MOLECULAR SHAPE SIMULATOR: A COST-EFFECTIVE METHOD FOR LEARNING MOLECULAR GEOMETRY

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ABSTRACT

This study involved 104 students of the Matriculation Science Program discusses how problems related to teaching and learning of Molecular Geometry are overcome. The focus of this study is the use of the Molecular Shape Simulator to help improve students' understanding of Molecular Geometry and use it as an alternative to the traditional ball and stick model set. This study was carried out using the Kemmis and McTaggart action research model and consists of two cycles. The first cycle involved the use of the application in a lecture while the second cycle involved the use of application in a tutorial. The study found 45% of students scored A in the first cycle. In the second cycle, the remaining 55% student had another class on molecular geometry, this time in smaller groups of 15 to 20 students and the students were allowed to use the application individually. At the end of the two cycles, 95% of the students scored As. Students' feedback was obtained using a questionnaire. Students found the application very helpful, easy to use and made the topic interesting and easier to understand. Molecular Shape Simulator helped students understand and properly describe shapes of molecules and allowed teachers to achieve learning objectives faster and at lower cost compared to the classic ball and stick model set. This study finds the Molecular Shape Simulator to be a cost-effective tool for learning molecular geometry.

Key words: Science education, chemistry, molecular geometry, educational application, and twenty-first-century learning.

INTRODUCTION

This action research is conducted to improve teaching and learning practice of chemistry in a matriculation college of the Ministry of Education Malaysia. In this study, a mobile application, the Molecular Shape Simulator (MSS), would be used in the teaching of Molecular Geometry. The use of this application aims to address the teaching and learning problems arising from the reorganization of the matriculation chemistry course. This report will describe issues faced by students and teachers and how the application is used to solve the problems. This paper also describes how the application helps achieve learning outcomes with more efficient use of time and at a lower cost than previous methods. The report begins with the background of the teaching and learning of Molecular Geometry and is followed by a brief description of the Molecular Shape Simulator which form the basis of the intervention. Subsequently, implementation of the action research will be reported beginning from the reflection of past teaching and learning section.

TEACHING AND LEARNING OF MOLECULAR GEOMETRY

The Semester 1 Matriculation Chemistry curriculum consists of seven chapters. The fourth chapter is Chemical Bonding in which the Molecular Geometry is one of its sub-topics. Knowledge of molecular geometry is an important prerequisite not only for understanding other general chemistry topics like Orbital Hybridization and Molecular Polarity but also is important for understanding other subjects like Organic Chemistry and Biology. More specifically, Molecular Geometry is important because the physical, chemical and biological properties of a chemical substance is determined by the three-dimensional arrangement of its atoms (Chang, 2019). If a student does not master this topic, the student will not only be unable to understand matriculation chemistry but would also have difficulty with other courses requiring good chemistry background such as pharmacy, molecular biology, environmental science, and engineering.

The most important skill gained by students by learning Molecular Geometry is the ability to take any two-dimensional representation of a molecule such as chemical formula and Lewis structure from a piece of paper and mentally reconstruct a three-dimensional image of the molecule (Brown, 2018). This skill, however, is difficult to obtain. Study has shown that one of the most significant chemistry misconceptions among university-level chemistry students is related to molecular geometry (Uyulan et al, 2014).

The use of physical models has been the traditional way of helping students acquire the skill to relate two-dimensional chemical symbol with three-dimensional molecular geometry (Lok et al.2016). As students think about and handle these models, abstract concepts become easier to visualize. And because this skill is crucial to understanding chemistry, the matriculation program has allocated a two-hour laboratory session to allow students to learn molecular geometry using ball and stick model sets (Kementerian Pendidikan Malaysia, 2013). This class is the sixth of nine laboratory practical classes of the first-semester chemistry curriculum and has been in use since 2003. During this class, 3 to 4 students will share a set of ball and stick model kit and build models of all 13 molecular classes and complete worksheet-based tasks. Hands-on experience using the models is found to enhance students' understanding of Molecular Geometry in addition to what is learned in lectures and tutorial classes. Based on my experience, the Molecular Geometry practical class is well-liked by students and has been very useful in helping students visualize the molecular shapes and understand the topic.

