

Computational Chemistry as a Media in Learning Chemical Molecules Through 3D Visualization to Enhance Students' Spatial and Analytical Abilities

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ABSTRACT

Chemical molecules are a challenging topic for students because they are abstract and difficult to visualize. Students continue to struggle with understanding sub-microscopic concepts and lack the analytical skills necessary to solve chemical problems. Spatial and analytical abilities are essential for developing a deeper understanding of chemical molecule structures. This study aims to enhance students' spatial and analytical abilities by applying the Inquiry-Based Learning model using PyMOL as a 3D visualization medium in teaching chemical molecule structures. The method used in this study is a quasi-experiment with a pretest-posttest control group design, involving two groups of tenth-grade classes. The experimental class utilized PyMOL as a 3D visualization medium, whereas the control class employed Molymod kits. The results showed that students who learned using PyMOL experienced significant improvements in both spatial and analytical abilities. Correlation analysis showed a positive relationship between spatial and analytical abilities. Students' responses to the learning process are positive. This study demonstrates that using PyMOL as a medium for technology-based 3D visualization can make abstract concepts easier to understand and help students develop critical and systematic thinking skills.

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INTRODUCTION

Learning chemical molecules presents challenges for both students and teachers. Students often struggle to understand abstract chemical molecules at the microscopic scale, and teachers struggle to teach concepts in ways that are easily understood (Lohning et al., 2019; Abdinejad et al., 2020; Baji & Haeusler, 2021). The process of learning chemical molecules requires connecting abstract theories with the real structures. It involves students using spatial skills for interpreting and visualizing 3D structures, and analytical skills for problem-solving (Fatemah et al., 2020; Lidiawati et al., 2021; Guspatni, 2021; Fernandes et al., 2021; Lok & Hamzah, 2021; Zhao et al., 2022). The main problems in learning about chemical molecules are students with low spatial and analytical abilities. Spatial skill is related to right-brain functions, which are responsible for creative and abstract thinking. Spatial ability is needed to visualize, interpret, and manipulate two-dimensional (2D) diagrams into three-dimensional (3D) visualizations (Prakarsya, 2019; Astuti et al., 2020; Fatemah et al., 2020; Ijirana et al., 2022; Smith et al., 2020). Meanwhile, analytical skills relate to left-brain functions, which involve structured, systematic, and analytical reasoning. Analytical ability is essential for identifying core problems, categorizing parts of a phenomenon, understanding their relationships, and applying logical reasoning (Demir, 2022; Wahyuningsih & Sunni, 2020; Heliawati et al., 2021; Wang et al., 2023; Ping et al., 2022).

This difficulty is also reflected in International Assessments. The TIMSS (Third International Mathematics and Science Study) and PISA (Program for International Students Assessment) have reported that Indonesian students had low scores. Although the Indonesian Ministry of Primary and Secondary Education has made efforts to improve the education system, international rankings in mathematics and science have shown consistent declines over time. For example, in the last three TIMSS periods, Indonesian students ranked 36th in 2007, 36th in 2011, and 44th in 2015. Furthermore, the 2018 PISA results indicated that 70% of Indonesian students could not reach level 2 in problem-solving, while globally, only 23% of students were in the same category (Sabara et al., 2022; Putri et al., 2025). The TIMSS and PISA results indicate that many students face challenges in connecting chemical theories with molecular representations. One of the factors contributing to these challenges is the application of teacher-centered learning in the classroom.

Teacher-centered learning models often limit the development of these essential abilities, which include spatial and analytical skills. Teacher-centered learning focuses only on delivering material to the students. When learning focuses only on delivery material without engaging students' cognitive processes, Students tend to show less interest in learning, low motivation, limited conceptual understanding, and low critical thinking abilities (Rahmawati et al., 2021; Heliawati et al., 2021; Ijirana et al., 2022; Gunawan et al., 2023). As a result, many students remain passive and struggle to connect abstract theories with real chemical molecule structures. The learning fails to develop students' spatial and analytical abilities (Firmayanto et al., 2020; Heliawati et al., 2021; Rahayu et al., 2022).

A preliminary study was conducted at Cahaya Rancamaya Islamic Boarding School, Bogor. The study involved a spatial ability test adapted from Paul Newton and Helen Bristoll's instrument, consisting of 50 questions: 25 multiple-choice and 25 short-answer questions, administered in 90 minutes. The result showed that students' average spatial ability was low, with a mean score of 19.97. This evidence highlights the urgent need to strengthen both spatial ability related to right-brain creative and abstract thinking, as well as analytical ability needed for understanding chemical molecule structures. Based on this result, teachers need to develop students' spatial abilities, which are related to right-brain creative and abstract thinking. Teachers also need to strengthen students' analytical skills, which are essential for understanding chemical molecules and relating to the left-brain side of the brain. Therefore, it is crucial to implement 21st-century learning approaches that integrate technology into the teaching of chemical molecules.

