning units revealed that: (1) Students found that learning activities were very interesting and these helped them to understand chemical bonding concepts, (2) Students were impressed with the learning activity and very exciting about various kinds of visualized models, graphic diagrams and styrofoam molecules, (3) Students found that chemical bonding concepts were more accessible and easier to understand than using the textbook, and (4) Most of the students enjoy the programmed learning activities.

This results on lack of attitude improvement is inconsistent with the findings of Gibson and Chase (2002), who conducted an inquiry-based science program, to stimulate greater interest in science, and scientific careers within middle school students. They found that students maintained a more positive attitude and a high interest in science careers. Moreover, this was inconsistent with Vianna, Sleet, and Johnstone (2009) who developed laboratory courses for improving the specific procedures to minimize the load on students' working memory and attitudes to the laboratory course. They concluded from research conducted over the three years period that the developed laboratory courses was effective both in reducing the load on students' working spaces and in improving their attitudes to the laboratory course. These inconsistencies may well be related to the time factor as already discussed.

While much has been accomplished toward developing a reliable and valid instrument to measure students' scientific attitudes (Moore; & Foy. 1997), it is important to consider that change may not be immediate but may take time (Marcelle; & Michael. 2003).

8. Recommendations

From the research findings, the learning units incorporated with information processing theory were able to enhance students' learning which included improving the student's achievement and science process skills. To utilize these findings, several recommendations are proposed.

8.1 Recommendations for school administrators

The findings from analyses of quantitative data provided evidence to show that chemical bonding learning units were effective in enhancing students' conceptual understanding of bonding concepts and science process skills. Therefore, the school administrators should encourage teachers to develop their own learning units to promote students' learning achievement and conceptual understanding continuously by using the 5Es model of inquiry incorporated with information processing theory to reduce students' working memory load.

School administrators should support teachers by organizing professional development programs to enhance pedagogy knowledge on approach for inquiry teaching based on re-designed curriculum materials to minimize limitations of students' working memory overload. This support will enable teachers to teach science more effectively.

8.2 Recommendations for chemistry teachers

The study provides useful information in developing the learning units on chemical bonding incorporated with information processing theory for minimizing learning situations where a high working memory is demanded. The following issues might be taken into further consideration when the learning units are implemented in classrooms.

8.2.1 To understand chemical bonding concepts, the students need to construct mental model or mental representation because these concepts cannot be seen. The teacher can use molecular models to provide concrete examples connecting what the students are familiar with to the unfamiliar concepts e.g. low cost styrofoam balls and balloons.

8.2.2 The design and delivery of school chemistry courses should take into account the predictions from information processing theory derived from different working memory models and that such changes will bring about improvement in students' performance. This may involve changing the order of presentation, method of presentation, and theoretical implications. It may involve the careful use of appropriate analogy and molecular models.

8.2.3 The choice of teaching presentation specifically to reduce working memory demand and to focus strongly on essentials in context of chemistry is likely to be helpful for improving student performanec in school. Further work needs to be carried out to explore whether the benefits of the approach adopted here bring specific benefits to those with lower working memory spaces.

8.2.4 Chemistry teachers should actively propose, develop, organise and participate in seminars and workshops on curriculum deveolpment and implementation based on chemistry topics incorporated with information processing theory.

8.4 Recommendations for further studies

8.4.1 The designing features of the chemistry course and intervention strategies incorporated with the other working memory models of working memory (i.e. unitary and workspace models) is recommended to be considered restructuring the chemistry curriculum and for testing. A comparative study on the effectiveness across these models is also interesting for further research study.

8.4.2 A two-tier test to study students' understanding of chemical bonding concepts is recommended to examine the students' achievement in-depth on students' understanding of the concept. The minimization of guessing might be achieved by asking students to report their confidence in their responses being correct at the two tiers.

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APPENDIX

Appendix A: The lists of participants in this study

A.1 The list of experts who evaluated the learning units

A.2 The list of experts who evaluated the achievement test and science process skills test

A.3 The list of teachers who participated in the research study

A.1 The list of experts who examined and verified the learning units

The quality of the draft learning units was assessed by the group of three experts. The learning units was evaluated regarding the appropriateness and the congruence of the components of learning units including the student and teacher guidebooks and assessment instuments. The lists of experts were presented in TABLE 26.

TABLE 26 THE LISTS OF EXPERTS FOR VERIFY AND EXAMINING THE DRAFT LEARNING UNITS

Name	Status	Qualifications
1. Asst.Prof. Dr. Duangporn Pupaka	Dean of Science and Technology Faculty at Rajabhat Rajanagarindra University	Ed. D.(Science Education)
2. Dr. Manas Boonprakob	Former lecturer at Behavioral Science Research Institute, Srinakharinwirot University	Ed.D. Curriculum and Instruction (Post-secondary Education)
3. Asst.Prof. Dr. Kanaporn Rasmimariya	Chemistry teacher at Srinakharinwirot Pratumwan Demonstration School	Ph.D (Curriculum and Instruction)

A.2 The list of experts who evaluated the achievement test and science process skills test

The quality of the assessment tools was assessed by three experts. The achievement test and science process skills test was revised according to experts' comments and suggestions. Content validity such as accuracy of the test, wording and correctness of the test and the Index of Item Objective Congruence (IOC) between test items and learning outcomes in the IOC evaluation form were also evaluated. The lists of experts were presented in TABLE 27.