MOLECULAR SHAPE SIMULATOR

Molecular Shape Simulator is an educational application that is available for free on the internet (Phet, 2016). It was developed under the Physics Educational Technology (PhET) Interactive Simulation project at University Colorado Boulder, USA. All simulations developed by PhET are free and are designed to be highly interactive and engaging, in an open learning environment that provide animated feedback to the user (Finkelstein et al, 2006). The simulations are physically accurate and provide highly visual, dynamic representations of physics principles. Simultaneously, the simulations seek to build explicit bridges between students' everyday understanding of the world and the underlying physical principles, often by making the physical models (such as current flow or electric field lines) explicit.

This application is based on the modern HTML5 software that allows apps to be used on mobile devices like tablets and smartphones. The application can be downloaded and saved in a device (file size is only 2.1 Mb), so it can be used without an internet connection.

Molecular Shape Simulator is very useful for the teaching and learning of Molecular Geometry because it has the following features:

1. It allows users to build all classes of basic molecular geometry, atom by atom or view any molecular shape class by simply selecting one from a list.
2. The users have a choice whether to display all related information such as bonding angles, non-bonding electron pairs, type of molecular geometry and type of the electron pair arrangement or simply show the molecular shape. This is shown in Figure 1
3. The molecular image can be moved and rotated by touch input. This feature makes the image of molecules in the application appear three-dimensional.
4. It can also be used to assist students and teachers in learning and teaching topics other than Molecular Geometry such as Orbital Hybridisation and Molecular Polarity

