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Using Simple Molecular Model to Enhance Students' Understanding on Molecular Geometry Based on VSEPR Theory

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Abstract: Using Simple Molecular Model to Enhance Students' Understanding on Molecular Geometry Based on VSEPR Theory. Numerous studies had reported that students in all level found that study chemistry is difficult. The main cause of the difficulty is the inability of students to visualize the atom or molecules. This study aims to enhance students' understanding by using the simple molecular model as the learning resources to help students visualize the shape of the molecules. To achieve the aim, this study employs one-group pre-test post-test design. A conceptual test was used as pre-test and post-test to measure students' understanding before and after learning with the simple molecular model. Fifty-four first-year cohort students of Chemistry Education Study Program of Department of Mathematics and Science Education of Faculty of Teacher Training and Education, Tanjungpura University were involved in this study. Students' pre-test and post-test scores were analyzed using a paired sample t-test with SPSS. Based on data analysis, a statistically significant improvement in scores (*p value* = 0.001) was found, which indicates that the Simple Molecular Model could enhance students' understanding on Molecular Geometry.

Keywords: simple molecular model, molecular geometry, vsepr theory, students' understanding.

Abstrak: Penggunaan Model Molekul Sederhana untuk Meningkatkan Pemahaman Siswa Pada Materi Geometri Molekul berdasarkan Teori VSEPR. *Berbagai penelitian telah melaporkan bahwa siswa di semua tingkatan mengalami kesulitan dalam belajar kimia. Penyebab utama dari kesulitan tersebut adalah ketidakmampuan siswa untuk memvisualisasikan atom atau molekul. Penelitian ini bertujuan untuk meningkatkan pemahaman siswa dengan menggunakan model molekul sederhana sebagai sumber belajar untuk membantu siswa memvisualisasikan bentuk molekul. Untuk mencapai tujuan tersebut, penelitian ini menggunakan rancangan one-group pre-test post-test. Tes konseptual digunakan sebagai tes awal dan tes akhir untuk mengukur pemahaman siswa sebelum dan sesudah pembelajaran dengan model molekul sederhana. Sebanyak 54 mahasiswa tahun pertama Prodi Pendidikan Kimia, Jurusan Pendidikan Matematika dan IPA, Fakultas Keguruan dan Ilmu Pendidikan, Universitas Tanjungpura terlibat dalam penelitian ini. Nilai pre-test dan post-test mahasiswa dianalisis menggunakan paired sample t-test dengan SPSS. Berdasarkan hasil analisis data, ditemukan peningkatan skor yang signifikan secara statistik (p value = 0,001), yang menunjukkan bahwa Model Molekul Sederhana mampu meningkatkan pemahaman mahasiswa tentang Geometri Molekul berdasarkan Teori VSEPR.*

Kata kunci: *model molekul sederhana, geometri molekul, teori tolakan pasangan elektron, pemahaman mahasiswa.*

