

การพัฒนาความเข้าใจโมโนมิติ เรื่อง พันธะเคมี โดยใช้หน่วยการเรียนรู้ที่สอดแทรกทฤษฎีกระบวนการ สารสนเทศ สำหรับนักเรียนชั้นมัธยมศึกษาตอนปลาย ENHANCING HIGH SCHOOL STUDENTS' CONCEPTUAL UNDERSTANDING OF CHEMICAL BONDING BY USING LEARNING UNITS INCORPORATED WITH INFORMATION PROCESSING THEORY

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บทคัดย่อ

การวิจัยนี้มีจุดมุ่งหมายเพื่อ (1) พัฒนาหน่วยการเรียนรู้เรื่องพันธะเคมี ที่สอดแทรกทฤษฎีกระบวนการสารสนเทศสำหรับนักเรียนชั้นมัธยมศึกษาตอนปลาย (2) ศึกษาประสิทธิภาพของหน่วยการเรียนรู้ต่อผลสัมฤทธิ์ทางการเรียน และ (3) ศึกษาโมโนมิติที่คลาดเคลื่อนที่เกี่ยวข้องกับเรื่องพันธะเคมีและโครงสร้างการออกแบบกิจกรรมการเรียนรู้มีจุดมุ่งหมายในการลดการใช้หน่วยความจำปฏิบัติการ (Working memory demand) ที่ใช้ในการประมวลผลในกระบวนการเรียนรู้ โดยการปรับลดความซับซ้อนของการนำเสนอเนื้อหาบทเรียนในรูปแบบที่เป็นขั้นตอนที่สั้นๆ และเชื่อมโยงกัน การปรับเปลี่ยนลำดับของการนำเสนอเนื้อหาที่เข้าใจง่ายขึ้น และการเชื่อมโยงเนื้อหาในหน่วยการเรียนรู้ให้สอดคล้องกับพื้นฐานความรู้เดิมของนักเรียน หน่วยการเรียนรู้พัฒนาขึ้นตามมาตรฐานการเรียนรู้ของหลักสูตรการศึกษาขั้นพื้นฐานพุทธศักราช 2544 สารวิทยาศาสตร์ที่ 3.1 เรื่องสารและสมบัติของสารสำหรับนักเรียนมัธยมศึกษาปีที่ 4 เนื้อหาของหน่วยการเรียนรู้ประกอบด้วย 7 หน่วยการเรียนรู้ได้แก่ (1) ทำโมอะตอมจึงสร้างแรงยึดเหนี่ยวระหว่างกัน (2) พันธะไอออนิก (3) พันธะโคเวเลนต์ (4) ความแข็งแรงของพันธะโคเวเลนต์ (5) รูปร่างและสภาพขั้วของโมเลกุล (6) แรงยึดเหนี่ยวระหว่างโมเลกุล และ (7) พันธะโลหะ

หน่วยการเรียนรู้ที่พัฒนาขึ้นนำมาใช้กับกลุ่มตัวอย่างนักเรียนชั้นมัธยมศึกษาปีที่ 4 จำนวน 40 คน ที่โรงเรียนมัธยมศึกษาแห่งหนึ่งใน จ.สระบุรี เป็นระยะเวลา 26 คาบเรียน ในภาคเรียนที่ 2 ปีการศึกษา 2553 ในช่วงเดือนธันวาคม 2553 ถึงเดือนกุมภาพันธ์ 2554 เครื่องมือที่ใช้ในการเก็บรวบรวมข้อมูลประกอบด้วย หน่วยการเรียนรู้ เรื่องพันธะเคมี และแบบทดสอบวินิจฉัยความเข้าใจโมโนมิติ เรื่องพันธะเคมีและโครงสร้าง ผลการวิเคราะห์ข้อสอบรายข้อของแบบทดสอบวินิจฉัยความเข้าใจโมโนมิติ พบว่า โดยเฉลี่ย 83.4% ของนักเรียนตอบคำถามถูกในส่วนแรกของข้อสอบ ในขณะที่ 56.2% ของนักเรียนในกลุ่มตัวอย่างสามารถตอบคำถามถูกทั้งสองส่วน ผลการวิเคราะห์ค่า class average normalized gain ($\langle g \rangle$) ของนักเรียนทั้งชั้นอยู่ในระดับคะแนนปานกลาง ($\langle g \rangle = 0.51$) และผลของค่าสถิติ t-test สำหรับกลุ่มตัวอย่างกลุ่มเดียว พบว่าค่าเฉลี่ยของคะแนนสอบหลังเรียนของนักเรียนมีค่าสูงกว่าก่อนเรียนอย่างมีนัยสำคัญทางสถิติที่ระดับ 0.01