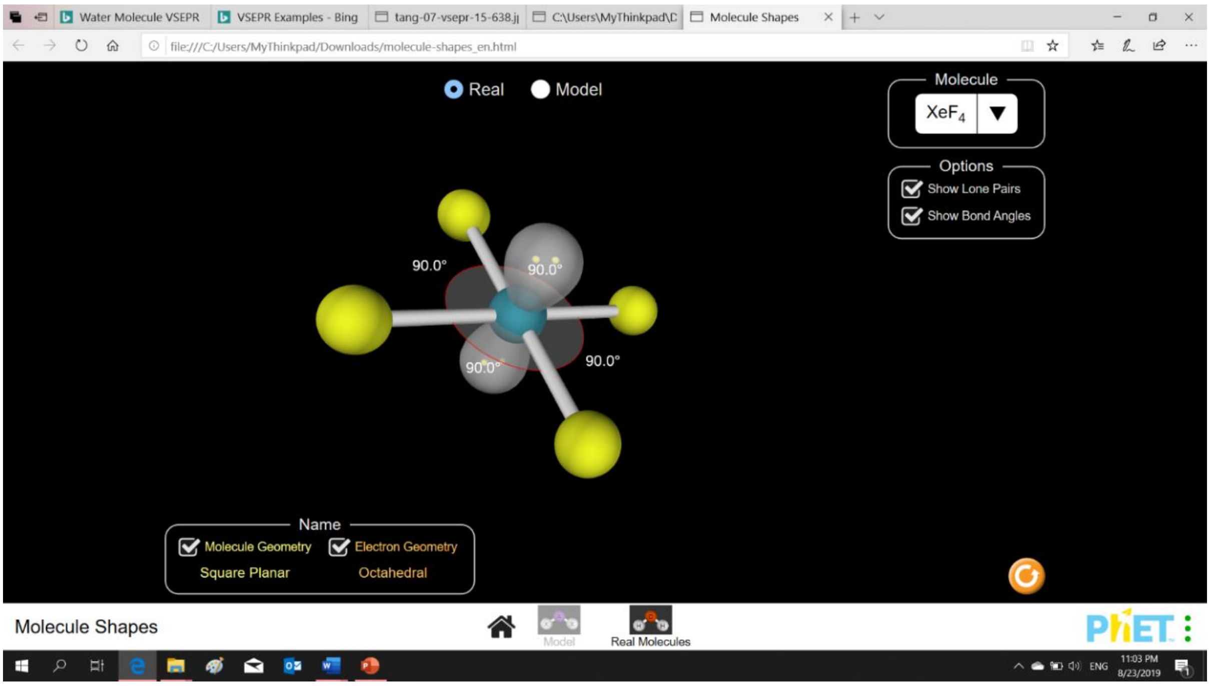

Figure 1. Screenshot of the Molecular Shape Simulator

REFLECTION ON PAST TEACHING AND LEARNING

Based on past experiences, Molecular Geometry is a very difficult topic to teach because students are unable to visualize the shape of molecules. In lectures, I had to describe three-dimensional molecular shapes using two-dimensional images on slides and notes. Similarly, when students review lecture notes and study molecular geometry, they usually must rely on the same static two-dimensional images in reference books. This makes learning molecular geometry difficult for students. This view is also shared with other chemistry teachers. According to a teacher at the college:

"The student cannot imagine the actual arrangements of atoms in molecules. Students are confused with the molecular drawings (in notes) compared to the actual shape of molecules. So, it is rather challenging to teach this topic. Even if teachers bring ball and stick models to lectures, students still cannot imagine the shapes of molecules"

In 2018 the Ministry of Education Matriculation Program was transformed from the traditional curriculum to an outcome-based curriculum. This leads to many changes in the curriculum at various levels. For the chemistry course, it was decided that the number of practical classes of the first semester is reduced from nine to six to allow practical classes to be carried out in a new framework that introduces formal pre-laboratory and post-laboratory activities (Kementerian Pelajaran Malaysia, 2018). The integration of pre-laboratory (and post-labs) into chemistry practical classes is in line with current developments of chemistry education. Agustian and Seery (2017) found from many studies that integrating pre-laboratory activities has many advantages, Among them:

1. Increase the efficiency of students' laboratory work.
2. Improved conceptual learning activity and discussion.
3. Make students feel more confident, motivated and reduces student anxiety.

However, one of the practical dropped was Practical 6: Molecular Geometry. This practical which in my opinion has been invaluable for students in learning Molecular Geometry would no longer be taught during upcoming academic sessions. After one academic session, the effect of the absence of Practical 6 begin to emerge. As a chemistry teacher explains:

"Without practical 6 (Molecular Geometry), students no longer have the opportunity to "see" the molecules themselves, and no "hands-on" experience handling the molecular models. More importantly, students have no experience converting two-dimensional Lewis Structure to a three-dimensional object. It's like this, students need to experience the molecular shapes and do some trial and error. "

And when asked how she overcame the problem, she replied:

"I bring the molecular model to class. This is not ideal as time is short and only a few students could use the models at a time. Another thing. Without the models, I constantly need to repeat what is taught in lectures again and again. It's tiring."

I completely agree with her view because since the previous session I noticed other chemistry teachers started bringing ball and stick models set to class. This is done with the hope that the use of physical models will help students visualize the concept. If they teach lectures, they will bring a larger model. And for small group tutorials, they use the smaller model set. As for me, I only use models occasionally, if I have the opportunity. Most of the time, I teach with the help of images of three-dimensional models in reference books or similar images from my laptop.

RESEARCH PROBLEM

Reflection of past teaching and learning shows there is a need to find a more effective tool to teach and learn Molecular Geometry. Removal of Practical 6 from the curriculum means that students are no longer able to strengthen their understanding of the topic through hands-on learning using the ball and stick model set. Although the time allocated for the lectures and tutorials of the topic is still the same, without Practical 6 the time allocated for students to discuss this topic has been reduced by two hours. As such, any alternative teaching approach or tool must be able to achieve the targeted learning outcomes with the effectiveness of the old method in a shorter time.