Previous studies have demonstrated the potential of 3D visualization tools to enhance understanding of chemical molecules (Dickmann et al., 2019; Lin & Wu, 2021). However, most of this research has been conducted in higher education with relatively little exploration in classrooms. Our preliminary study findings confirm that students at the secondary level continue to face significant challenges in spatial and analytical reasoning. Therefore, a clear research gap exists in applying computational chemistry tools, such as PyMOL, to support high school students in learning molecule structures. A visualization technique that utilizes the PyMOL application can improve students' understanding of chemical molecules (Dickmann et al., 2019; Widarti et al., 2020; Coan et al., 2020; Guspatni, 2021; Kuit & Osman, 2021; Lin & Wu, 2021). Computational chemistry, through the PyMOL application, helps students transform from interpreting 2D molecular images found in textbooks to real 3D models and solving problems systematically (Abdinejad et al., 2020; Astuti et al., 2020; Demir, 2022).

The objective of this study is to investigate the use of PyMOL as a medium to enhance students' understanding of chemical molecule structures. The study aims to enhance students' spatial and analytical abilities, which are essential for visualizing and solving problems related to chemical molecules. Spatial ability enables students to imagine and manipulate three-dimensional forms of

molecules. Analytical ability helps students identify, categorize, and interpret chemical phenomena logically and systematically. PyMOL is a software tool for computational chemistry that enables interactive 3D visualization of chemical molecules. This study offers an alternative learning approach that facilitates the abstraction of molecule concepts. The integration of computational applications into the classroom is expected to enhance students' interest in chemistry, improve their understanding, and support the development of 21st-century skills required for the chemical learning process.

METHOD

This study applied a quasi-experimental research design. A quasi-experimental design shares characteristics with both experimental and non-experimental designs. The researcher examines the effect of a given treatment without complete control over the research. The research design used a pretest-posttest control group design, without complete random assignment (Creswell & Creswell, 2018). The learning model is Inquiry-Based Learning. The research involved two classes: an experimental class and a control class, each comprising 20 tenth-grade students from a senior high school. The total number of students involved in this study is 40. The control class was taught using a learning model supported by 3D Molymod visualization media. The experimental class used 3D visualization media based on computational chemistry models through the PyMOL application. The research design is presented in Table 1.

Table 1. Research Design

Class	Pre-test	Treatment	Post-test
A	O ₁	-	O ₂
B	O ₁	X	O ₂

Note:

A = Control Class

B = Experimental Class

O₁ = Giving Pre-test

O₂ = Giving Pre-test

X = Treatment using PyMOL as a medium of computational chemistry

The students are given 15 essay questions, consisting of 10 questions to evaluate spatial ability and five questions to evaluate analytical ability. Spatial ability is evaluated by six indicators, as referenced in Aliman et al. (2024), which are Analytical, Representation, Scale, Application, Spatial Interaction, and Comprehensive, as listed in Table 2. Analytical ability is evaluated by four indicators, as referred to in Setraksa and Namvan (2024), which include Identification, Evaluation, Complex Understanding, and Analysis. The students in the experimental class completed an observation sheet about PyMOL as a medium in the learning process, which consisted of 10 statements. The scoring system for essay questions utilizes a Likert scale ranging from 1 to 4. Likert scale statements (1 = strongly disagree to 4 = strongly agree) were used to capture their perceptions of PyMOL as a learning medium. The Indicators of abilities and questions used in the Experiment are shown in Table 2.

Table 2. Indicator of Abilities and Questions

Ability	Indicator of Ability	Indicator of Questions
Spatial	Analysis	The spatial model is used to predict the 3D shape of molecules.
	Analysis	The molecule shape is analyzed based on the VSEPR theory.
	Representation	The 3D molecule shape is identified from the visual representation.
	Representation	The 3D molecule shape is determined by the atomic symbols that comprise a molecule.
	Scale	The 3D molecule shape is connected between the molecular scale and the chemical properties at the macroscopic scale.
	Application	The VSEPR concept is applied to describe molecular shapes and predict their properties and applications.
	Spatial interaction	The molecule shape is analyzed in 3D dimensions using the VSEPR theory.
	Spatial interaction	The spatial interactions between molecules are identified through the influence of molecular bonds.
	Comprehensive	Interpretation of the relationship between lone pairs of electrons and the molecular shape.
	Comprehensive	The 3D molecule shape is understood based on its influence on molecular polarity and properties at the macroscopic scale.
Analytical	Identification	The molecule shape is identified and the interactions of electron pairs are explained.
	Evaluation	The molecule shape is analyzed based on the VSEPR theory.
	Contextual	The 3D molecule shape is identified from the visual representation.
	Analysis	The 3D molecule shape is determined by the atomic symbols that comprise a molecule.
	Analysis	The 3D molecule shape is linked between the molecular scale and chemical properties at the macroscopic scale.

