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Development of Grade-10 Students' Conceptual Understanding of Dot Structure and Molecular Shape from Learning by Using Magnet and Pin Kits

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Abstract. This research aims to develop grade 10 students' conceptual understanding of the topic of dot structure and molecular shape from learning by using the Magnet and Pin kits. The research methodology is one group pretest-posttest design. The participants are 33 grade 10 students from a school in Khon Kaen province (Thailand), acquired by purposive sampling. The data was collected using the Dot structure and Molecular shape Conceptual Test (DMCT). The DMCT will be used to collect data for the pre-test and post-test. There are six items in the DMCT (difference in six molecular formulas; PF_5, ClO_4^-, CO_3^{2-} ,O_3, ClF_3, and $XeOF_4$). The answers form DMCT were analyzed by classifying the conceptual understanding at 5 levels according to the conceptual framework of Çalik, Ayas, and Coll (2009). The results found that before learning, most of the students had a conceptual understanding at the NU level of the ClO_4^-, CO_3^{2-} ,O_3, ClF_3, $XeOF_4$ molecule and had SAC level understanding of the PF_5 molecule. It showed that the students' conceptual understanding of all molecules was very low. After learning with the Magnet and Pin kits, most of the students' conceptual understanding level increased to the SU level for the PF_5, CO_3^{2-}, ClF_3 and $XeOF_4$ molecules and increased to the PU level for the O_3 and ClO_4^- molecule. This shows that the use of Magnet and Pin kits in learning to draw the Lewis dot structure and to make molecular shape prediction can help students achieve an overall higher level of conception from NU & SAC to SU & PU levels. The students could specify the type and number of central atoms, surrounding atoms, number of bond pair electrons, and lone pair electrons. The students could also draw the Lewis dot structure correctly and they could draw images to represent three-dimensional shapes of molecules and correctly specify the names of molecular shapes.

Keywords: Conceptual understanding, Magnet and Pin kits, Dot structure, Molecular shape

INTRODUCTION

From the researcher's teaching experience, many students say that "Chemistry is a difficult subject", which is consistent with the analysis of science educators. This explains the reasons for the difficulty of chemistry in 3 reasons: 1) The content is abstract. Some things are not visible to the naked eye, such as atoms and molecules. 2) There is a language barrier that hinders the learner's understanding of the subject. This includes the use of specific vocabulary that has a different meaning from the meaning of the same words in everyday life. The use of various symbolic languages such as formulas, equations, constants, the use of a foreign language, namely, English, and 3) the learning arrangements conflict with the nature of learners' learning, that is, teaching is focused on the transmission of content from the teacher to the student instead of focused on the learning process (Wichaidit, 2015). The content that is difficult for students to understand is covalent bonds, which has various foundational subtopics that must be understood first, such as, drawing a Lewis dot structure leading to drawing a line structure, specification of bond types (single bond, double bond, triple bond) and prediction the molecular shapes by using the Valence Electron Pair Repulsion (VSEPR) theory.

The Lewis dot structure is used to describe the bonding between atoms that form the compounds. For covalent compounds, the Lewis dot structure is used to represent the formation of covalent bonds between the non-metal atoms in the covalent molecules. The dots are used instead of the valence electrons that are shared between atoms. The Lewis dot structure leads to the prediction of the three-dimensional shape of the molecule by using the VSEPR theory. This theory assumes that the electrostatic repulsion between valence electrons in bonding causes the surrounding atoms to remain as far apart as possible. In the case of the molecule that has the lone pair electrons on the central atom, the repulsion between lone pair electrons and bond pair electrons causes changes in the molecular shape and bond angle. The molecular shape is divided into two categories, according to whether or not the central atom has lone pair electrons. In the case of molecules in which the central atom has no lone pair electrons, these molecules have the general formula AB_x, where A is the central atom, B is the surrounding atom and x is the number of the surrounding atom. In most cases, x is between 2 to 6. In the case of molecules in which the central atom has lone pair electrons, these molecules are designated the general formula as AB_xE_y, where A is the central atom, B is the surrounding atom, x (may vary from 2 to 4) is the number of the surrounding atom, E is the symbol for the lone pair electron on the central atom and y (may vary from 1 to 3) is the number of lone pair electrons (Chang, 2010).

In the high school curriculum, the topic of the Lewis dot structure is necessary for students in the understanding of chemical bonding. The skill of dot structure drawing is an ability that the students must have. The Lewis dot structure is necessary for understanding the formation of chemical bonds, which will help the students to predict the molecular shape leading to understanding of the properties of matter, e.g., polarity, intermolecular force, solubility, melting point, and boiling point. Even though it is necessary, many books on general chemistry do not represent the Lewis dot structure in a simple manner. This lack of a simple explanation causes difficulties for many students when they try to represent molecules (Pardo, 1989). There are many studies on how to present an easy-to-understand method of the Lewis dot structure teaching, e.g., the 6*N*+2 rule (Zandler and Talaty, 1984), the step-by-step approach (Ahmad and Omar, 1992), the direct electron pairing approach (Ahmad and Zakaria, 2000), the use of the tactile magnets packaged model (Kimball, 2012), the use of the atomic tile model (Kiste et al., 2016), the use of the pipe cleaner and plastic bead model (Turner, 2016).

The students' misconceptions of the dot structure and molecular shape were similar to the misconceptions mentioned by previous researchers. For example, the student's misconception of the dot structure and molecular shape may be as follows: The central atom can be any element, but the number of valence electrons of the completed central atom is eight. The Lewis dot structure is drawn only for bond pair electrons to complete the octet according to the Octet rule. The Molecular shape depends on the polarity of the molecules. The H_3O^+ molecule has no lone pair electron because it has a charge (Urasin and Supasorn, 2011). The students were unsure as to which atom to choose as the central atom and the number of lone pair electrons. Students did not understand how lone pairs electrons affect the molecular shape. The BF_3 molecule is a T-shape even though the B atom has no lone pair electrons. Students drew the NH_3 and PH_3 molecules as a T-shape because they understood that there is only one lone pair electron at the N and P atoms. The students did not specify the bond angles in molecular shapes (Sunson and Wuttisela, 2015).

From the researcher's observation, it was found that many students were confused when drawing the Lewis dot structure of complex structured molecules. Students are unable to imagine the correct molecular shape only by memorizing the names of molecular shapes. Most of the students with a good ability in learning science have private science tutoring in addition to learning in the classroom. Therefore, these students may neglect to understand deeply in class. This occurrence corresponds to the observation in the work of Supatchaiyawong, Faikhamta, and Suwanruji (2015).

According to related research studies, it was known that the use of models for hands-on activities encourages discussion among teachers, students, and peers within the group. The models quickly reveal preconceptions and misconceptions as well as increase the time used to think (Wuttisela, 2014). Model-based learning activities could enhance the students' mental model and informed understanding of the nature of the model according to the scientific model (Supatchaiyawong, Faikhamta, and Suwanruji, 2015). The students had significantly higher scientific conceptual understanding after the study than before (Sunson and Wuttisela, 2015).

The examples of using the models for teaching chemical bonds are as follows: The tactile magnets packaged model was used to construct the Lewis dot structure and the ball-and-spring model kit was modified with tactile puff paint for building 3D molecular geometry (Kimball, 2012). The atomic tile model was used to create models of covalent bonding and to translate between Lewis structures and molecular models. Students who used the atomic tiles performed relatively well on the summative classroom assessment items with complex structure questions (Kiste et al., 2016). The pipe cleaner and plastic bead model was used to represent the bonding between atoms in molecules and used to consolidate the student's understanding of covalent bonding. This model proved to be highly engaging for the students and a useful stimulus for discussion (Turner, 2016). The studies mentioned above provided the inspiration for the construction of the Magnet and Pin kits used in this research study.