คำสำคัญ: พันธะเคมี ทฤษฎีกระบวนการสารสนเทศ หน่วยการเรียนรู้

Abstract

The purpose of this study is to 1) develop the Chemical Bonding Learning Units incorporated with Information Processing Theory for high school students, 2) examine the effectiveness of the learning units by assessing students' learning achievement score, and 3) investigate students' alternative conceptions associated with chemical bonding and structure. The aim in designing the chemical bonding learning units is to minimize learning situations where a high working memory is demanded. Designing the learning units were based on students' working memory demand and strategies to reduce working memory demand including presenting the abstract concepts in a more stepwise fashion, changing the presentation order of the topics, and relating learning materials to prior knowledge were considered. The chemical bonding learning units was developed based on the science strand 3.1 and sub-standard of matter and properties in Thailand's Basic Education Curriculum (B.E.C) 2001 for grade 10 students. The content of learning units treated under seven concepts of chemical bonding and structure are: (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 were implemented across 26 learning periods during December 2010 through February 2011 in the second semester of the 2010 academic year with 40 students of 10th grade at high school level, Saraburi Province. The instruments were the learning units, the diagnostic instrument and Chemical Bonding and Structure Test (CBST). Findings revealed that the learning units enhanced students' conceptual understanding of bonding concepts. For all items of CBST, 83.4% of the students responded correctly at the first part, whereas 56.2% responded correctly both parts. The paired samples t-test indicated that the students' achievement mean score after learning using the learning units was higher than that before at $p < 0.01$. Even though the

class average normalized gain ($\langle g \rangle$) did not achieve at the established criterion high gain level but the $\langle g \rangle$ was justified and categorized as medium gain level” ($\langle g \rangle = 0.51$).

Keywords: Chemical bonding, Information Processing Theory, learning unit

Introduction

Chemistry, one of the most important subjects among science, is a fundamental and an essential knowledge in the curriculum for high school level students. Since students' conceptions of chemical bonding have long been recognized as important [1], attention has been made to enhance students' conceptual understanding of this topic [2]. One of chemistry teaching goal is to develop more effective and scientifically aligned strategies to teach key concepts of chemical bonding. However, many studies indicated that traditional approach in 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. 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 even if the former instruction [3-5]. Furthermore, the bonding is considered to be a very complicated concept by teachers and students [6-8].

Information Processing Theory studies the flow of information through the cognitive system. It tries to explain how people acquire, interpret, store, 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 of the learning process and lead to understand the limitation of learning when we attend to a stimulus it passes into short term memory [9], or working memory space [10]. The Information processing theory emphasizes the important of students' working memory demand of cognitive tasks.

Working memory is viewed as a capacity-limited, unitary memory store which temporarily keeps information for further processing. Information in working memory decays after two seconds if not rehearsed [11]. Rehearsed information is encoded and saved in long term memory. Miller [12] 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 [13]. Chunking is the process through which the 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 [14]. The working memory space permits learner to keep information long enough to make sense of sequences of words and directions to solve problems or to make

decisions. Therefore, working memory is part of the brain that holds information, work on it, organize and arrange, before storing it in the long term memory [15].

Attention has been given to ways in which research findings on working memory should be applied to facilitate science learning. Research study indicated that performance on cognitive tasks is expected to drop when the information load exceeds students' working memory capacity [13]. 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. Research study [14] claimed that the instructional materials should be redesigned with the goal of reducing unnecessary load caused by the instructional design in order to minimize working memory demand on the tasks. Therefore, the instructional materials should be redesigned with the goal of reducing unnecessary load caused by the instructional design [16].