▪ INTRODUCTION

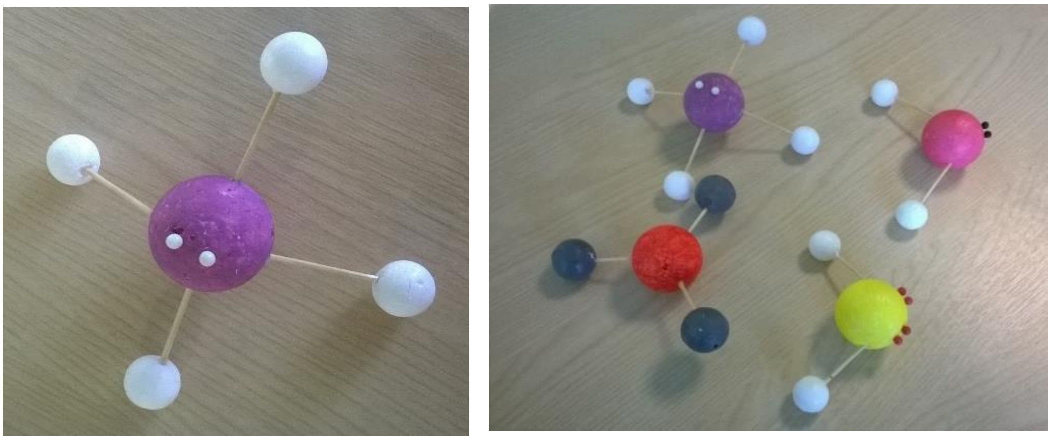
Molecular geometry is a key topic studied in General Chemistry courses due to its important role in determination of the physical and chemical properties of compounds (Meyer & Sargent, 2007). Hence, Gillespie (1997) suggested that this concept must be incorporated into general chemistry courses. Valence Shell Electron Pair Repulsion (VSEPR) theory is used to predict the shapes of simple molecules based on minimizing the electrostatic repulsion of electron pairs surrounding a molecule's central atom.

Previous research has shown that some students find the determination of molecular geometry to be challenging (Furio & Calatayud, 1996; Yilmaz & Özgűr, 2012; Uyulgan, Akkuzu, & Alpat, 2014; Saritas, 2015; Erman, 2017; Behera, 2019). A number of researchers have reported misconceptions related to this concept (Behera, 2019). Harrison & Treagust (1996) reported that grade 12 students (age 16 or 17) experienced the misconceptions related to the shape of molecules, whereas 25% of students (N=84) thought that the shape of molecules is due to only to the repulsion between the bonding electron pairs. Meanwhile, the other 22% of students stated that the shape of molecules is due only to the repulsion between the nonbonding electron pairs. This problem was also identified in Indonesia, as reported by Sumarni (2010) who stated that 74.2% of first-year students of Chemistry Education at the University of Semarang State (UNNES), Indonesia in the 2009/10 experienced misconceptions when drawing the shape of molecule. Students tend to ignore the effect of lone pair electrons around the central atom to the shape of the molecules.

Reflecting on my own three years' experience as a General Chemistry course pre-service chemistry instructor, I have found that many students struggle to predict the shapes of molecules correctly. Many students try to memorize the shape of common examples used in teaching which may mean they don't understand the factors that influence molecular geometry and are unable to derive the shapes of 'unseen' examples (Harrison & Treagust, 1996). An example of a determining factor that students often overlook is the presence of lone pairs of electrons, for example students predicting that ammonia will be trigonal planar because they ignored the lone pair electrons (Furio & Calatayud, 1996). Another common mistake made by students who don't learn the process is to ignore number of substituents around the central atom. Some students assume that molecules with similar formulae will adopt the same shapes. For example, when they asked to predict the shapes of the commonly seen example ammonia (NH_3) and the less commonly see boron trifluoride (BF_3) and some students assume they are both trigonal planar. This answer is incorrect, as ammonia has a central atom in group 15 of the periodic table (whereas boron trifluoride has a central atom in group 13 of the periodic table) so there is one lone (non-bonding) pair of electrons surrounding the central atom. This means the molecule adopts a trigonal pyramidal shape and the H-N-H bond angles are smaller than would be predicted for a shape with four bonding pairs of electrons around the central atom.

In order to be able to determine molecular geometries, students need to develop the ability to visualize molecules (including the central atom' substituents) as bonding and lone pairs of electrons. As suggested by Jones and Kelly (2015), visualization is a way of improving students' understanding of abstract concepts in chemistry. Visualization is known to play an important role in understanding chemistry concepts, such as chemical bonding, determination of the shapes of molecules, intermolecular forces, etc. Visualization and modelling tools offering more accurate and informative images of the molecular (or particulate) level to be used to describe how atoms and molecules might interact and move (Jones & Kelly, 2015). Based on the work of Jones and Kelly, this study incorporated a simple molecular model building activity that made a clear distinction between bonding pairs and lone pairs of electrons. The impact of this activity on overcoming students' common misconceptions was investigated.