For the reasons mentioned above, the Lewis dot structure and molecular shape is a highly abstract content in chemistry and invisible to the naked eye and difficult to imagine. Therefore, it is necessary to find a new method of learning process that will help students see more concretely in conjunction with the reasons mentioned above. The researcher invented the Magnet and Pin kits to be used as a model for learning in the topic of Lewis dot structure and molecular shape. The goal is to give students a deeper understanding of the concepts in this regard, and not just the memorization of the content.

RESEARCH OBJECTIVE

This research aims to develop the grade 10 students' conceptual understanding of Lewis dot structure and molecular shape topics from learning by using the Magnet and Pin kits.

METHODOLOGY

This research study used the one-group pretest-posttest design. The students' understanding of the Lewis dot structure and molecular shape was interpreted from their replies to the dot structure and molecular shape conceptual test (DMCT) before and after the intervention of the Magnet and Pin kits. In addition, examples of the students' responses from the pre-test and post-test are also explained to support the classification of conceptual understanding levels.

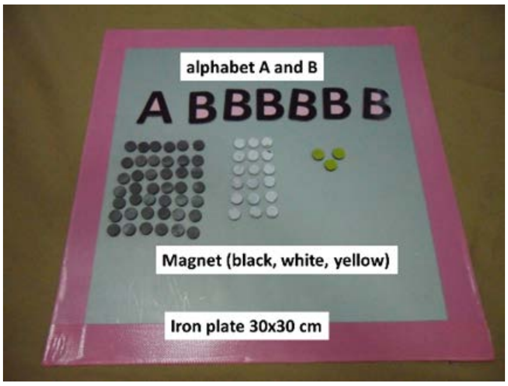
Participants

The participants are 33 grade 10 students from a school in Khon Kaen province (Thailand) in 2nd semester of the academic year 2016, acquired by purposive sampling.

Intervention of the Magnet and Pin Kits

The Magnet and Pin Kits were developed in order to scaffold students to construct meaning of Lewis dot structure and molecular shape. The components of the Magnet and Pin kits are shown in Figure 1. The Magnet kit is made from an iron plate, alphabet letters

A and B, and circular magnets used to guide the students in drawing the dot structure of covalent molecules. After that, the shapes of the covalent molecules were generated by the Pin kit, made from a spherical eraser, pins, and droplet pins. Examples of using Magnet and Pin kits were described in the previous work of Kamkhou and Yuenyong (2019).



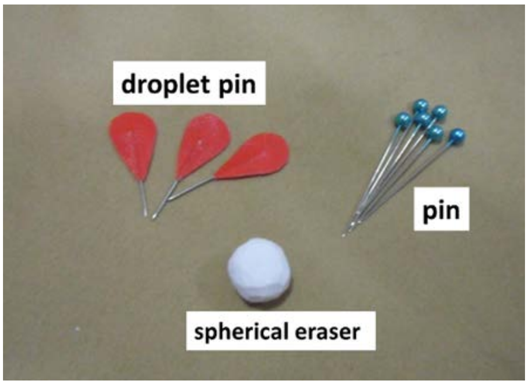


Figure 1: The components of the Magnet kit (left) and Pin kit (right)

According to Kamkhou and Yuenyong (2019), the teaching and learning about the Lewis dot structure and molecular shape through scaffolding of the Magnet and Pin Kits was provided for four steps. These included (1) examining students' existing ideas, (2) scaffolding of the Magnet and Pin kits, (3) challenging students' ideas, and (4) communicating students' ideas.

Step 1 Examining students' existing ideas: The students are given a worksheet which contains the molecular formulas CCl_4, XeF_4, and CO_3^{2-} and are instructed to draw the dot structure of each formula. The students are asked whether there were problems or difficulties. The students' responses are recorded on the board by the teacher. After that, the students are asked to match the molecular formulas of covalent compounds with 4 types of molecular shapes, namely, H_2O, CH_4, NH_3, and CO_2. The students are asked to specify which principles they used in choosing the molecular shapes. This step aims to check the students' prior knowledge.

Step 2 Scaffolding of the Magnet and Pin kits: The teacher explains how to use the Magnet and Pin kits to generate dot structures and molecular shapes of CO_3^{2-} and XeF_4 molecules, following the description in the work of Kamkhou and Yuenyong (2019).

Step 3 Challenging students' ideas: The students are taught to use the Magnet and Pin kits. The students use the Magnet and Pin kits to generate the Lewis dot structures and molecular shapes, as shown in Table 1. The teacher plays the role of a facilitator - giving advice, consulting, encouraging, and explaining the parts that the students do not understand.

Step 4 Communicating students' ideas: The teacher randomly selects students to present their dot structures and molecular shapes of molecules. Subsequently, the teacher gives feedback and summarizes the main learning concepts in the topics of the Octet rule, the Lewis dot structure drawing, and prediction of molecular shape by VSEPR theory.

Table 1: The molecular formulas for learning by using the Magnet and Pin kits

Case Study	Molecular formula	General formula	Name of molecular shape
No lone pair electrons on the central atom	NO_3^-	AB_3	Trigonal planar
	SO_4^{2-}	AB_4	Tetrahedral
	PCl_5	AB_5	Trigonal bipyramid
Contains lone pair electrons on the central atom	SO_2	AB_2E	Bent (or V-shape)
	BrF_3	AB_3E_2	T-shape
	IF_5	AB_5E	Trigonal pyramid

The Dot structure and Molecular shape Conceptual Test (DMCT)

The dot structure and molecular shape conceptual test (DMCT) was developed by the author via three steps. First, the principles of conceptual understanding test construction and test samples from various formats such as documents, books, research articles, and theses were studied to specify their suitability for the sample group. Then, the DMCT was created and validated by two high school chemistry teachers and two assistant professors in chemistry education. There are six items in the DMCT with the difference in six molecular formulas: PF_5, ClO_4^-, CO_3^{2-} ,O_3, ClF_3, and $XeOF_4$. The six molecular formulas were taken from two cases. The two cases were selected in accord with the curriculum: (1) The case of no lone pair electrons on the central atom, consisting of PF_5, ClO_4^-, and CO_3^{2-}, and (2) the case of containing lone pair electrons on the central atom, consisting of O_3, ClF_3, and $XeOF_4$. The selected molecules are comparable to those taught in the classroom (follow Table 1). All items contain four short answer questions as shown in Figure 2, consisting of (1) specifying the type and the number of central and surrounding atoms, the number of bond pair, and lone pair electrons. (2) drawing the Lewis dot structure, (3) drawing the molecular shape by specifying the bond angle, and (4) specifying the name of the molecular shape. The pre-test and post-test are the same versions but with some changes in the question order.