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 with Information Processing Theory--to minimize learning situations involving working memory demand on students--were designed.

The effectiveness of the developed learning units was examined from students' learning achievement. The aim in designing the proposed

learning units was to minimize learning situations where an overloaded working memory was required. The curriculum materials were designed to minimize limitations of learning caused by working memory space. Strategies to reduce cognitive load included presenting the abstract concepts in stepwise fashion, changing the topics presentation, and relating learning materials to prior knowledge were employed. The curriculum materials for the proposed learning units based on sub-strand 3: Matter and Properties under standard Science 3.1.

Objectives

The aims of this research were:

- 1) To develop the chemical bonding learning units incorporated with Information Processing Theory for high school students.
- 2) To examine the effectiveness of the learning units by assessing students' learning achievement score.
- 3) To investigate students' alternative conceptions associated with chemical bonding and structure.

Methods

Research design

The learning units incorporated with Information Processing to minimize learning situations with concerning students' working memory capacity were developed. The One Group Pretest-Posttest Design was employed to examine the effectiveness of the developed learning units.

Participants

Participants were 40 students of 10th grade

at Dhebsirin Pukae School, Saraburi Province, Thailand. One classroom was selected from four classrooms and one chemistry teacher who participated in instructional procedures and considered instructional materials has experience in teaching chemistry for 2 years.

Variables

1) The independent variable is the chemical bonding learning units incorporated with Information Processing Theory.

2) The dependent variable is learning students' learning achievement.

Research instruments

1. The chemical bonding learning units incorporated with Information Processing Theory

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 scientific inquiry, the learning objectives of each learning units were established. After the concept flow had been determined, procedures for developing the learning units were as following:

1.1 Selecting instructional strategies used in the learning units and instructional materials.

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).

Dimensional analysis or task analysis [17] 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.

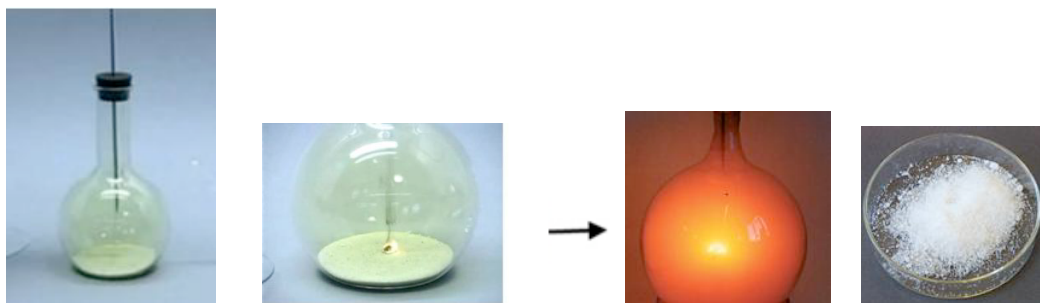
(3) Operation usually represents application to the specific figurative model that is needed to obtain the results and is prescribed by the subject's general and specific operative models, according to the problem domain in question.

The task analysis was outlined to organize strategies to reduce working memory loading during the presentation of the sequence of activity for constructing the learning unit. The task analysis also was used for providing 'thought' steps that student have to deal with in the cognitive tasks and provided the guideline to organize activities in the learning units as following example of learning unit 2:

Table 2 The task analysis of learning unit 2

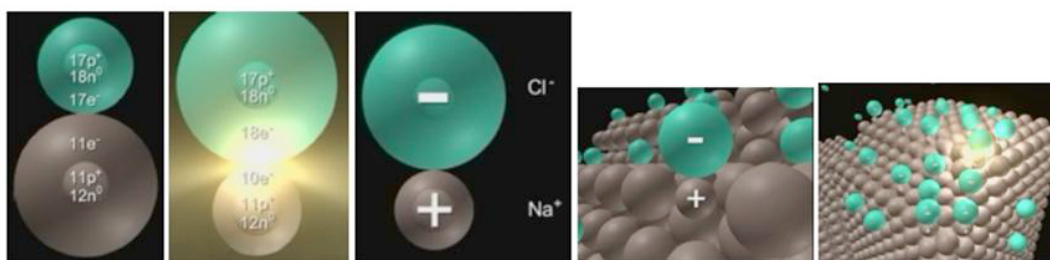
Activity/ Content	Strategies	Student' thought steps				
		Prior knowledge	General figurative model (GFM)	Specifi figurative model (SFM)	Operation	Thought steps
1. Present sequences of diagram integrated with text about process of formation of ions to form sodium chloride	Reduce external load working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

Note: 1. Present the following sequences of diagram integrated with text about process of formation of ions to form ionic compound. In the following diagrams integrated with text: sodium (Na) and water in chlorine gas (Cl₂), combine to form sodium chloride (NaCl), common table salt.