The control and experimental classes were given pre-tests and post-tests. Pre-tests were administered to students before the classroom treatment, while post-tests were administered to students after the treatment. The experimental class integrated interactive 3D chemical molecule visualization using PyMOL, while the control class used Molymod media. Students' responses to essay items were scored using a four-point rubric aligned with the respective ability indicators. The observation sheet responses were analyzed to provide supporting information about students' experiences during PyMOL. Quantitative data were analyzed using statistics and tests. Normality and homogeneity tests were conducted to check statistical assumptions. To measure the effectiveness of PyMOL, paired-sample t-tests were conducted to compare post-test results between the classes.

RESULTS AND DISCUSSION

The implementation of the learning process is a fundamental component of the research. The topic of this study focused on learning about chemical molecules. This topic was covered in two separate classes: the control group and the experimental group. The control class consists of 20 students. The students in the control class receive treatment using chemical molecule models, such as those from Molymod. The experimental class consists of 20 students. The students in the experimental

class receive treatment using chemical molecules modeled with the PyMOL application as a computational chemistry tool to support visualization of chemical molecules. The learning process followed a pretest-posttest control group design, as proposed by [Creswell and Creswell \(2018\)](#) and [Hasanah et al. \(2020\)](#). The stages included class division, administering a pre-test, implementing the treatment in both classes, administering a post-test, and analyzing the students' spatial and analytical abilities between the two classes. After the classes were divided, a pre-test instrument was administered to students in both the control and experimental groups. The pre-test consisted of 15 essay questions. It aims to evaluate students' initial spatial and analytical abilities. The spatial ability indicators used in the pre-test were adapted from [Aliman et al. \(2024\)](#), which include Analysis, Representation, Scale, Application, Spatial Interaction, and Comprehension. The analytical ability indicators were based on [Setraksa and Namvan \(2024\)](#), which included: Identification, Evaluation, Contextual Understanding, and Analysis. Students completed the pre-test using Google Forms on Chromebooks.

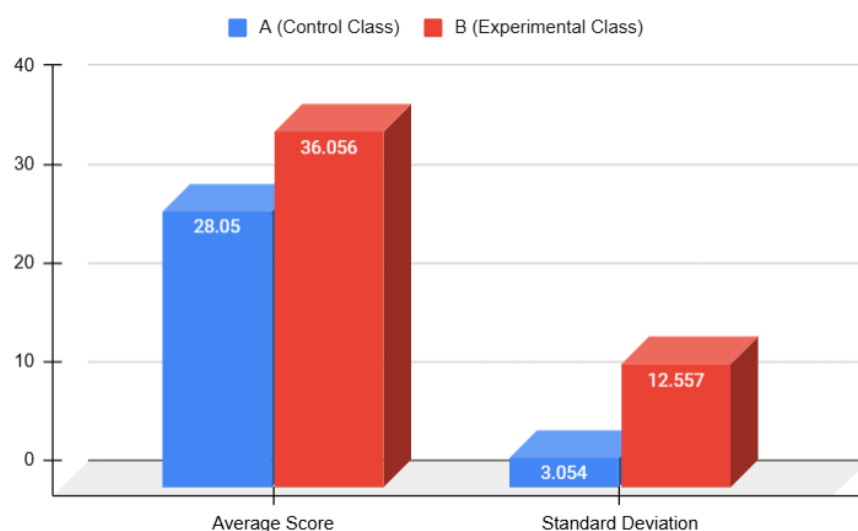


Figure 1. Average Pre-test Scores and Standard Deviation of Experimental and Control Classes

Based on Figure 1, the average pre-test score of the control class was 28.05, while the experimental class had an average score of 36.056. The students in the control class indicated low initial abilities in spatial and analytical thinking related to chemical molecules. The standard deviation in the control class was low. Most of the students obtained scores between 25 and 31. The distribution of students' scores was homogeneous or normal. Most of the students obtained scores between 25 and 45. There were two students with high scores of 78.3 and 61.6, which were outliers. The high standard deviation indicated heterogeneous initial abilities among the students. The diversity of students' scores suggests a difference in the initial understanding. The average score in the experimental class is higher than that in the control class. These results formed the basis for the study.