To describe the molecules, teachers usually use the Molymod® set. Molymod® consist of atoms in different colors and can be connected to other molecules easily using the sticks to form specific shapes. These kits can be used to describe some key chemical concepts, such as the bond between atoms, hydrocarbon, polymer, or molecular structure. However, Molymod® models do not allow lone pair electrons to be shown when describing molecular geometry. Therefore, this model cannot fully describe the effect of lone pair electrons on the shapes of molecules.



(a) **(b)**

Figure 1. (a) (b). Simple molecular model made from polystyrene balls, cocktail-sticks and map pins.

On the other hand, simple molecular model as presented in Figure 1, made from polystyrene balls could describe the unshared electron around the central atom by putting the map pins. Therefore, students will learn how the unshared electron at central atom will affect the shape and bond angle of molecules. In order to facilitate visualization of the 3D structures of the molecule, students had to build simple three-dimensional models of the molecules, clearly indicating the locations of bonding and lone pairs of electrons.

▪ METHOD

The study conducted in Faculty of Teacher Training and Education (FKIP), Department of Mathematics and Science Education, Tanjungpura University, Pontianak. Fifty-four first-year cohort students from Department of Chemistry Education Faculty Teacher Training and Education, Department of Mathematics and Science Education, Tanjungpura University were voluntarily participated in this study which consist of 2 classes A1 and A2. All students involved in the study took the questionnaire and both tests (pre-test and post-test).

This study employs a quasi-experiment with one-group pre-test and post-test design.

Data Collections

Two methods were used to collect data in this project: questionnaires, tests to measure students' understanding before and after using the molecular model. The first method of data collection involved the use of questionnaires to collect students' feedback, comments and suggestions related to the appearance, content, and value of learning experience of the molecular model. The statements were based on closed-questions using a five-point Likert scale (strongly agree, agree, neutral, disagree and strongly disagree). The questionnaires were circulated to participants at the end of each part of the study, after the learning process. The questionnaire consists of 7 statements.

The second data collection method employed in this study was conceptual testing. This approach makes use of pre-tests before, and post-tests after the intervention. These tests were designed to measure the conceptual understanding of participants before and after the learning process using the molecular model. Both tests made use of open-question type. The open-type question is an examination question that requires an answer in a sentence, paragraph, or short composition (Merriam-Webster Online Dictionary). The open-question type requires the student to recall the relevant factual information, organize the ideas, and write an extensive response. One of the advantages of using the open type questions is students are offer a chance to demonstrate their knowledge, skills, and abilities in a variety of ways. The conceptual tests used in this study is aimed for students to show their understanding of the molecular geometry. The post-test made use of analogous questions to those asked in the pre-test to ensure that level of difficulty of each test was consistent. The conceptual test consists of 3 short-open-ended questions. The second instrument is the response questionnaire consist of 7 statements. Both instruments were validated using content validity. Content validity involved 3 lecturers from Department of Chemistry Education, Faculty Teacher Training and Education, Tanjungpura University. All validators stated that both instruments were valid and feasible to collect the data.

Data Analysis

Data which is collected through tests (pre-and post-test) and questionnaires was analyzed quantitatively. The score of both tests were analyzed using IBM SPSS Statistics 25. *Paired sample t-test* was used as data of students' pre-test and post-test score was related since the students involved are the same. According to Bryman and Cramer (2011) related or *paired sample t-test* can be used to compare the means of the same participants in two conditions or at two points. Questionnaire data was tabulated and analyzed using Microsoft Excel. Microsoft Excel was chosen based on two reasons, the first Microsoft Excel offers complete features to analyze the questionnaire data, such as the mathematical formula, graph, chart, etc. Secondly, it easy to use as Microsoft Excel has been familiar to the researcher. Microsoft Excel was used to show the percentage of students' perceptions and views based on the questionnaire data. It also used to tabulate the pre-test and post-test data prior to the SPSS analysis.