Sodium (Na) and water in chlorine gas (Cl_2) Sodium chloride (s)

2. Observe following sequences of diagram integrated with text about formation of ions to form ionic lattice, then answer exercise.



Steps of lattice formation: (1) Before formation of ions, (2) Electron transfer from sodium to chlorine, system released energy, (3) Formation of sodium ion and chloride ion, (4) Electrostatic attraction between sodium ion and chloride ion, and (5) Lattice formation.

1.2 Designing the learning units

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 scientific inquiry, the learning objectives of each learning units were established. After the concept flow had been determined, instructional strategies for designing each learning unit was selected. The contents and learning activities of the 7 learning units were developed and derived from the outline of learning objectives, concepts flow, and task analysis as mentioned

in Table 1 as a guideline. The learning units including activities, lesson plans, and learning periods were summarized in Table 2.

Table 2 Summary of the chemical bonding learning units.

Learning Units	Activities	Lesson	Periods
	Plan		
1. Why do atoms bond?	Classify types of bonding	1	2
2. Ionic Bonding	Formation of ionic bond and lattice structure	2	2
	Reaction of ionic compounds in water	3	3
	Names and formulas	4	2
3. Covalent bonding	Formation and nature of the covalent bond	5	2
	Types of covalent bonds, Lewis dot structure, and names and formulas	6	2
4. Strength of covalent bonds	Bond length, bond energy and the strength trends	7	2
5. Molecular geometry and polarity	VSEPR model and molecular shape	8	3
	Polarity of molecule	9	3
6. Intermolecular forces	Intermolecular forces in common molecules	10	2
	Properties of covalent network structure	11	1
7. Metallic bonding	Metal and properties of metals	12	2
Total		12	26

The results of evaluation on appropriateness and validity by three experts were categorized as high level of appropriateness (mean score ranged between 4.00 and 4.33). The results of Index of Item Objective Consistency (IOC) on the components of learning units were consistency in all aspects of evaluation (IOC = 1.00). The results of appropriateness and validity of the learning units indicated that all components in each learning unit were related to each other and the learning units were strongly recommended to implement.

2. The assessment instruments

The Chemical Bonding and Structure Test (CBST) consisted of 34 items. 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 given in the first tier, which included the correct answer and three alternative reasons involving alternative conceptions. The CBST was verified by three experts to find the Index of Item Objective Congruence (IOC) between test items and learning objectives. The IOC was found to be 0.67-1.00. The discrimination, item difficulty and reliability of the CBST were determined. Summary of characteristics for the CBST was reported in Figure 1 and sample of the CBST diagnostic instrument test item was showed in Figure 2.

Concepts evaluated	1. Why do atoms bond –Item 1 2. Ionic bonding –Items 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 3. Covalent bonding – Items 14, 15, 16, 17, 18 4. Strength of covalent bonds –Items 19, 20 5. Molecular geometry and polarity – Items 21, 22, 23, 24, 25, 26 6. Intermolecular force – Items 27, 28, 29, 30, 31, 32 7. Metallic bonding – Items 33, 34
Response format	Two tier multiple choice First tier – content knowledge Second tier – reasons for content response
Recommend grade level	Grade 10 or higher
Discrimination indices (t-test index)	Range (1.84 – 8.82) 1.80 – 3.59 (Items 4, 5, 8, 9, 11, 15, 16, 19, 20, 21, 25, 28, 31, 32, 33, 34) 3.60 – 5.39 (Items 1,3, 6, 12, 18, 22, 23, 24, 26, 29) 5.40 – 7.19 (Items 2, 7, 13, 27) 7.20 – 8.90 (Items 10, 30, 14, 17)
Difficulty indices	Range (0.31 – 0.80) 0.30 – 0.39 (Items 1,7) 0.40 – 0.49 (Items 3, 5, 6, 10, 12, 17, 26, 27, 30, 31) 0.50 – 0.59 (Items 2, 8, 13, 18, 20, 32, 34) 0.60 – 0.69 (Items 4, 9, 11, 19, 21, 23, 24, 28, 29, 33) 0.70 – 0.80 (Items 14, 15, 16, 22, 25)
Reliability (KR-20)	0.867

