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ENHANCEMENT OF INDONESIAN HIGH SCHOOL STUDENT CONCEPTUAL MASTERY ON VSEPR TOPIC USING VIRTUAL SIMULATION OF MOLECULE SHAPES: A CASE STUDY OF QUASI-EXPERIMENTAL EVIDENCE

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ABSTRACT

The Valence Shell Electron Pair Repulsion (VSEPR) is an essential topic for high school student's fundamental understanding of 3D shapes of chemical compounds. Due to the spatial aspect of the topic, the students were forced to imagine the geometry of the molecule by predicting the free or bonded electron pair repulsion. Suitable learning media to accommodate those features should be precisely selected to help students properly understand the geometry of the molecule based on the VSEPR topic. This study compared the significant difference in the application of two media of animation video and interactive simulation toward the control and experimental groups, respectively, to enhance conceptual mastery of the VSEPR topic. This study was a statistical quasi-experiment study with two classes of control (animation video) and experimental (interactive simulation) groups. The results of the significant difference test of the groups showed that the distribution of the experimental and control groups was not normal (significantly different) and normal (not significantly different), respectively. Analysis results using Mann-Whitney for the non-parametric free two samples comparative test with a 95% confidence level showed that the application of virtual simulation on the experimental group impacted more in improving the conceptual mastery of the VSEPR topic. Furthermore, there was an identified significant improvement in sub-concepts of the VSEPR topic in binding pair, molecular shape, and electron repulsion. These findings could support the teachers in designing lesson plans for students to master the VSEPR topic.

Keywords: conceptual mastery; learning media; virtual simulation; VSEPR topic

INTRODUCTION

The VSEPR topic, as one of the chemistry topics at the high school level, emphasizes basic understanding of molecular geometry of simple covalent compounds. This concept is considered fundamental for a further chemistry topic, especially in organic chemistry and biochemistry. Many studies have reported that some students found difficulties in imagining three-dimensional structural molecule shapes (Rahmawati et al., 2021). The topic regarding the geometry of molecules categorized as abstract is the main reason for students' difficulties in properly visualizing molecule shapes (Kiernan et al., 2021).

Instead of using the widely used physical VSEPR model, sometimes called a moly mod kit, some digital learning media can also help students visualize the geometry of molecule shapes, for example, animation video, and virtual simulation. As multimedia-based learning and molecule visualizations have transformed over the past de-

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cades (Jones, 2013), various computer-generated chemistry models have been rapidly recognized by chemistry learners, especially in the topic concerned with three-dimensional molecular geometry.

In the previous 15 years, the availability of a dedicated computer laboratory has rarely considered for conducting student-oriented activities using computer-based learning media (Santos et al., 2019). Moreover, computer hardware and software should also be consistently updated to fulfill the intended requirement. Thus, the usage of computer-based learning in chemistry curriculum media is considered a cost-consuming activity for some schools. In common cases, teachers may select different approaches by showing the computer modeling in front of the classroom to enhance the understanding of the molecule structure topic (Springer, 2014).

Currently, many high school students have their own portable devices so that they can easily access computer-based learning resources (Becker et al., 2020). Accelerated by the Covid-19 outbreak, students have become more adapted to digital learning content and learning media through long-distance learning and search-engine habits (Ellianawati et al., 2021). This computerized learning era may also be beneficial for classroom activities of three-dimensional chemistry topics at the high school level since molecular geometry of simple molecules can be detail visualized in a three-dimensional perspective, is a main challenge of the VSEPR topic learning.

Precise learning media with suitable features can support a proper basic understanding of molecular structure concepts for students and support further understanding of complex molecular concepts (Rodenbough & Manyilizu, 2019). Virtual computer-based technology has been rapidly developed and used in chemistry topics with three-dimensional features, for example, the use of immersive virtual reality (IVR) as a device to support the learning of three-dimensional structures (Jiménez, 2019); virtual reality (VR) as an aid to stimulate positive attitudes during chemistry learning (Brown et al., 2021) that effectively enhance student chemical outcome and a tool to comprehend a particular biomolecular docking process; iPad as a touch-screen device effectively contributes to developing visuospatial and representational competence skills (McCollum et al., 2014), and computational software as a learning tool to properly obtain main concepts of molecule shapes (Ochterski, 2014).