STUDY OBJECTIVES

This study aims to investigate the use of an application called the Molecular Shape Simulator as an alternative to Molecular Model Kit in teaching molecular geometry to matriculation students.

The specific objectives of this study are:
1) Determine students' level of achievement after learning molecular geometry using MSS.
2) Determine students' views on the usability of MSS a tool for learning molecular geometry.
3) Evaluate the possibility of large-scale use of MSS as a substitute to the traditional physical model kit.

METHOD

Action Research Model

The action research model developed by Kemmis & McTaggart (1988) is used in this study. According to the model, each action research cycle consists of four steps; reflect, plan, act and observe. Based on this model, action research can begin from any one of the four steps. Once the four steps are done the action research is said to have completed a cycle. Depending on whether the research objectives are fully accomplished or not, the researcher will decide whether another cycle is necessary (Figure 2).

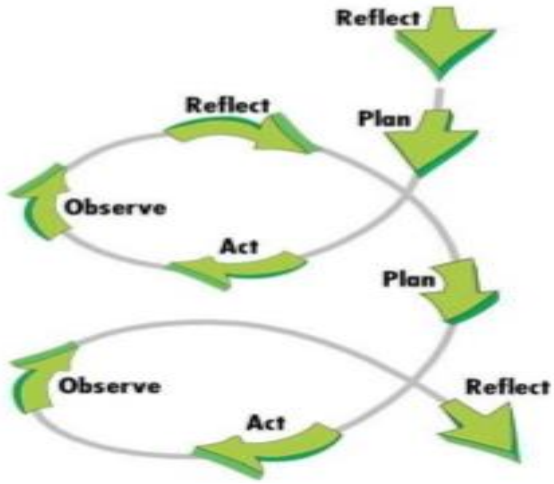

Figure 2.The Action Research Spiral (Kemmis & McTaggart, 1988)

Target Group

This action research is participated by S3A lecture group comprising 104 students from the Science Matriculation Program of the 2019/2020 academic session. I decided to conduct the study on all students under my care as all these students in this class no longer have the two-hour Molecular Geometry Lab scheduled this semester and thus can benefit from the use of the Molecular Shape Simulator to improve their understanding of the topic.

Data Collection Instruments

Molecular Geometry Achievement Test (MGAT) is used to determine the effect of the intervention of this study. The test consists of 10 multiple choice questions on molecular geometry. The questions were selected and modified from tutorial question sets, reference books, and sets of questions that have been used for internal assessment tests at the college in previous academic sessions. MGAT reviewed by two experienced teachers to ensure content validity and reduce errors. Scores are reported as percentages.

To determine students' view on the use of the Molecular Shape Simulator for learning molecular geometry, a questionnaire is used. The questionnaire consists of 10 Likert-scale items of 1 to 4 (strongly disagree, disagree, agree and strongly agree) and an additional open question to obtain further views and comments.

Proposed intervention

Based on the reflection of previous lessons and discussion with fellow teachers, it is decided that the Molecular Shape Simulator can be an appropriate tool to address the problems of teaching molecular geometry. The action research framework is shown in Figure 3. In Step 1 of the first cycle, an intervention plan was proposed involving the use of Molecular Shape Simulator application for the teaching and learning of Molecular Geometry. This was followed by Step 2 in which the plan was carried out by conducting a lecture using Molecular Shape Simulator. In Step 3, the students took the MGAT to determine their level of achievement. Based on the test scores observation and reflection, the researcher will decide whether another cycle is necessary.

In the first step of Cycle 2, modifications were made to the lesson plan based on observation and student feedback. Students who did not score A in Cycle 1, will undergo another lesson on Molecular Geometry. The lesson will be conducted in smaller groups and will be more hands-on compared to the lecture. Based on the test scores of the second cycle the researcher will decide whether the action research objectives have been achieved or a third cycle is needed.