▪ RESULT AND DISCUSSION

The simple molecular model was used in the learning process for teaching molecular geometry based on VSEPR Theory. On the day of the study, a pre-test was given before students start the activity. The format of the pre-test is short answer questions, comprise of 3 questions.

Students started the activity by reading the brief explanation of the theory. They then answered each question. After correctly identifying the shape of the molecule, students worked on assembling a molecular model. Students then recorded a log of the steps needed to predict the shape of molecule in their own words. The last step of the process was a discussion of the molecular model with the instructor. Each pair then presented their model to the other students. The instructor provided feedback on whether the model was correct or not. A questionnaire was given to students after the activity was done. The questionnaire consists of seven statements. The questionnaire adapted Likert scale type with 5 options to gather students' responses related to the Simple Molecular Model.

Students' Understanding of Molecular Geometry

In order to assess student understanding of the concepts, students were tested both before (pre-test) and after (post-test) the intervention, using the same set of questions. The format of the tests is the single tier short answer type questions, consist of 3 questions. The questions asked the students to predict the shape of different molecules and to provide their reasoning. Details of the comparison of students' pre-test and gains scores can be seen on Figure 2.

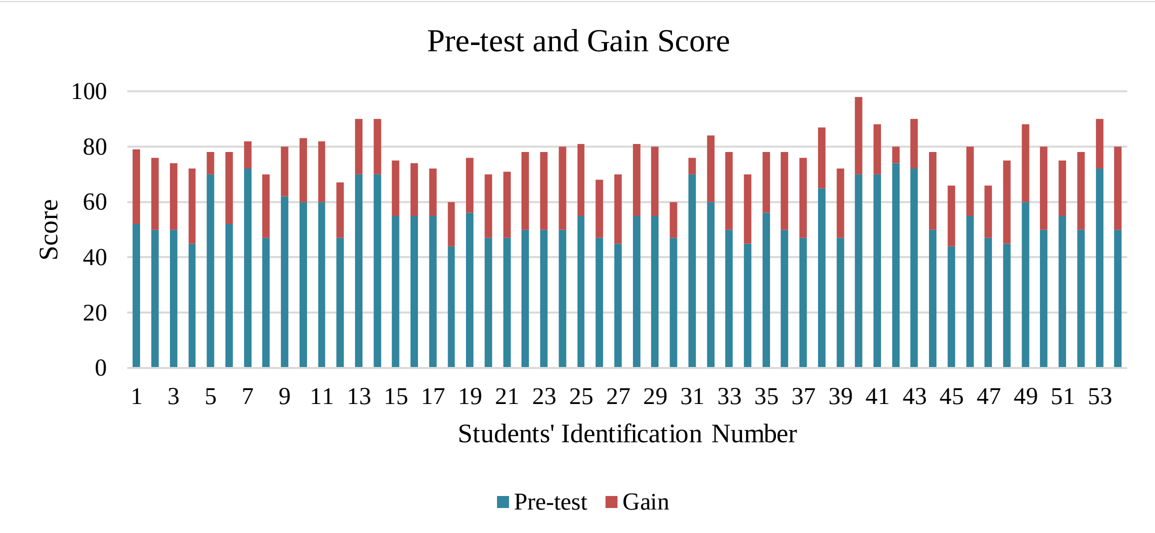


Figure 2. Students' Pre-test and Gain Score (N=54)

Figure 2 presented data of students' pre-test and gain score (the difference score between post-test and pre-test). The maximum scores for both pre-test and post-test are 100. As can be seen on Figure 2 that the performance of all students improved between pre-test and the post-test. Eleven students scored above 80 for the post-test.