Simulation is defined as simple visualization or a summarized model of actual matter or condition. Virtual simulation can visualize unobserved scientific phenomena and make students actively involved in the related virtual world so that they can optimally apply their knowledge, ability, and understanding (Al-Moameri et al., 2018). Many science teachers have used virtual simulation to simplify the abstract concept and explain the complex idea and complicated processes (Widiyatmoko, 2018), from explaining models of the hydrogen atom (Clark & Chamberlain, 2014) to visualizing three-dimensional porous molecular organic crystals (Jelfs & Cooper, 2013). To visualize a particular chemistry concept, it has been reported that interactive simulation is highly recommended for developing the conceptual mastery of students. Three-dimensional appearance of the simulation drives students to spatially visualize molecule shapes and to provide a deep understanding of the molecule shape concept (Smith et al., 2020). This attributed feature also helps students improve their conceptual mastery of molecule shapes. Therefore, virtual simulation has the potential features to help students understand the concept of molecular shapes based on the VSEPR topic.

Chemistry interactive simulation learning media developed by Colorado University named PhET (Physic Education Technology) can display chemical particle visualization to build student understanding (Perkins et al., 2010). An interactive PhET chemistry simulation is designed to enhance several learning goals (Moore et al., 2013). One of these interactive simulations focuses on the visualization of basic three-dimensional molecule shapes based on the VSEPR topic that can be actively operated by the students. This interactive and controllable virtual simulation has potential features to be used in a classroom activity to enhance high school students' conceptual mastery of molecule shape topics according to the VSEPR topic.

Alternatively, rapid developments in information and communication technologies have resulted in a tremendous global evolution in computers and smartphones. The development of animation videos in the smartphone apps also contributes to the learning culture (Szymkowiak et al., 2021). The use of videos in teaching is beneficial for the learning process (Mojica, 2019). The usage of video clips from movies, television series, and YouTube has proven to be potential to enhance the teaching and learning experience of different concepts in introductory chemistry. Most students consider that video clips are useful as they find them to be exciting, educational, and helpful for their learning process.

Animation videos can be designed to visualize abstract concepts of chemistry topics into illustrative molecular models and moving scenes, subsequently. The interactivity of common animation video-based learning media is displayed with several features, such as the ability to pause the video in a particular scene (and directly go to previous or next video content), control the video speed, and generate limited "communication" between the narrator and the viewer by adding speech along the story-line or by putting designed subtitles. Observations have shown that by viewing the video, high school students can obtain more detail about the technical aspects of the chemistry laboratory than by listening to the presentations of professional scientists (Burgin et al., 2020). The animation videos have been proven to help students understand complex chemistry topics at the molecular level, such as topics regarding dispersion interactions (Gottschalk & Venkataraman, 2014) and electron transport chain (Wikandari et al., 2021). Video usage in chemistry learning is predicted to grow since the popularity of open-source YouTube videos platform. It has been observed that YouTube videos help students obtain an understanding of the chemistry topic of "group properties" (Bohloko et al., 2019). YouTube videos are available 24/7 for students showing pedagogical benefits that enable students to continue to review the videos even after the completion of the class (Ranga, 2017). Currently, there is a novel technique of video-based learning through an assignment of video-making (YouTube) as an alternative and enjoyable approach to the article-writing task (Smith, 2014).

Virtual simulation and video animation have the potential features to be used in a classroom activity to enhance high school students' conceptual mastery of molecule shape topics according to the VSEPR topic. However, there is no report regarding the comparison of the significant differences in the application of these two media in mastering the VSEPR concept. The current research compares the application of virtual simulation and video animation in the control and experimental group, respectively, to enhance conceptual mastery of the VSEPR topic.