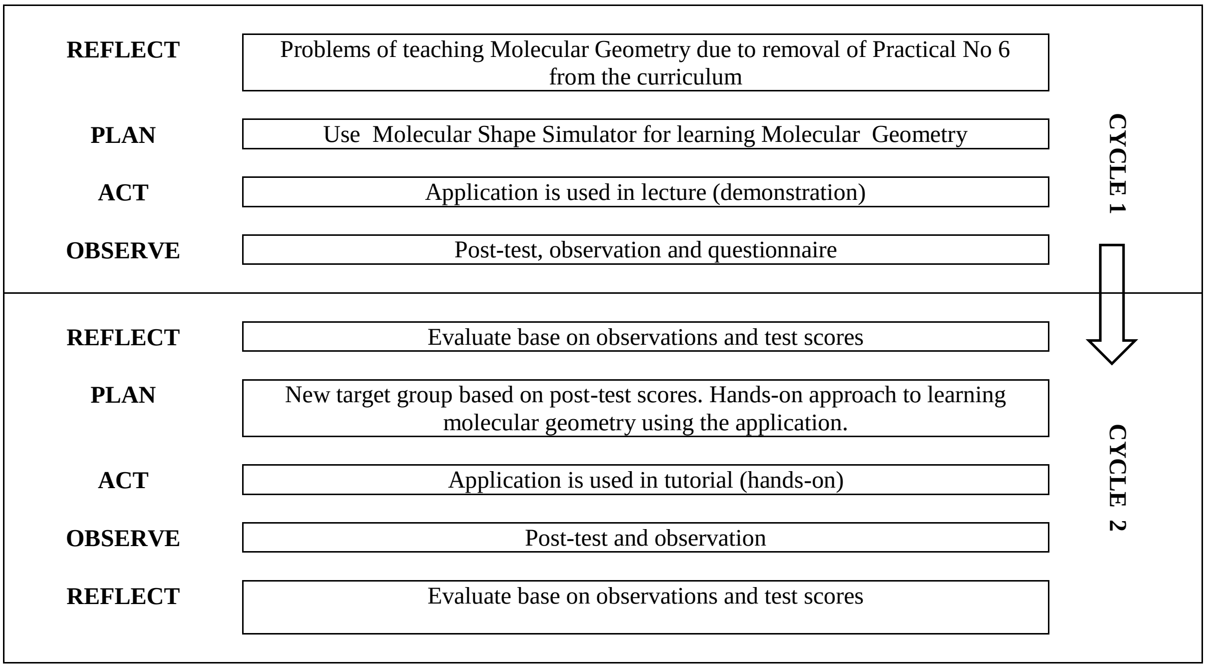

Figure 3. Framework of Study

RESULT AND DISCUSSION

Post Test Scores

Students' level of achievement in Molecular Geometry was determined twice in the study. First, after the Molecular Geometry lecture and then, after the students have undergone classroom tutorial session on the same topic. Post-lecture average score is 6.1 with a wide score range from 2 to a perfect score of 10. This score can be considered moderately good as it is equivalent to a B- (based on the grading system of the college). Of the 104 students tested 47 obtained As with a score of 7 and above. These students have therefore achieved the learning objectives of Molecular Geometry, whereas the other 57 students who scored less than 7 have not. The 57 students later had another class on Molecular Geometry in smaller groups consisting of 15 to 20 students each.

After an hour's lesson, the students took the post-test again. Post tutorial average score increased to 9 with a narrower score range (4 to 10). Out of 57 students, 50 scored As, two B- and two D while the remaining three did not take the test. Detailed comparison of both post-lecture and post-tutorial scores are shown in Table 1 and Figure 4.

Table 1. Summary of post-lecture and post-tutorial scores.