Figure 1. Summary of characteristics for the CBST

From Figure 1, the reliability of the CBST measured by Cronbach alpha was 0.867. Discrimination indices (t-test index) ranged from 1.84 – 8.82 and those greater than 1.75 were considered acceptable without the need for further revision of the test items. Difficulty indices ranged from 0.31 to 0.80 providing a wide range of difficulty in the items.

Question Statement	The XY ₂ molecule which the central atom X had two nonbonding and two bonding electron pairs, this molecule is likely to be
Tier 1 (I)	(I) V-shaped (II) Linear (III) Trigonal planar (IV) Trigonal pyramidal
Tier 2 (B)	Reason A) The shape of molecule is due to the two single arranged around the central atom. B) Repulsion between the bonding and nonbonding electron pairs result in shape. C) Repulsion between the nonbonding electron pairs is not results in shape. D) The shape of molecule is due to the two single bonds arranged around the central atom and repulsion between the nonbonding electron pairs is not results in shape.

Figure 2. Sample of the Chemical Bonding and Structure Test items

Data collection and data analysis

1. Data collection

In this implementation, participating students took the pre-test of learning achievement test before instruction. The participating teacher participated in instructional procedures, considered instructional materials, and gave comments in each learning units. Finally, the participating students took the test of learning achievement and science process skills test after completion of all learning units.

2. Data analysis

The developed learning units were implemented across 26 periods during December 2010 through February 2011. All research instruments were used for collecting data before and after implementation of the learning units.

In this research study, the effect of implementing the learning units on students' learning achievement of chemical bonding concepts

was examined by using class average normalized gain (<g>) described as following:

$$<g> = \frac{\text{Posttest} - \text{Pretest}}{\text{Total score} - \text{Pretest}}$$

Notice: (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

The achievement score of the CBST was analyzed to determine students' class average normalized gain. The finding was used to justify whether students had a satisfactory achievement with respect to an established criterion at high gain level.

The comparison of the students' learning achievement before and after using the learning units was examined. The paired sample t-test was performed statistically to find out whether

difference in achievement score exists.

Moreover, the data from administering the CBST were processed with software that tabulated the percent of subjects who answered the first tier of each question correctly and the percent who answered both tiers correctly. These were analyzed to provide the existence of alternative conceptions of chemical bonding and structure.

Results

1. The achievement score from administering the achievement pre-test and post-test was analyzed to determine students'

class average normalized gain ($\langle g \rangle$). From analyzing the students' achievement on chemical bonding, the results indicated that students' class average normalized gain shows the medium gain level ($\langle g \rangle = 0.51$).

2. The results of comparison of students' achievement mean score before and after implementation were shown in Table 3. The results of paired samples t-test indicated that the students' achievement mean score after implementing the learning units was higher than before at the 0.01 level of significance.

Table 3 Comparisons of the pretest versus posttest scores on students' learning achievement and science process skills.

Score	N	Mean	S.D.	Mean of Difference	t	p
Learning achievement						
Posttest	40	67.075	17.383	36.35	12.363**	0.000
Pretest	40	30.725	6.417			

**p < 0.01

3. Results of students' percent correct response to the CBST items were analyzed to provide the existence of alternative conceptions of chemical bonding and structure. Table 4 presents the results of students' percent correct response to the CBST items after implementing the learning units.