METHODS

The subject sample of the study was 64 Public High School students in Bandung, Indonesia. They were in the first semester of the tenth grade. The subject sample was divided into two groups, control, and experimental groups. The method used in this study was quasi-experimental with a pretest-posttest design of a nonequivalent control group (Nicolaidou et al., 2021). In this design, a minimum of two groups was required in which each group acted as an experimental group and a control group (Wiersma & Jurs, 2009; Gopalan et al., 2020). The experimental design is presented in Figure 1. Where O_1 and O_2 were the pretest and posttest, respectively. X_1 and X_2 were learning processes in mastering the VSEPR topic using the virtual simulation of PhET Molecule Shapes and video animation, respectively.

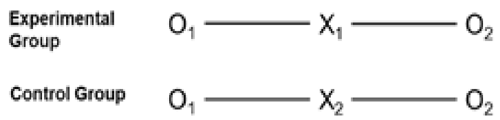

Figure 1. Experimental Design of Quasi-Experimental with Pretest-Posttest Design of Nonequivalent Control Group

Student learning experiences of both groups in X_1 and X_2 provided an idea of the shape of the molecule: linear, bent, trigonal planar, tetrahedral, trigonal pyramidal, seesaw, T-shape, rectangular planar, rectangular pyramid, and octahedral. Furthermore, the students also learned about bonding pairs, electron repulsion, and molecule polarity. The pretest and posttest instruments contained 25 multiple-choice questions that were completed in short essay form to explain the reason for selecting the answer. The question represented a sub-concept of the VSEPR topic, i.e., bonding pairs (items no 2 and 3), electron pairs (items no 1 and 4), molecule shapes (items no 5–18), electron repulsion (items no 19 and 20), and polarity of the molecule (items no 21–25). The scoring guidelines followed the rule: score 2 if the both answer and reason were correct, score 1 if the answer was correct but the reason was wrong, and score zero if both the answer and reason were wrong.

The research instrument was then validated by the expert to confirm the compatibility of test items with the learning indicators. After the content had been validated, the instrument was tested on 129 students in the eleventh grade who had acquired the VSEPR lesson in the tenth grade. The test result was then analyzed by the Item and Test Analysis (ITEMAN) program version 3.00 to obtain the data on difficulty level and item discrimination index. This data could be the basis for the items whether it required to be revised or not. Next, the research instrument was tested for reliability using Kuder and Richarson 20 (KR-20) with an accepted reliability index at a minimum value of 0.60 (Osadebe & Nwabeze, 2018).

At first, a pretest was provided to the experimental and control group. Pretest was useful for checking equality between the two groups (Wiersma & Jurs, 2009). Then, different treatments were administered to the two research groups at the time of learning. The treatment given to the experimental group used virtual simulation of PhET Molecule Shapes, while the control group used video animation. After the learning process, both groups were given a post-test. The post-test questions were the same as the pretest.

The scores obtained from the pretest were then analyzed to determine the significant differences between the control and experimental groups. After the learning process, the post-test was scored and converted into a normalized gain (N-gain) score. The average %N-gain between the two groups was compared using the statistical tool SPSS 17.0, including the normality test, homogeneity test, and independent t-test for parametric data or Mann-Whitney test for non-parametric data.

RESULTS AND DISCUSSION

The average pre-test scores of the two groups being studied were obtained from the instrument tools with a 0.61 reliability index. The results of validity and reliability analysis are presented in Supplementary Files 1 and 2, respectively. The differences in pre-test results appeared as not significant for both groups being studied (0.818) as displayed in Table 1. Both average scores appeared in a relatively low score (score range 0–100). This indicates that the students have not been exposed to adequate knowledge of the geometry of molecular shapes. Hence, their molecular shape knowledge is considered equal before performing subsequent classroom.