Students' pre-test and post-test scores were grouped into six different categories as presented in Table 1. Based on the table, 28% of students achieved pre-test score in the lowest category (below 49/100) whereas no students achieved this category in the post-test. This may suggest that students experienced some misconception related to molecular geometry concepts and poor understanding. A further research would be needed to confirm this. The highest percentage is 43%, that fell into the second category (50-59/100) but again no students reach this category in the post-test.

Table 1. Pre-test and Post-test range Score

Score range	**% Pre-test**	**% Post-test**
<49	28	0
50-59	43	0
60-69	11	11
70-79	19	50
80-89	0	30
90-100	0	9

The most stands out percentage is 30% of students got between 80-90 at post-test. In addition to that, 9% of students achieved score between 90-100 at post-test. Overall, students' post-test scores were better compared to those pre-tests' scores as none of them got less than 60 points as presented on Figure 3.

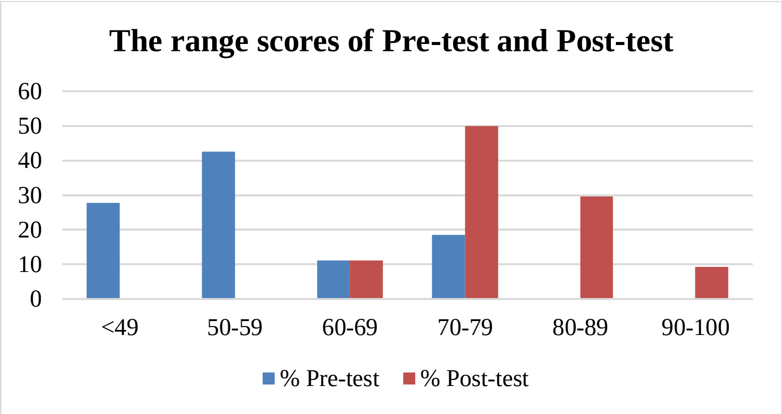


Figure 3. The percentage of students' range score on pre-test and post-test

To verify the findings, both pre-test and post-test data were analyzed using a paired samples *t*-test, which demonstrated a statistically significant difference between the pre-test and post-test scores (*p-value <0.001*). The results indicate that the activity of playing the assembling molecular model can effectively support student learning of this concept. Details of the *t*-test results are reported in Table 2.

Table 2. The result of Paired Samples t-test

Score	**Mean**	**N**	**SD**	***Correlation***	***t Value***	***p Value***
Pre-test	55.07	54	9.049	.760	-27.861	.000
Post-test	77.52	54	7.560			

The increasing score of students' score on post-test perhaps due to the simple molecular model allow students to visualize the 'real' shape of the molecule. They can see why the molecules adopt a different shape. As stated by Jones & Kelly (2015) that visualization play an important role to learn chemistry. Vavra, *et al* (2011) also suggested to apply the visualization in science learning process. In addition to that, emphasizing the integration of the three levels of representations (macroscopic, symbolic, and sub-microscopic) will enhance students' understanding (Yakmaci-Guzel & Adadan, 2013; Tuysuz, *et al*, 2011; Sutrisno, Poedjiastoeti, & Sanjaya, 2017).

Students' Perceptions and Responses to Simple Molecular Model

The findings in this section are presented based on the result of the questionnaire, which presented in table and graph. Table 4 presented the seven statements used in the questionnaire along with the percentage of students' agreement on Likert scale. Meanwhile, the graph shows the proportion of students' responses for each statement of the questionnaire.