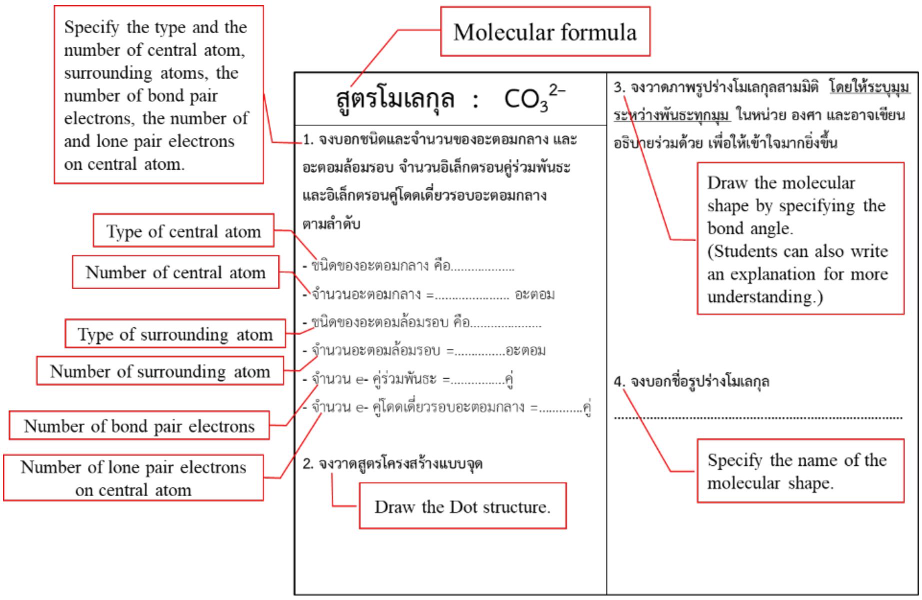


Figure 2: The example of questions in the Dot structure and Molecular shape Conceptual Test (DMCT)

Data Collection

The DMCT was used as the pre-test to determine the presence of conceptual understanding before learning. The DMCT was also used as the post-test after the learning activity with the Magnet and Pin kits to compare the conceptual understanding between the pre-test and the post-test.

Data Analysis

The students' responses obtained from the pre-test and post-test were classified into five levels of conceptual understanding, following the work of Çalik, Ayas, and Coll (2009): Sound understanding (SU), Partial understanding (PU), Partial understanding with Specific Alternative Conception (PUSAC), Specific Alternative Conception (SAC), and No Understanding (NU). The criteria for classification are shown in Table 2. In addition, examples of the students' responses and accompanying explanations from the pre-test and post-test are also included in the results section.

Table 2: The classification criteria of the students' conceptual understanding

Level	Classification criteria
SU	• Specify the type and number of central and surrounding atoms, the number of bond pair and lone pair electrons around the central atom are all correct 100%. • Able to draw all the Lewis dot structure correctly. • Able to draw the picture of molecular shapes along with specifying the bond angles correctly. • Specify the name of the molecular shape correctly.
PU	• Specify the type and number of central and surrounding atoms, the number of bond pair and lone pair electrons around the central atom is about 70% or higher. • Able to draw the Lewis dot structure but not completely correct. • Able to draw the picture of molecular shapes along with specifying the bond angles correctly. • Specify the name of the molecular shape correctly.
PUSAC	• Specify the type and number of central and surrounding atoms, the number of bond pair and lone pair electrons around the central atom is about 50% or higher. • Able to draw the Lewis dot structure but some parts show a lack of understanding. • Able to draw the picture of molecular shapes along with specifying the bond angles correctly but some angles show misunderstanding. • Specify the name of molecular shape correctly or the slightly inaccurate one.
SAC	• Specify the type and number of central and surrounding atoms, the number of bond pair and lone pair electrons around the central atom is less than 50%. • Draw the Lewis dot structure improperly. • Draw the picture of molecular shapes incorrectly and the bond angle is not specified. • Specify the name of the molecular shape incorrectly.
NU	• Specify the type and number of central and surrounding atoms, the number of bond pair and lone pair electrons around the central atom incorrectly or no answers. • Draw the Lewis dot structure improperly or no answers. • Draw the picture of molecular shapes incorrectly or no answers. • Specify the name of the molecular shape incorrectly or no answers.

The number of students was calculated as a percentage for each level of conceptual understanding and reported separately. In addition, examples of responses for each level are provided.

RESULTS

The student's answers from the DMCT pre-test and post-test for six individual items were classified into 5 levels of conceptual understanding, as shown in Table 3.

Table 3: The comparison of students' level of conceptual understanding for each item before and after learning with the Magnet and Pin kits

Molecular Formulas	Test	Level of conceptual understanding				
		SU number (%)	PU number (%)	PUSAC number (%)	SAC number (%)	NU number (%)
PF_5	Pre-test	0 (0.00)	1 (3.03)	1 (3.03)	**19 (57.58)**	12 (36.36)
	Post-test	**25 (75.76)**	6 (18.18)	2 (6.06)	0 (0.00)	0 (0.00)
ClO_4^-	Pre-test	0 (0.00)	0 (0.00)	0 (0.00)	13 (39.39)	**20 (60.61)**
	Post-test	8 (24.24)	**15 (45.45)**	7 (21.21)	2 (6.06)	1 (3.03)
CO_3^{2-}	Pre-test	0 (0.00)	0 (0.00)	0 (0.00)	10 (30.30)	**23 (69.70)**
	Post-test	**12 (36.36)**	**12 (36.36)**	7 (21.21)	1 (3.03)	1 (3.03)
O_3	Pre-test	0 (0.00)	0 (0.00)	0 (0.00)	10 (30.30)	**23 (69.70)**
	Post-test	8 (24.24)	**14 (42.42)**	11 (33.33)	0 (0.00)	0 (0.00)
ClF_3	Pre-test	0 (0.00)	0 (0.00)	1 (3.03)	13 (39.39)	**19 (57.58)**
	Post-test	**15 (45.45)**	5 (15.15)	11 (33.33)	2 (6.06)	0 (0.00)
$XeOF_4$	Pre-test	0 (0.00)	1 (3.03)	0 (0.00)	10 (30.30)	**22 (66.67)**
	Post-test	**11 (33.33)**	9 (27.27)	6 (18.18)	2 (6.06)	5 (15.15)

From Table 3, the analysis of students' responses from the pre-test and post-test are presented individually according to the six different molecular formulas as follows:

1. The molecular formula of PF_5

Before learning, most of the students (57.58%) had a conceptual understanding at the SAC level. For example, student number 7's answer (shown in Figure 3) revealed that the student correctly specified the type and number of the central atom and surrounding atoms (P and five F atoms, respectively), but the number of lone pair electrons on P atom (2 pairs) and the number of bond pair electrons (3 pairs) around P atom were incorrectly specified. This relates to the student drawing an incorrect Lewis dot structure, that is the two valence electrons of P atom did not share with two F atoms for bonding. When considering the molecular shape drawing, it was not related to the Lewis dot structure. It did not have a central atom and the bond angles were not specified. Also, the name of the shape was incorrect.