Table 1. The Result of Significant Difference Test of Experimental and Control Group

Group	Amount of Subject	Average score	Distribution	Varian	*p* (Sig.)
Experimental	32	6.94	Not Normal	Homogeny	0.818 (Not significant)
Control	32	6.44	Normal	Homogeny	

Subsequently, both student groups being studied showed improvement in their conceptual mastery, indicated by each post-test average score that increased around six times for the experiment group and four times for the control group. After being derived and categorized into several sub-concepts, average scores of pre-tests and post-test were converted into %N-gain average for each sub-concept as depicted in Table 2.

Table 2 shows that the experiment group had the highest %N-gain average for the sub-concept of binding pairs (54.95%) and the lowest %N-gain average for the polarity of the molecule (31.73%). The control group had the highest %N-gain average of sub-concept of electron pairs (41.93%) and the lowest %N-gain of sub-concept of electron repulsion (6.77%). It also can be briefly inferred from Table 2 that three %N-gain averages of the experiment group were higher than the control group, i.e., binding pair, molecule shapes, and electron repulsion. While %N-gain averages for sub-concepts of electron pair and polarity of molecules were considered not different between the two student groups.

Sub-concepts of binding pairs and molecule shapes were slightly increased since the virtual simulation used in this study could be interactively controlled by the students. The operator could pick some un-bound atoms or binding pairs, visually simplified by spherical ball and stick model, respectively, and combine them into a particular simple molecule then obtain the idea of the formation of some simple molecules and observe the geometry of the molecule from different angles. These virtual hands-on experiences deliver interactive three-dimensional features such a physical molecular kit that is still unable to be provided by two-dimensional digital learning media of animation video (Esselman & Block, 2018; Niece, 2019). This improvement of the molecule shapes sub-concept also supports previous findings that state that the three-dimensional feature of interactive simulation can help students easily visualize the molecule shapes model based on the VSEPR topic (Brown et al., 2021).

Meanwhile, sub-conceptual mastery improvement of electron pair repulsion is considered because the interactive used in this study clearly distinguishes between un-binding electron and binding pairs. The binding pair is visualized as a cylindrical stick as explained before, while the un-binding electron pair is exhibited as a conical cloud that is wider than the binding pair and can be flexibly repulsed each other when the operator placed the cloud near another cloud (Farheen & Lewis, 2021). This observed repulsion effect is also simulated as an effect from the size of the cloud of electron pair charge that the bigger the electron pair cloud, the stronger the electron repulsion produced (Zhao et al., 2019). These findings support Brown et al. (2021) study in which simulation can simplify and visualize the complex idea. Since the concept of the electron cloud is derived from the complexity of Heisenberg uncertainty, at least for high school students, implies that the location of an electron is difficult to exactly locate at a particular time to propose an idea of an electron cloud.

Table 2. The Average of Pretest, Posttest, %N-gain Average, and Significance of Each Sub-concept in the Experimental Group and Control Group

No.	Sub-Concept	Experimental Group				Control Group				Var.	p (sig.)
		Pre-test (%)	Post-test (%)	%N-gain Average	Distribution	Pre-test (%)	Post-test (%)	%N-gain Average	Distribution		
1	Bonding pairs	0.94	5.13	54.95	Not-normal	1.25	2.81	23.44	Not-normal	Not homogeny	0.004 (Significant)
2	Electron pairs	2.25	5.13	49.22	Not-normal	0.69	3.88	41.93	Normal	Homogeny	0.396 (Not significant)
3	Molecule shapes	3.19	21.44	40.90	Normal	3.63	15.00	24.03	Not-normal	Homogeny	0.002 (Significant)
4	Electron repulsion	0.25	4.00	47.40	Not-normal	0.38	1.19	6.77	Not-normal	Not homogeny	0.000 (Significant)
5	Polarity of molecule	0.31	5.94	31.73	Not-Normal	0.50	4.88	27.81	Normal	Homogeny	0.995 (Not significant)