	Mean	Median	Range
Post lecture	6.1	6	2-10
Post tutorial	9	9	4-10

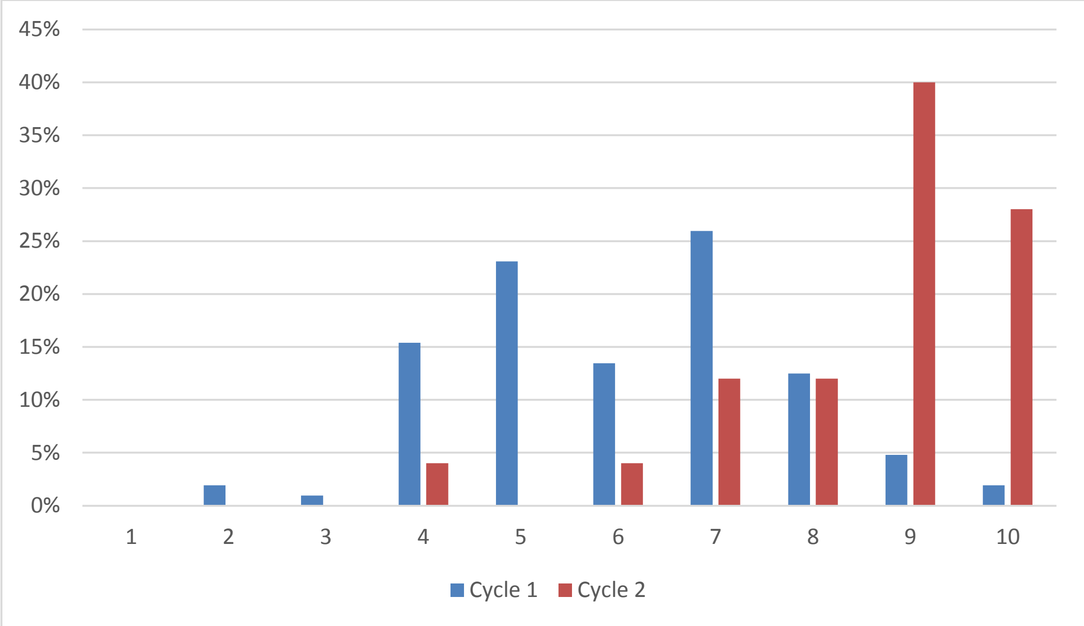

Figure 4. Post-lecture and post-tutorial score distribution

Result from questionnaire

Out of the 104 student that learned Molecular Geometry using the app, only 95 returned their questionnaires. Based on responses given to question 2, 4, 6 and 10, it is clear that the Molecular Model Simulator have a positive impact on students learning. More than 90% of the students agree that the application is very effective in helping students learn the topic, make the concept and teachers' lesson easier to understand and give a clear overall picture of the topic.

Based on responses to question 3, 7, 8 and 9, it is found that the application is very suitable for teaching and learning molecular geometry. More than 90% of the responses agree that the application is suitable for use during lectures, small classes and also as a self-learning aid. Finally based on responses to question 1 and 5 more than 90% of the students agree that they enjoy using the application and are more interested in learning molecular geometry because of this application. A more detailed summary of the questionnaire results is shown in Table 2.

Table 2. Summary of Likert Scale Questionnaire

Statement	1	2	3	4	% Agree
I enjoy using MSS application to learn this topic.	0%	7%	55%	38%	93%
I easily understand the concept topic with MSS.	0%	6%	56%	38%	94%
Molecular Shape Simulator app is easy to use.	0%	8%	52%	40%	92%
The MSS allows me to visualize the molecular shapes	0%	4%	55%	41%	96%
The MSS app increase my interest in the topic.	0%	13%	59%	28%	87%
I understand what is taught by the teacher more when MSS is used	0%	6%	61%	33%	94%
MSS app is suitable for use in lectures.	0%	4%	54%	42%	96%
MSS app is suitable for use in tutorials.	0%	11%	54%	36%	89%
MSS app is suitable as a self-study tool	0%	5%	60%	35%	95%
MSS is effective for learning molecular geometry.	0%	6%	62%	32%	94%
*1=strongly disagree, 2=disagree, 3=agree and 4=strongly agree					

Based on responses to the open question, students are generally of the view that the use of the Molecular Shape Simulator application has positive effects on the learning of Molecular Geometry. Out of 96 students who returned the questionnaire, 77 stated that the use of Molecular Geometry Simulator is something positive or conveyed a similar idea in their comment. These comments can be grouped into the following themes as shown in Table 3.