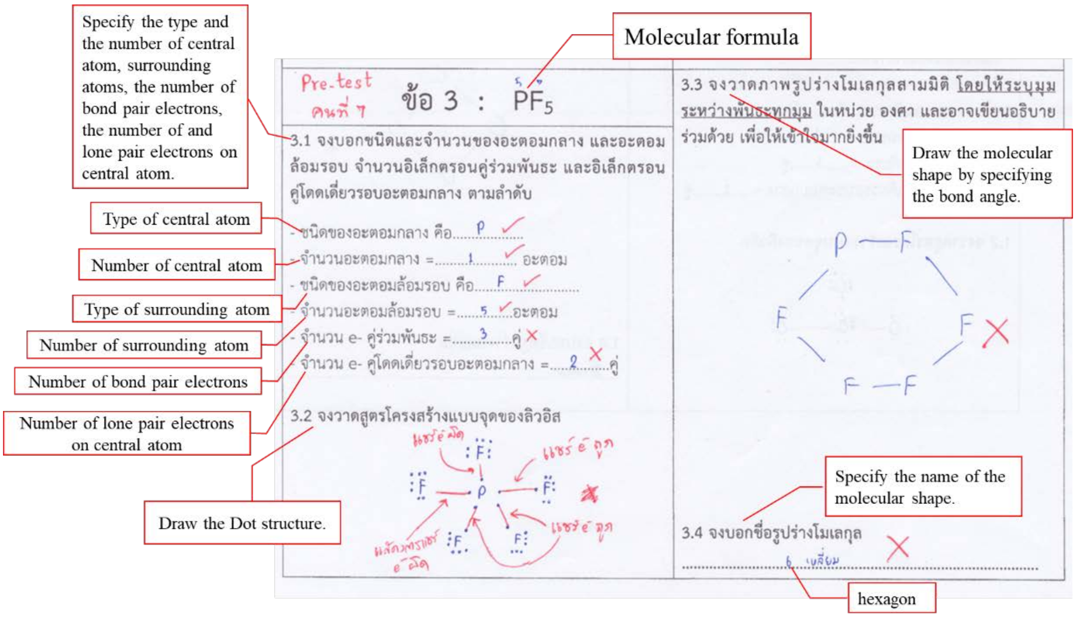


Figure 3: The students' answers of PF_5 molecule from pre-test at the SAC level (Student No. 7)

After learning with the Magnet and Pin kits, most of the students (75.76%) had a conceptual understanding at the SU level. For example, student number 3's answer (shown in Figure 4) revealed that the student could draw the correct Lewis dot structure, leading to the student correctly specifying that the P atom has no lone pair electrons due to all being used to form five bonds with the F atom. The molecular shape drawing, bond angle specifying (90^o and 120^o), and the name of the shape (trigonal bipyramid) are correct.

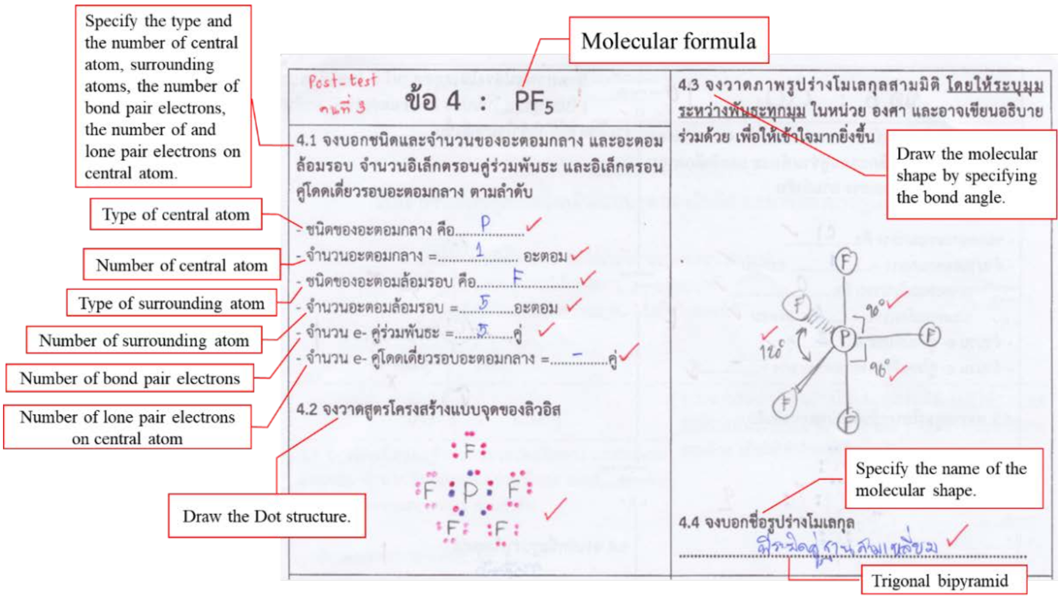


Figure 4: The students' answers of PF_5 molecule from post-test at the SU level (Student No. 3)

2. The molecular formula of ClO_4^-

Before learning, most of the students (60.61%) had a conceptual understanding at the NU level. For example, student number 1's answer (shown in Figure 5) revealed that the student incorrectly specified the O atom as the central atom but correctly specified the number of surrounding atoms for four atoms, which may be obtained by guessing from the subscript number on O atom in the ClO_4^- formula. The specification of the number of bond pair electrons (7 pairs) and lone pair electrons (6 pair) was incorrect. The molecular shape of ClO_4^- was incorrectly drawn and the name of shape was incorrect.

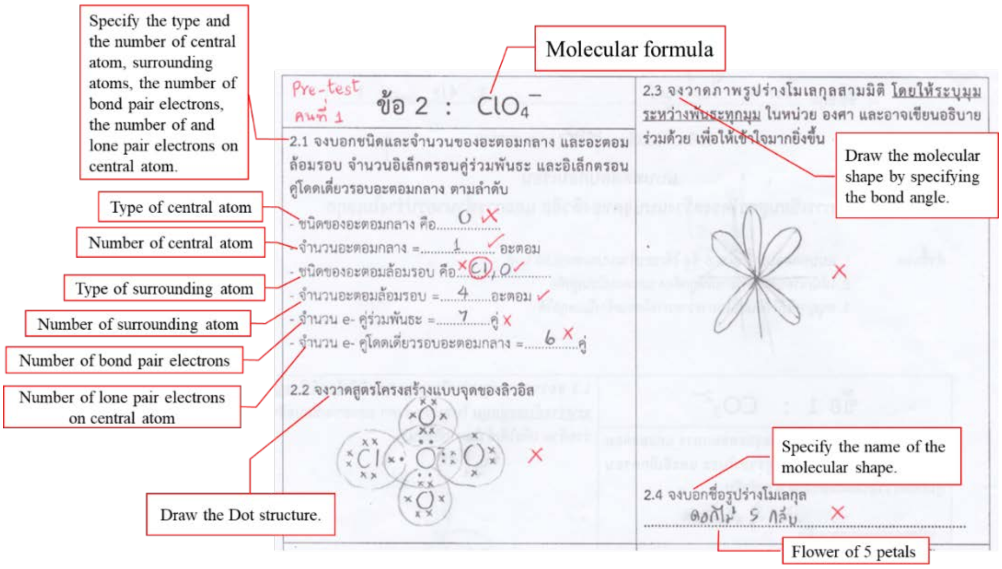


Figure 5: The students' answers of ClO_4^- molecule from pre-test at the NU level (Student No. 1)

After learning with the Magnet and Pin kits, most of the students (45.45%) had a conceptual understanding at the PU level. For example, student number 33's answer (shown in Figure 6) revealed that the student could draw the correct Lewis dot structure, which is related to correctly specifying that the Cl atom has no lone pair electrons due to all the valence electrons being used to form a covalent bond and three coordinate covalent bonds with O atoms. The drawing of the molecular shape and the name of shape (tetrahedral) were correct, but the bond angles of 90^o and 120^o were incorrect (The correct answer is ~109.5^o).