However, although the %N-gain average of the electron repulsion sub-concept is increased due to virtual simulation utilization, the %N-gain average of the sub-concept of electron pair is not categorized as improvement using virtual simulation. Whereas, the sub-concept is considered very related to the un-binding electron pair sub-concept. This finding might occur because there is a point represented for the electron pair sub-concept in the measurement tool that has a difficulty level of 0.92. Although it is allowable to be used for pre-test and post-test, the tool is still possibly unable to powerfully differentiate sub-conceptual mastery of electron pairs between the two groups being studied.

However, although visual representations are shown to be pedagogically beneficial because they can reduce the visual complexity of molecular relationships related to polar or nonpolar (Höst et al., 2012), the sub-concept of the polarity of a molecule is unable to significantly improve by virtual simulation. The students tested in this study are considered still found difficulties regarding determining the moment resultant of a particular molecule because the virtual simulation used in this study does not charge the moment of each electron bond. It is considered to still occur during some learning activities of molecule shape and its polarity. In several high school handbooks, it is still written that symmetrical molecule shapes are categorized as a non-polar molecule and vice versa (Erlina et al., 2021). These statements are not fully correct because the polarity and non-polarity of the molecule must also be considered from the net resultant moment of covalent molecules (Basuki, 2020). Furthermore, according to the questionnaire filled out by the students after the post-test, they still assume that all simple molecules with electron pair(s) attached to them are considered polar molecules.

Overall, the improvement of sub-conceptual mastery of binding pairs, molecule shapes, and electron pair repulsion shows that interactive simulation can develop student conceptual mastery as (Linn et al., 2010) implies that geometry and chemistry can be connected with the aid of suitable learning media through three-stage approach to 3D thinking, i.e., visualization of geometric figures, connection the figures with molecule arrangements, and the introduction of the abstract concept of electron repulsion, subsequently (Donaghy & Saxton, 2012). In addition, interactive simulation allows the student to actively explore and be enthusiastically involved in the virtual world of molecule shapes based on the VSEPR topic and possibly to develop their understanding beyond the actual content. In the classroom circumstances being studied, interactive simulation allows students to proactively explore further learning experiences of molecule geometry learning, such as pulling an atom model at a particular distance from the neighboring atom and electron pair to discover the repulsion effect and moving the molecule models on different sides to spatially observe angle appearances in a different point of views. This further exploration of geometry appearance from different angles implies that the 3D virtual learning media is beneficial for student educational experiences due to it supports chemistry learner spatial ability development (Merchant et al., 2012; Günersel & Fleming, 2013), induced classroom atmosphere that supports productive inquiry with minimal guidance (Moore et al., 2013), and enhances student high order thinking skills (Donaghy & Saxton, 2012), subsequently.

It is somewhat different from a two-dimensional digital animation video that has been firmly designed so that the students have limited access to explore the content from their scenario or perspective.

CONCLUSION

The application of virtual simulation impacted more than animation video to improve the conceptual mastery of the VSEPR topic, especially for sub-concepts of molecule shape, electron pair repulsion, and binding pairs. These findings supported the teachers in designing lesson plans for students to master the VSEPR topic. By implementing this virtual simulation in a classroom activity, related chemistry teachers could also help visualize electron pair cloud and its repulsion. However, the interactive simulation used in this study was unable to improve understanding regarding the sub-concept of molecule polarity because the content within the interactive simulation was not completely attributed to the sub-concept of the polarity of the molecule. It was suggested to generate further study to develop virtual simulations attributed to the sub-concept of polarity molecules. It was also required to build an interactive simulation that could be used offline, considering not all high schools in Indonesia had been supported with infrastructure and affordable internet. Furthermore, content displaying chronological learning steps was also required to be developed so that the students could learn with minimal instruction from the teacher.

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