Table 3. Responses to Open Question

	Main theme of comment	Frequency
1.	The use of MSS is good for learning Molecular Geometry	35
2.	The use of MSS is fun and interesting	13
3.	The use of MSS makes the topic easier to learn and understand	25
4.	No response	19
5.	Others	4

Some example of positive comments are as follows:

> *"Much easier to learn from apps and websites compared to documents"*
> *"Interesting because easier for me to visualize the shapes, but it would be better if audio is included to explain in more detail"*
> *"Molecular geometry can be understood easily with 3D illustration"*
> *"I can learn easier and the lesson becomes more interesting"*
> *"I understand the concept better with the application"*

In one comment, the student was very specific about a feature in the application:

> *"It's the best when the teacher was able to show how lone pair electrons can be added to the molecule, during lecture just now"*

This comment refers to the feature that enables the app to show lone pair electrons influence molecule shape which from my point of view is key to helping students understand molecular geometry.

There is one student who commented on the problem with the use of the application:

> *"Sometimes it is difficult to see the shapes determined and also the angles keep moving"*

This comment given by the student after the first cycle made me realize that some students do not fully understand how to use the application. The problem was overcome in the second cycle after detailed instruction on how to use the application is given by the teacher before the students begin their assigned tasks.

The potential of large-scale use of MSS as a substitute to the traditional physical model kit is highlighted by its advantage over traditional physical model. The comparison is shown in Table 4.

Table 4: Advantages of Molecular Shape Simulator over Physical Model

	Physical Model (Ball and Stick)	Molecular Shape Simulator
Cost	RM 94 /set RM 6016/64 set /college	Free (consider donation to PhET)
Allocated usage	2 hours of practical class /semester	Unlimited, anytime anywhere.
Ownership	Property of college	Can be stored in mobile devices
Features	Build molecular models	Build molecular models Show bond angles (theoretical and actual) State molecular geometry Show lone pair electrons State electron pair geometry Show multiple bonds

CONCLUSION

The study finds that the Molecular Shape Simulator helps students understand molecular geometry and solve the problem faced by teachers. Excellent post-test scores are achieved by 96 (out of 104 students) after two hours of instruction. Four students did not attend the second class while the remaining four comfortably passed although did not get A. In the third cycle, these students will be given lessons and learn molecular geometry in even smaller groups until they also score As. Based on the post-test achievement level it can be concluded that the application is very useful in helping students understand molecular geometry. Feedback from the questionnaire shows that more than 90% of students are of the view that the Molecular Shape Simulator makes learning molecular geometry more interesting, easier to understand and fun. The students are also of the view that the application is not only useful for classroom instruction but also for self-learning.

From my own experience, the level of achievement is very good, considering the students only had two hours of instruction in molecular geometry. Half of the students achieved As after one hour of lecture and almost all the remaining half got A after another hour of tutorial. Normally (without the use of the molecular shape simulator) students achieve this level of understanding on molecular geometry only after they had the two-hour class with the ball and stick model set, in addition to the lecture and tutorial. This means that the use of MSS can achieve in an hour of lecture and an hour of tutorial what previously require the same two-hour instruction plus another two-hour session using the ball and stick models. In terms of cost, MSS is free and can be stored in students' devices, whereas a set of ball and stick molecular model set costs RM 94 and can only be used by four students during classes. The college in which this study is conducted have 64 sets of the model to cater the need of 1200 science students. Thus, the total cost of the models is RM 6016. Based on time and cost factors, MSS app is more cost-effective than ball and stick models.

The objective to improve instruction of molecular geometry by making it more interesting and easier to understand has been achieved by the use of the Molecular Shape Simulator. Also, the problems associated with the termination of Practical 6 have been overcome. In conclusion, the Molecular Shape Simulator is an effective teaching tool and should be considered for widespread use.

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