Table 4. Students' responses to the Likert statements in the questionnaire (N=54)

No	Statements on the first section of the questionnaire	Percentage (%)				
		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	The instructions are clear and understandable	-	-	-	39	61
2	The steps to predict the shape of molecules presented in worksheet helped me understand the topic	-	-	-	54	46
3	I understand how to predict the shapes of molecules after playing the game	-	-	-	33	67
4	I enjoyed learning with the molecular model	-	-	-	56	44
5	The presentation of the molecular model is interesting	-	-	-	61	39
6	Assembling the molecular model using polystyrene balls and cocktail sticks was useful	-	-	-	50	50
7	Making the molecular models helped me understand the influence of lone pairs of electrons on the shapes of molecules	-	-	-	52	48

Figure 4 portray the proportion of students' responses to the statements of the questionnaire. Majority of students are either agree or strongly agree to all items. Students either agree or strongly agree to all the statements. The most notable is statement no 6 with 100% (50% agree and 50% strongly agree) stated that they are strongly agree and agree that assembling the simple molecular model using polystyrene balls and cocktail sticks was useful. Overall, students showed a positive response toward the Simple Molecular Model. Based on the result presented in Table 4 and Figure 4, it can be seen that students show a positive response. The average level of agreement for all the statements was 99.3%, thus, it can be concluded that student attitudes towards the activity were very positive.

A positive response towards the simple molecular model may because of the topics presented in the engaging way. To gain students' interest, a teacher should use a different approach depend on the topic. As suggested by Wu & Foos (2010); Moreno, Hincapié, & Alzate (2014); Bayir (2014); Marti-Centelles & Rubio-Magnieto (2014); Knudtson (2015); Erlina, Cane & Williams (2018); Tsai, *et al*., (2020) chemistry can be presented in a fun way to engage students. Conceivably, students enjoy learning with the simple molecular model as they can assemble the models based on the molecular geometry of the molecules.

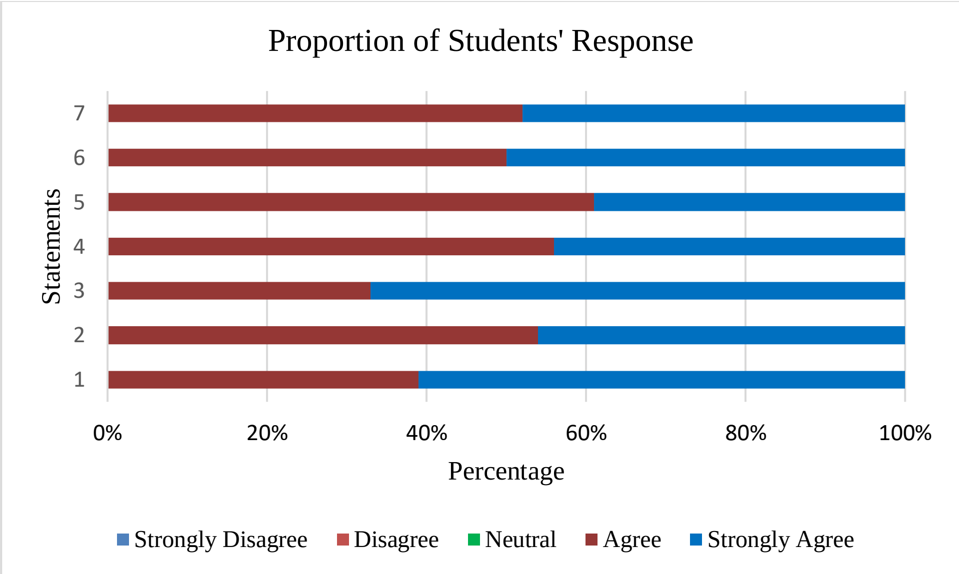


Figure 4. Proportion of students' responses (N=54) to the Simple Molecular Model

▪ CONCLUSION

Based on the findings, the simple molecular model using polystyrene balls could improve students understanding on the geometry molecules. This model allows students to grasp the influence of the lone pair to the molecular geometry as well as the bond angle. Students also shown a positive response toward the simple molecular model. This simple molecular model could be used as a learning resources to teach chemical bonding or organic chemistry. In addition to that, high school chemistry teachers could use this model in the classroom for teaching chemistry as the polystyrene balls were cheap and easy to get. In the future a research to measure the effectiveness of this molecular models should be carried on.

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