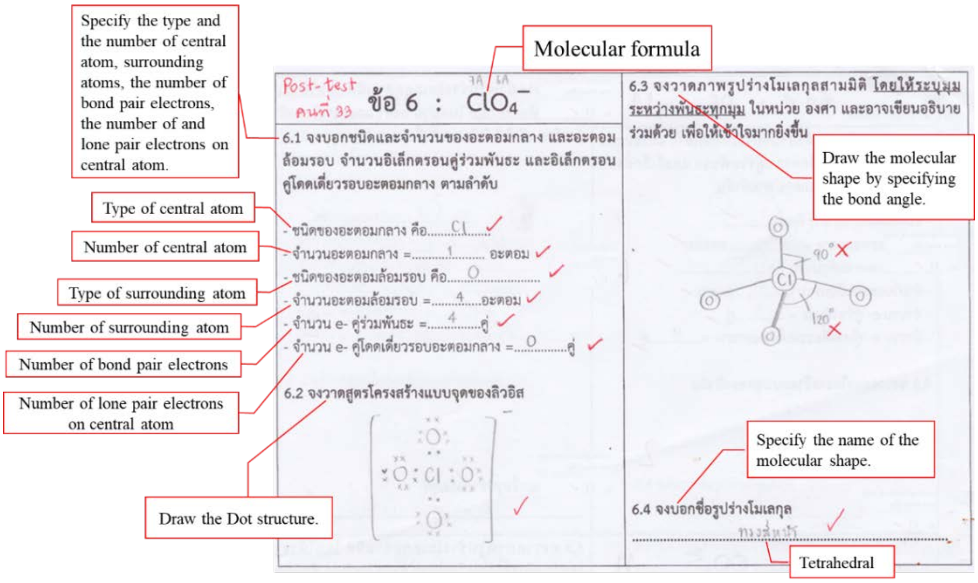


Figure 6: The students' answers of ClO_4^- molecule from post-test at the PU level (Student No. 33)

3. The molecular formula of CO_3^{2-}

Before learning, most of the students (69.70%) had a conceptual understanding at the NU level. For example, student number 31's answer (shown in Figure 7) revealed that the student correctly specified a C atom as the central atom and three O atoms as the surrounding atoms. The specification of the number of bond pair electrons (4 pairs) was correct but the number of lone pair electron (0 pair) was incorrect. The Lewis dot structure was improperly drawn due to the C atom having a lone pair electron and more than six valence electrons of the right-handed O atom. The molecular shape of CO_3^{2-} was incorrectly drawn and the name of the shape was incorrect.

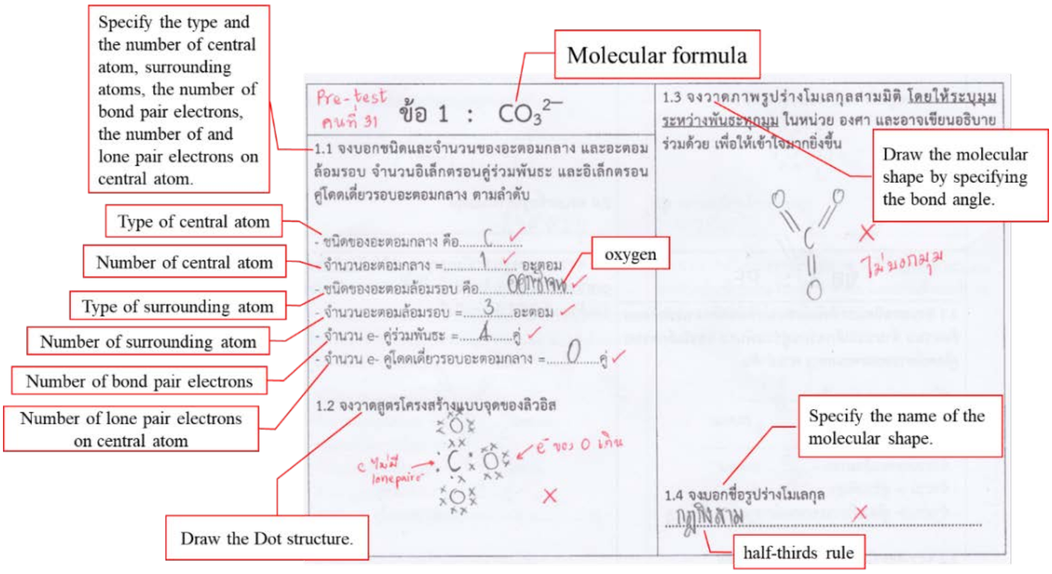


Figure 7: The students' answers of CO_3^{2-} molecule from pre-test at the NU level (Student No. 31)

After learning with the Magnet and Pin kits, the percentages of students at the PU and SU levels are the same (36.36%). For example, at the PU level, student number 26's answer (shown in Figure 8) revealed that the student could specify the C atom as the central atom and three O atoms as the surrounding atoms. The number of bond pair electrons (4 pairs) and lone pair electron (0 pair) was correct. The molecular shape and the name of the shape (trigonal planar) were correct. However, the Lewis dot structure was incompletely drawn due to more than four valence electrons on the C atom and missing six valence electrons of the left-handed O atom. While student number 20's answer (shown in Figure 9) was classified at the SU level because the answers are the same as student number 26, the Lewis dot structure was correctly drawn.

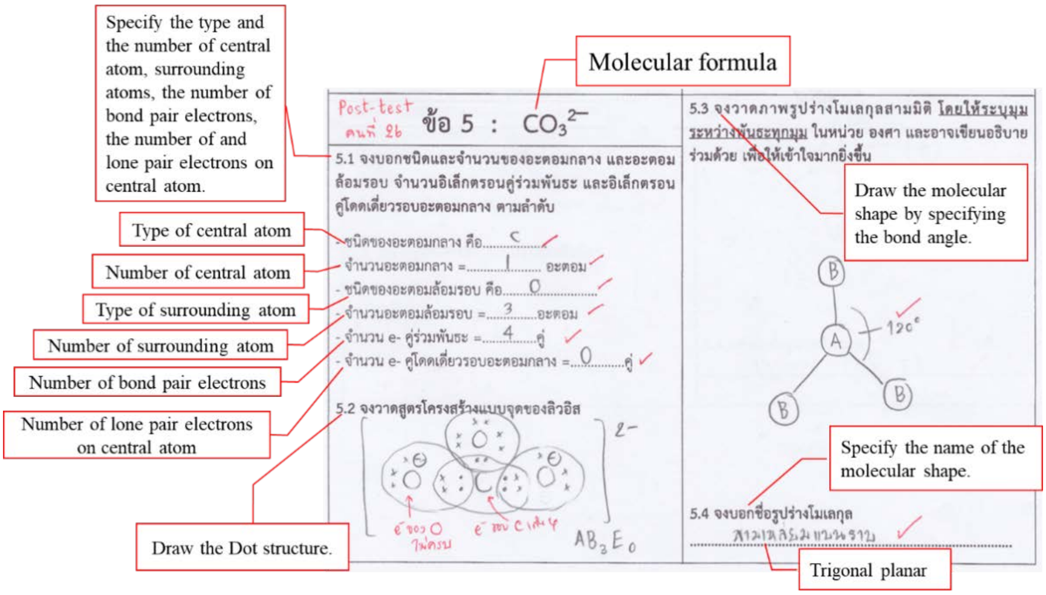


Figure 8: The students' answers of CO_3^{2-} molecule from post-test at the PU level (Student No. 26)