The results of analyzing students' alternative conceptions associated with chemical bonding (Table 4) suggested that large percentage of students (27.2%) guessed the answer or only had partial knowledge to achieve the

correct responses. While consider the correct response data in the tiers 1 and 2 column of the Table 3, it was found that the mean values were in the range of 53.8% to 80.0%. The topics which the mean values less than 50% were the strength of covalent bonds, molecular geometry and polarity and metallic bonding with the mean values of 38.8%, 43.3% and 42.5% respectively. While consider tier 1 results only, the highest scores above 90.4% were observed for intermolecular forces.

Table 4 Students' percent correct response to the Chemical Bonding and Structure Test items for tier 1 and tier 1 & 2.

Topics	Number of items	Tier 1		Tier 1 & 2		Mean difference Tier 1–Tier 1 & 2
		Mean	S.D.	Mean	S.D.	
Why do atoms bond?	1	95.0	14.5	80.0	12.4	15.0
Ionic bonding	12	86.9	5.7	75.0	14.9	20.4
Covalent bonding	5	81.5	8.8	57.55	21.2	24.0
Strength of covalent bonds	2	73.8	8.8	38.8	1.8	35.0
Molecular geometry and polarity	6	72.1	14.1	43.3	8.8	28.8
Intermolecular force	6	90.4	1.8	53.8	8.8	36.7
Metallic bonding	2	83.8	8.8	42.5	24.7	41.3
All items	34	83.4	9.7	56.2	16.1	27.2

The score of 80.0% and 75.0% after considering both tiers for the concepts of why do atom bond and ionic bonding respectively suggested that students had relatively better understanding of these concepts than others, whereas the 38.8% correct responses for the strength of covalent bonds with the lowest percentage suggested that students were lack of understanding this section. However, one should take into consideration the fact that these two sections were represented by two questions in the instrument. The mean difference for correct responses for tier 1 and both tiers was 35.0% for the strength of covalent bonds and 41.3% for the metallic bonding. According to the results, student's selection of an incorrect content choice and/or incorrect reason choice indicated the existence of alternative conceptions of the strength of covalent bonds and the metallic bonding.

These findings also suggested that on the average two-tier multiple choice tests can help identify the students with partial knowledge as well as their misconceptions. Teachers can use the CBST not only to identify students who lack complete understanding, but also types of students' misconceptions to target their teaching to improve students' learning outcomes.

Conclusions and Discussion

Conclusions

The results from analyses of paired sample t-test indicated that the learning units were effective to enhance students' conceptual understanding of bonding concepts. The class average normalized gain was improved at medium gain level ($\langle g \rangle = 0.51$) due to participate in the learning units. The results indicated that students who learned through the learning

units had a significant improvement on their conceptual understanding of chemical bonding concepts with statistical difference. Moreover, it can be implied that the learning units incorporated with Information Processing Theory were effective to enhance students' understanding of chemical bonding and structure and science process skills.

Discussion

1. In investigating the class average normalized gain of students' learning achievement, the medium gain level was established ($\langle g \rangle = 0.51$). This result was consistent with Hake [18], the normalized gains earned by the forty eight interactive engagement courses were 0.48, and none of the high average gain was found. Effects of formal reasoning ability on students' learning achievement resulted in process of scientific explanation [19–20]. Following researchers also found the same relationship [21–23]. In addition, formal reasoning ability on students' learning achievement was also reported in chemistry classes at the high school level [24–25]. This may be implied that students who have not attained formal operational ability will not able to comprehend meaningfully abstract concepts and principles of science [26–27], then, the high gain level was not found.

Even though students' class average normalized gain was not achieved at high level, the findings also indicated that a good improvement (with $\langle g \rangle = 0.51$) on students' understanding of chemical bonding concepts is due to implement the learning units incorporated with Information Processing Theory.

2. The results of comparison of students' achievement mean score before and after implementation were shown in Table 3. The results of paired sample t-test showed that the students' achievement mean score was higher than before at the 0.01 level of significance. This indicated that the learning units were effective to enhance students' understanding of chemical bonding concepts.

In this study, the use of instructional materials - which were specifically designed to minimize the impact of limitations in working memory space - increased student performance. The learning units were designed in the light of predictions suggested by information processing theory and every feature of learning units sought to minimize the demands on working memory. Thus, breaking down the cognitive tasks into separate meaningful steps that learners have to acquire in a course that emphasize strategies to reduce working memory loading during the presentation of the sequence of activity can improve students' performance in chemistry. In addition, working memory capacity can account for performance on tasks that involve both processing and storage, and both of these cognitive functions are likely to be required for most forms of scientific problem solving [14].