TABLE 27 THE LISTS OF EXPERTS EVALUATING THE ASSESSMENT TOOLS

Name	Status	Qualifications
1. Asst. Prof. Numfon Kujareanpisal	Chemistry professor at Science Faculty, Srinakharinwirot University	Ed. D.(Science Education)
2. Dr. Manas Boonprakob	Former lecturer at Behavioral Science Research Institute, Srinakharinwirot University	Ed.D. Curriculum and Instruction (Postsecondary Education)
3. Asst.Prof. Dr. Kanaporn Rasmimariya	Chemistry teacher at Srinakharinwirot Pratumwan Demonstration school	Ph.D (Curriculum and Instruction)

A.3 The list of participant teachers in the research study

The list of two participant teachers who involved in this study was teachers at the Somdej Phra Yanna Sangworn school and Debsirin Phukhae school. The first participating teacher used, examined and verified the components of learning units before pilot study and another teacher examined and verified the curriculum before implementation. The learning units were revised according to their comments and their suggestions. The details of the participating teachers were described as in TABLE 28.

TABLE 28 GENERAL INFORMATION REGARDING PARTICIPATING TEACHERS IN RESEARCH STUDY

Name	Education	Teaching Experiences (year)	Responsibilities
1. Ms. Sangduen Boknoi	M.Ed. (Chemistry)	19	Chemistry teacher
2. Ms. Jidapa Vachirasak	M.S. (Engineering)	2	Chemistry teacher

Appendix B: The results of evaluation on quality of the research materials according to the experts' opinion

B.1 The results of evaluation on IOC, p value and discrimination index of achievement test items

B.5 The results of evaluation on IOC of science process skills test items

B.1 The results of evaluation on IOC, p value and discrimination index (D) of achievement test items

TABLE 29 QUALITY OF THE ACHIEVEMENT TEST ITEMS

No.	Quality of test items			No.	Quality of test items		
	Experts' evaluation	Students' responding			Experts' evaluation	Students' responding	
	IOC	p	D		IOC	p	D
1	1.00	0.84*	0.31	18	1.00	0.74	0.25
2	1.00	0.47	0.63	19	1.00	0.11*	0.42
3	0.67	0.71	0.47	20	1.00	0.47	0.21
4	0.67	0.76	0.37	21	1.00	0.34	0.47
5	0.67	0.73	0.52	22	1.00	0.44	0.57
6	1.00	0.76	0.26	23	1.00	0.73	0.52
7	1.00	0.60	0.57	24	1.00	0.39	0.37
8	1.00	0.73	0.42	25	1.00	0.44	0.37
9	1.00	0.68	0.52	26	1.00	0.37	0.21
10	0.67	0.57	0.52	27	0.67	0.81*	0.26
11	0.67	0.50	0.57	28	1.00	0.76	0.37
12	1.00	0.73	0.31	29	1.00	0.55	0.26
13	1.00	0.37	0.42	30	0.67	0.68	0.63
14	0.67	0.29	0.37	31	1.00	0.68	0.42
15	1.00	0.52	0.63	32	1.00	0.39	0.37
16	1.00	0.60	0.57	33	1.00	0.73	0.31
17	1.00	0.44	0.37	34	1.00	0.29	0.26

Note: Reliability (KR-20) = 0.757

* Three items of the test (items 1, 19, and 27) were considered acceptable with the need for further revision for reserving the structure of the test.

B.2 The results of evaluation on IOC of science process skills test items

TABLE 30 THE RESULTS OF ASSESSING AND EVALUATING THE ITEMS OBJECTIVE CONGRUENCE OF SCIENCE PROCESS SKILLS TEST

No.	The consideration of item objective congruence with	N = 3			IOC	Interpretation
		E_1	E_2	E_3		
1	Observation	0	1	1	0.67	Can be used
2	Observation	1	1	1	1.00	Can be used
3	Observation	1	0	-1	0.00	Not can be used
4	Observation	1	0	-1	0.00	Not can be used
5	Measurement	0	1	1	0.67	Can be used
6	Measurement	1	1	0	0.67	Can be used
7	Measurement	1	1	1	1.00	Can be used
8	Measurement	1	1	1	1.00	Can be used
9	Classification	1	1	1	1.00	Can be used
10	Classification	1	1	1	1.00	Can be used
11	Classification	1	1	1	1.00	Can be used
12	Organizing data and communication	1	1	1	1.00	Can be used
13	Organizing data and communication	1	1	1	1.00	Can be used
14	Organizing data and communication	1	1	1	1.00	Can be used
15	Organizing data and communication	1	1	1	1.00	Can be used
16	Inferring	1	1	1	1.00	Can be used
17	Inferring	1	1	1	1.00	Can be used
18	Inferring	1	1	1	1.00	Can be used
19	Inferring	0	1	1	0.67	Can be used
20	Prediction	1	1	1	1.00	Can be used
21	Prediction	1	1	1	1.00	Can be used
22	Prediction	1	1	1	1.00	Can be used
23	Prediction	1	1	1	1.00	Can be used

TABLE 30 (continued)

No.	The consideration of item objective congruence with	N=3				Interpretation
		E_1	E_2	E_3	IOC	
24	Formulating hypothesis	1	1	1	1.00	Can be used
25	Formulating hypothesis	1	1	1	1.00	Can be used
26	Formulating hypothesis	1	1	1	1.00	Can be used
27	Formulating hypothesis	1	1	1	1.00	Can be used
28	Identifying and controlling variables	1	1	0	0.67	Can be used
29	Identifying and controlling variables	1	1	1	1.00	Can be used
30	Identifying and controlling variables	1	1	1	1.00	Can be used
31	Identifying and controlling variables	1	1	1	1.00	Can be used
32	Interpreting data and conclusion	1	1	1	1.00	Can be used
33	Interpreting data and conclusion	1	1	1	1.00	Can be used
34	Interpreting data and conclusion	1	1	1	1.00	Can be used
35	Interpreting data and conclusion	1	1	1	1.00	Can be used

Note: IOC $\geq$ 0.60 = highly congruence

IOC $<$ 0.60 = Not can be used

VITAE

VITAE

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