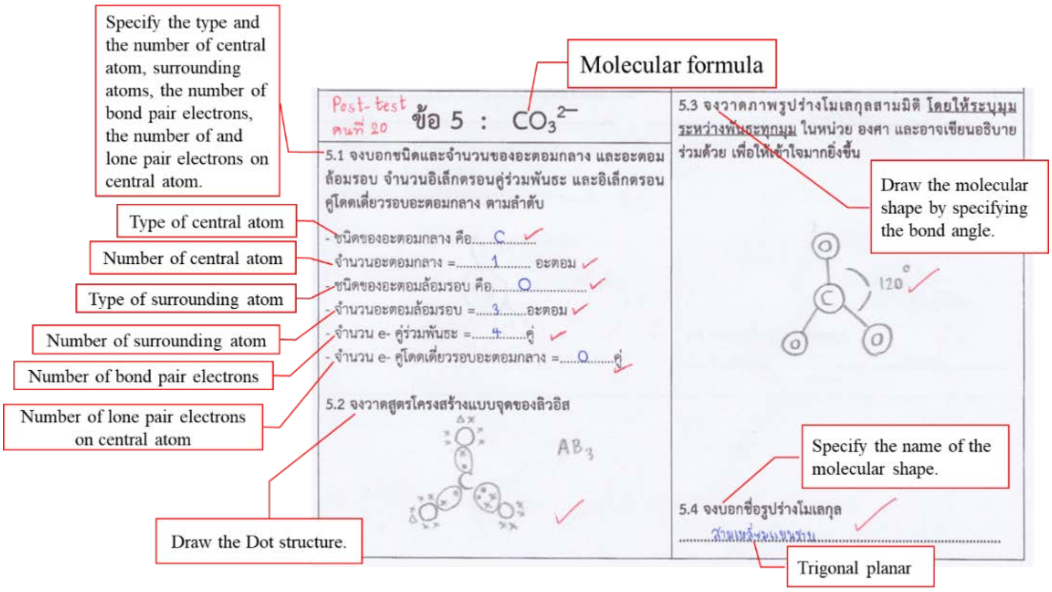


Figure 9: The students' answers of CO_3^{2-} molecule from post-test at the SU level (Student No. 20)

4. The molecular formula of O_3

Before learning, most of the students (69.70%) had a conceptual understanding at the NU level. For example, student number 6's answer (shown in Figure 10) revealed that the student correctly specified an O atom as the central atom and the remaining two O atoms as the surrounding atoms. But the student drew line structures instead of dot structures. This may have led to the incorrect molecular shape drawing and name of the shape.

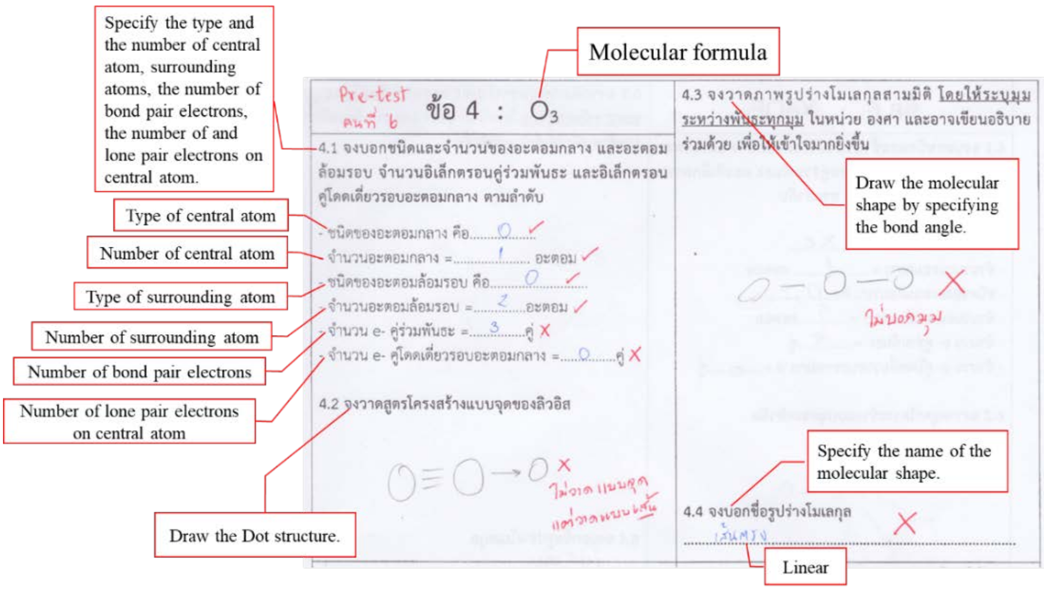


Figure 10: The students' answers of O_3 molecule from pre-test at the NU level (Student No. 6)

After the learning activity, most of the students (42.42%) had a conceptual understanding at the PU level. For example, student number 8's answer (shown in Figure 11) revealed that the student drew the Lewis dot structure with a slight error: the number of valence electrons on O atom as the central atom exceeded eight after sharing in covalent bond. However, the student knew that the O atom as the central atom has one lone pair electron, therefore making it possible to correctly specify the name of the molecular shape as V-shape (or bent) with the bond angle of lower than 120^o.

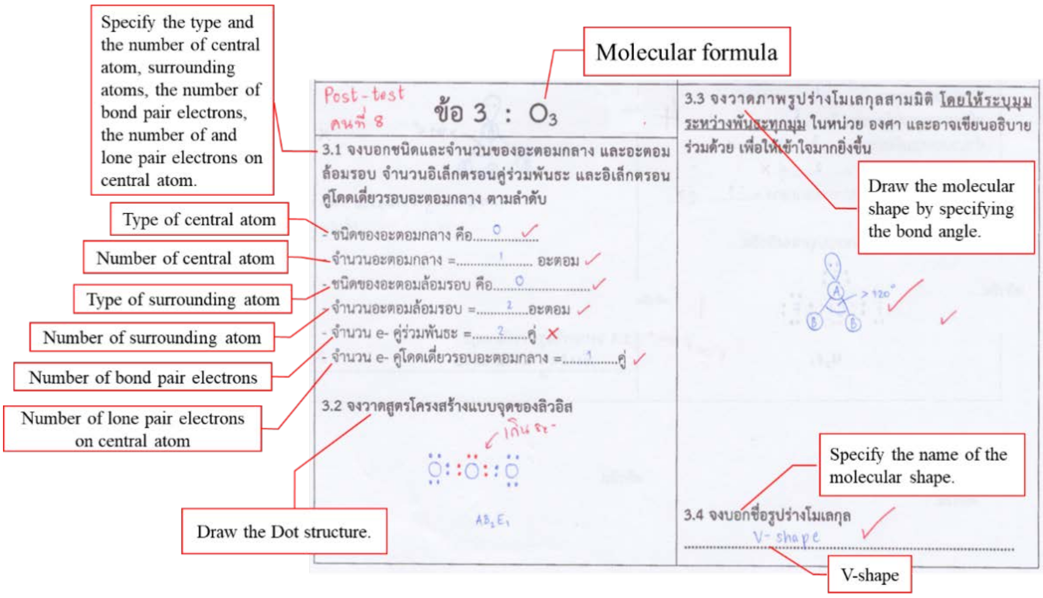


Figure 11: The students' answers of O_3 molecule from post-test at the PU level (Student No. 8)

5. The molecular formula of ClF_3

Before learning, most of the students (57.58%) had a conceptual understanding at the NU level. For example, student number 8's answer (shown in Figure 12) revealed that the student correctly specified a Cl atom as the central atom and three F atoms as the surrounding atoms. Both the number of bond pair electrons (7 pairs) and lone pair electron (7 pair) were incorrectly specified. The Lewis dot structure was improperly drawn due to the Cl atom bonding with three F atoms as the coordinate covalent bond and missing seven valence electrons of all the F atoms. However, the student did not answer the question on the molecular shape and the name of shape.