Consistently improved results were found when applied visual information aids involving pictures and diagrams were integrated with text in the design of a chemistry laboratory manual for eighty-three university students [28]. The results showed that 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.

3. From analysis of incorrect response combinations, the findings found that many students learned facts without an adequate understanding of the propositions and concepts involved. The findings of students' percent correct response to the CBST items suggested that a large proportion of the students who scored correct responses at the tier 1 level did not necessary to have an acceptable level of understanding. This notified that students might have either alternative conceptions or guessed at either one of the two-tiers. The results were also consistent with Peterson and Treagust [4].

Remarkably, the following concepts' covalent bonding and metallic bonding—appeared to have a high standard deviation (S.D. = 21.2 for concepts of covalent bonding and S.D. = 24.7 for metallic bonding,). High standard deviation indicates that students' scores are spread out over a large range of mean scores. Low standard deviation indicates that students' scores were also found in the concept of strength of covalent bonds. Students' scores are spread out over a small range of mean.

Moreover, there were evidences that student's selection of an incorrect content choice and /or incorrect reason choice indicated the existence of alternative conceptions of chemical bonding and structure. For example from Figure 2, when asked to predict the shape of the XY_2 molecule which the central atom X had two

nonbonding and two bonding electron pairs, 17.5% of students identified the XY_2 molecule as linear, 7.5% of students identified the XY_2 molecule as trigonal planar and 15% of students identified the XY_2 molecule as trigonal pyramidal. There were 17.5% of students predicted and explained the shape of the XY_2 molecule correctly. The unexpected results were 37.5% of student obtained the right answer for first tier, but gave a wrong reason for second tier.

In some cases, some students still had problems with a complex activity and breaking down the tasks into separate steps according to working memory model did not seem to help students to overcome alternative conceptions. In this study, with its limitation of time, breaking down the tasks into separate steps may not have work well for particular following concepts: 1) the strength of covalent bonds, 2) molecular geometry and polarity, and 3) metallic bonding. Even though the instructional material was presented in such a way that working memory demand is minimized, these students were not enabled to link the separate steps to previous knowledge in a meaningful way. Accordingly the students' alternative conceptions are quite resistant to be changed. It may be possible that some of the alternative conceptions have survived because it has been well documented that students often retain their existing views even following further instruction [29-33].

Recommendations

1. Recommendations for chemistry teachers

The chemistry teachers may adapt and apply the developed learning units and instructional

materials for teaching scientific concepts about chemical bonding to enhance learning achievement, develop science process skills and address alternative conceptions of students.

This finding supports a need for modifying the diagnostic test instrument to avoid guessing. In developing the two-tier multiple-choice diagnostic items, information about students' common alternative conceptions was obtained by having students provide free response explanations to their answers and conducting unstructured interviews with students who have previously been taught the concepts. Moreover, the chemistry teachers can benefit from the findings and reviewing the current instructional materials to ensure that the concepts are taught at a level consistent with the students' prior knowledge and cognitive factor especially students' working memory capacity.

2. Recommendations for further studies

From the experience and results, some further studies are recommended as the following:

2.1 The study should be extended into a larger group of population which consists of the different sample characteristics such as normal science students and non-science majors' students. This would allow results to be generalized to the population in high school level.

2.2 The methodology used in this study involved the use of a two-tier diagnostic test to study students' understanding of chemical bonding concepts. It is recommended that some students who achieve high and low scores should be interviewed to triangulate the results. Hence, further studies involving improvement

of the instrument to minimize guessing and triangulation of quantitative and qualitative data are recommended to achieve in-depth information on students' understanding of the concept. The minimization of guessing can be achieved by asking students to report their confidence in their responses of the two tiers answers.

2.3 The curriculum approach, the 5Es model of inquiry incorporated with Information Processing Theory, should be employed and its effectiveness should be further examined in other abstract content areas e.g. stoichiometry, equilibrium, electrochemistry, etc.

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