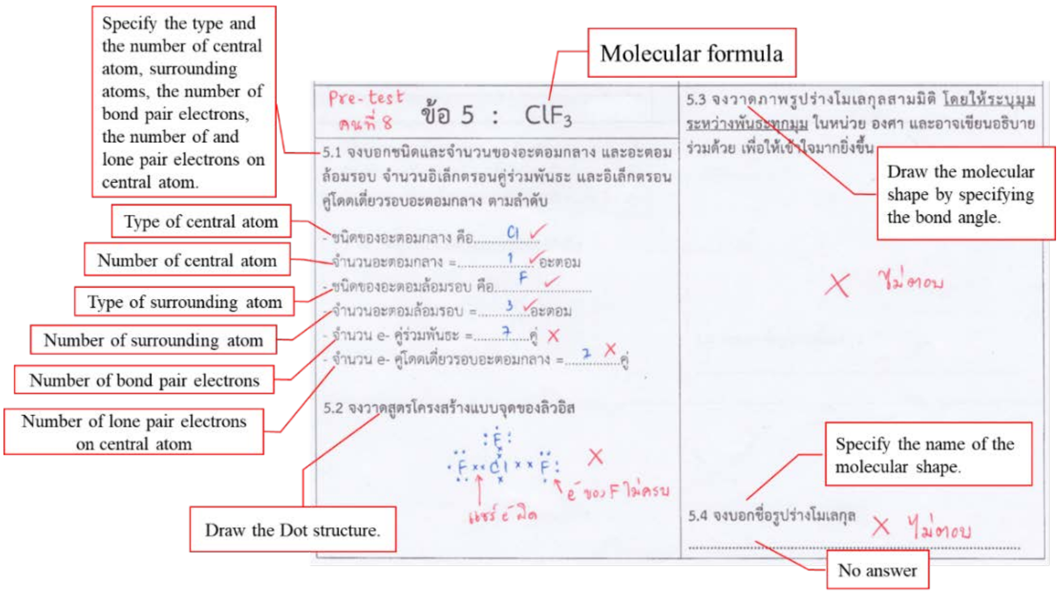


Figure 12: The students' answers of ClF_3 molecule from pre-test at the NU level (Student No. 8)

After learning with the Magnet and Pin kits, most of the students (45.45%) had a conceptual understanding at the SU level. For example, student number 6's answer (shown in Figure 13) revealed that the student could draw the correct Lewis dot structure, leading to correctly specifying those two lone pair electrons on the Cl atom and three bond pair electrons around the Cl atom. The molecular shape drawing, bond angle specifying as lower than 90°, and the name of the shape as T-shape are correct.

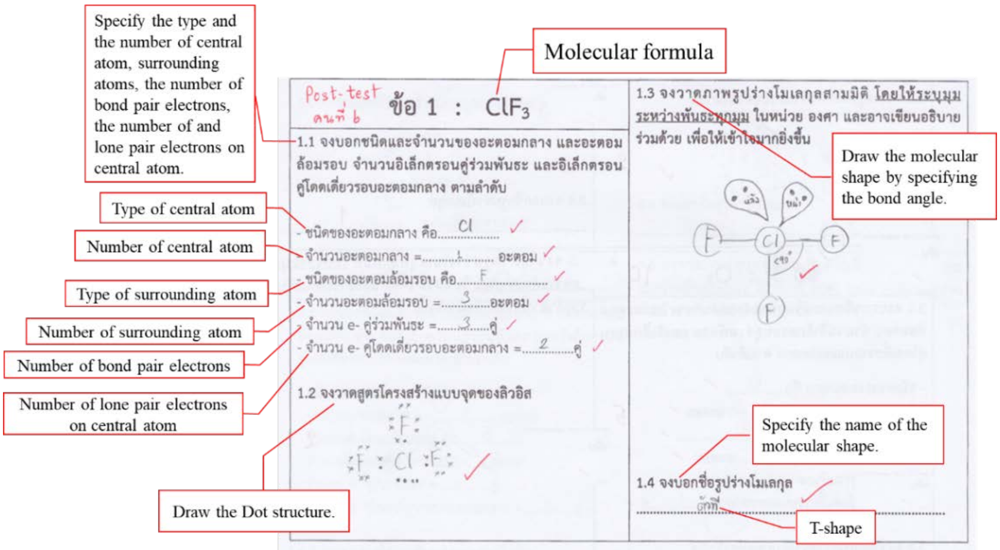


Figure 13: The students' answers of ClF_3 molecule from post-test at the SU level (Student No. 6)

6. The molecular formula of $XeOF_4$

Before learning, most of the students (66.67%) had a conceptual understanding at the NU level. For example, student number 26's answer (shown in Figure 14) revealed that the number of the central atom is two O atoms, the type of surrounding atom is F and Xe atoms, the number of surrounding atoms is 28 atoms, the 5 pairs of bond pair electrons and the 2 pairs of lone pair electron were incorrectly specified. The Lewis dot structure was incorrectly drawn. The molecular shape of $XeOF_4$ was incorrectly drawn and the name of the shape was incorrect.

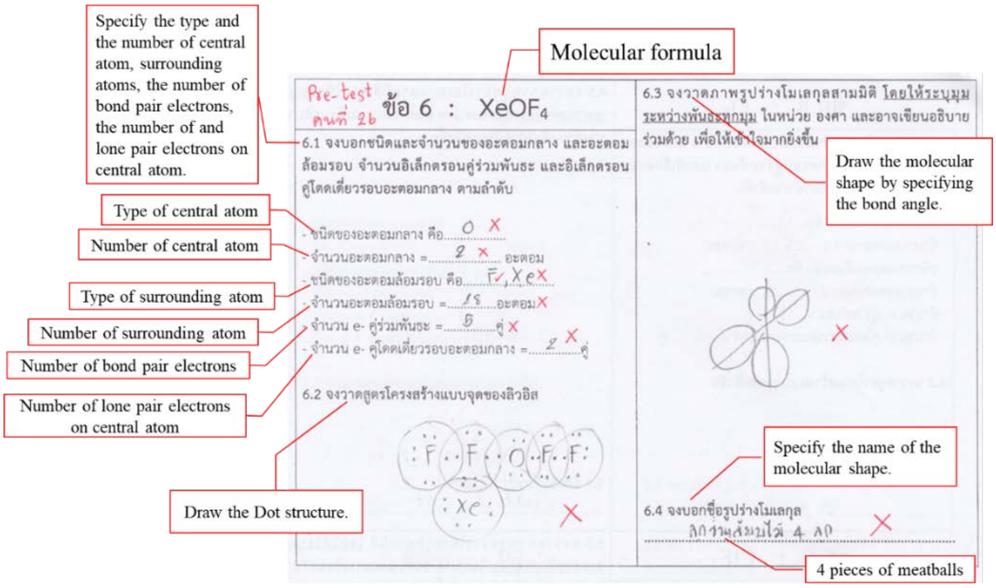


Figure 14: The students' answers of $XeOF_4$ molecule from pre-test at the NU level (Student No. 26)

After learning with the Magnet and Pin kits, the percentages of students at the PU and SU levels are very close (33.33% and 27.27%, respectively). For example, at the PU level, student number 16's answer (shown in Figure 15) revealed that the student could specify the Xe atom as the central atom and five surrounding atoms (O and F atoms). The number of lone pair electrons (1 pair) was correct, but the number of bond pair electrons (4 pairs) was incorrect. The molecular shape drawing and name of the shape as a square pyramid were correct. And the Lewis dot structure was perfectly drawn. While student number 9's answer (shown in Figure 16) was classified at the SU level because the Lewis dot structure was perfectly drawn, and all the answers were correct.

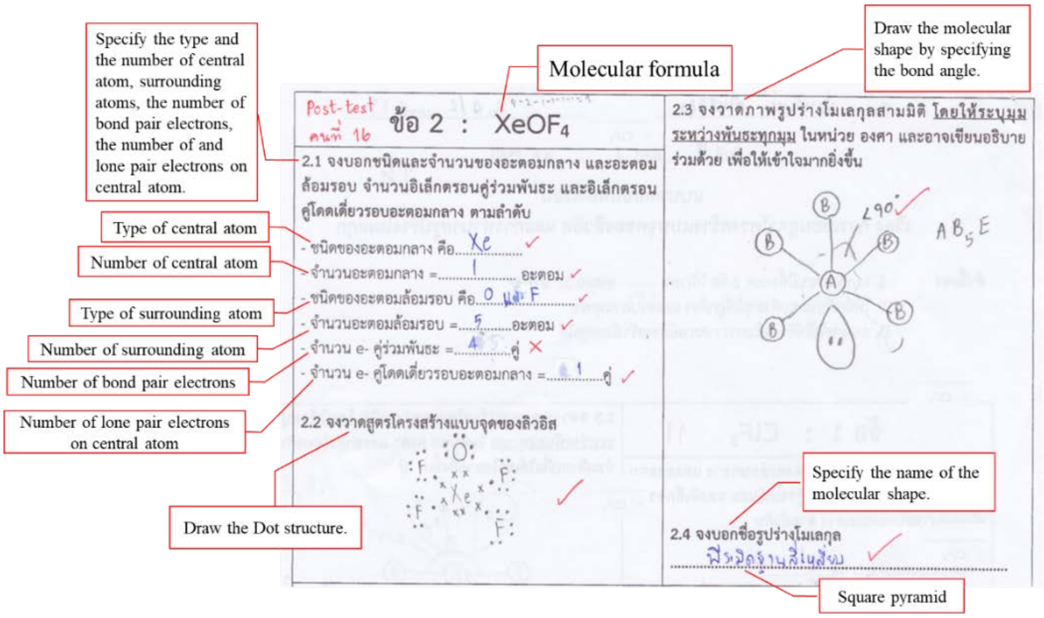


Figure 15: The students' answers of $XeOF_4$ molecule from post-test at the PU level (Student No. 16)

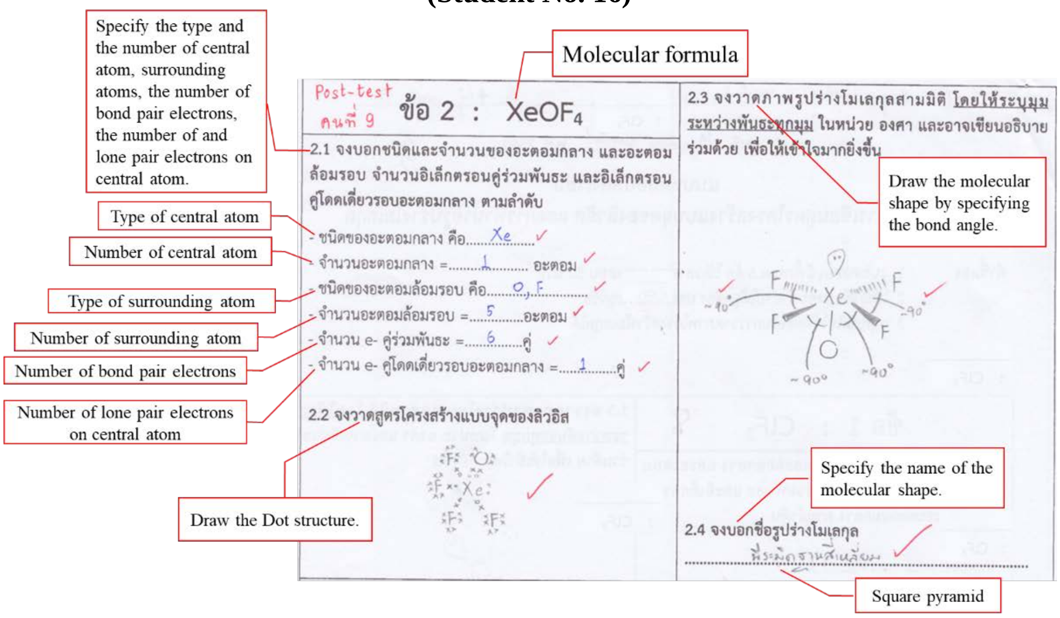


Figure 16: The students' answers of $XeOF_4$ molecule from post-test at the SU level (Student No. 9)

CONCLUSION AND DISCUSSION

The study of grade 10 students' conceptual understanding of Lewis dot structure and molecular shape from learning by using the Magnet and Pin kits found that before the learning activity, most of the students had a conceptual understanding at the NU level of the ClO_4^-, CO_3^{2-} ,O_3, ClF_3, $XeOF_4$ molecular formulas and had SAC level understanding of the PF_5 molecular formula. It showed that the students' conceptual understanding of all molecules was very low. After learning with the Magnet and Pin kits, most of the students' conceptual understanding level increased to the SU level for the PF_5, CO_3^{2-}, ClF_3 and $XeOF_4$ molecular formulas and the PU level for the O_3 and ClO_4^- molecular formulas. This shows that the use of Magnet and Pins kits to learn the drawing of the Lewis dot structure and the molecular shapes prediction can help students increase their understanding to the overall higher level of conception from NU & SAC to SU & PU levels. The students could specify the type and number of central atoms, surrounding atoms, number of bond pair electrons, and lone pair electrons with more than 70% accuracy. The students could also draw the Lewis dot structure correctly and perfectly. There may, however, be a slight misspecification of the number of valence electrons. The students could draw images to represent three-dimensional shapes of molecules and correctly specify the name of molecular shapes. It showed that learning by the Magnet and Pin kits can reduce the number of students at a low level (NU & SAC) of conceptual understanding and increase the number of students at higher levels (SU & PU) of conceptual understanding.

Students used the Magnet kit as a navigational tool that reduces the complexity of drawing a Lewis dot structure before the actual drawing on paper. During this process, the teachers can help validate the correctness of the students' Lewis dot structure. Suggestions may be given by changing the position of the circular magnets instead of erasing the drawings on paper as per the traditional method. The Pin kit was used to create the 3D molecular structures based on the Lewis dot structures using VSEPR theory to predict the molecular shapes. The molecular shapes were constructed by sticking the pins on a spherical eraser with the widest angle. The teachers can help students to validate the molecular shape and give further explanations if they do not understand. In other words, the Magnet and Pin kits are a tool to help check conceptual understanding through conversations between teachers and students. The teacher can use it to examine the student's misconceptions, leading to the possibility of solving problems immediately (Kamkhou and Yuenyong, 2019).

This study showed how the Magnet and Pin kits provided students to learn about dot structure and molecular shape with analogy of Magnet and Pin kits. This could be mentioned that students constructed new knowledge when the intervention is mediated by what they already know (Udomkan et al., 2015; Yuenyong and Thathong, 2015). When dealing with abstract concepts, students require opportunities to create visual representations of these concepts in order to make sense of them (Tan and Yeo, 2022).

Çalik, Ayas, and Coll (2009) argued that a crucial constructivist concept emphasizes the value of learners' prior knowledge while constructing teaching activities or techniques. In other words, the learner attempts to relate new knowledge to what he or she already knows; this serves as the foundation for analogies. It indicates that the Magnet and Pin kits as analogy provides a process of mapping of shared attributes. Analogies operate for this reason, and the learner here is behaving similarly to a scientist (Coll, France, and Taylor, 2005).

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