The next stage was the treatment phase, applied to both the control and experimental classes. These two groups were tested using the Inquiry-Based Learning model, with the only difference being the 3D visualization tools used. The Inquiry-Based Learning model consists of the following stages, proposed by [Hasanah et al. \(2020\)](#), which are Orientation, Formulating Questions, Hypothesis, Investigation, Data Analysis, Conclusion, and Reflection. The learning sessions for both control and experimental classes were conducted over two meetings (2×2 lesson periods), with one lesson period lasting 45 minutes, totaling 180 minutes of instruction within one week. The control class received treatment using the Inquiry-Based Learning model, supported by Molymod kits as 3D visualization

tools to help students understand chemical molecules. The experimental class received treatment using the Inquiry-Based Learning model, supported by the PyMOL application as a computational chemistry medium. This tool enabled students to visualize 3D chemical molecule structures interactively through laptops. The use of PyMOL is intended to help students better understand molecular geometry by manipulating, rotating, and analyzing three-dimensional chemical molecule models. Both the control and experimental classes completed the learning sessions according to the respective treatments given.

After the completion of the teaching/treatment process, the next stage was administering a post-test to all students in both the control and experimental classes. The post-test was designed to measure students' learning outcomes after receiving different instructional treatments. In the control class, learning was conducted using Molymod kits as a medium for 3D visualization of chemical molecules. Molymod allowed students to build and manipulate static molecule structures with their hands, offering a tangible but limited representation of chemical molecules. In contrast, the experimental class used the PyMOL application as a computational chemistry-based medium for 3D molecule visualization. PyMOL enabled students not only to view molecules from various angles but also to interact with them, supporting the development of spatial visualization and analytical abilities. Comparing outcomes of two instructional settings through the post-test, the study revealed whether the integration of modern computational visualization provided added value compared to physical models in improving students' understanding of chemical molecule concepts.

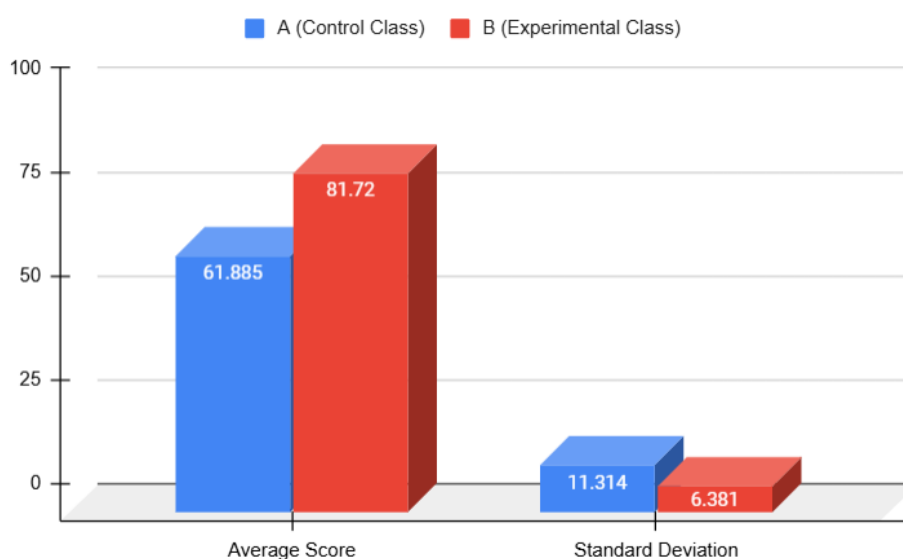


Figure 2. Average Post-test Scores and Standard Deviation of Experimental and Control Classes

Based on Figure 2, the control class achieved an average score of 61.885 on the post-test. This indicates that students' abilities improved after getting the lesson using Molymod as a media for 3D molecular visualization in control class. Students' abilities in representing chemical molecules spatially and analyzing also showed improvement. The standard deviation of the the post-test was 11.31. This standard deviation reflects a high level of variation in students' post-test score from the average score. It suggests that students showed diverse spatial and analytical abilities after learning with Molymod as a media for 3D visualization. The experimental class obtained average score was 81.72. The result indicated the students in experimental class showing improvement when they got treatment using computational chemistry media with PyMOL application for 3D visualization.

Students' abilities to represent chemical molecules spatially and analytically also increased. The standard deviation of the post-test data was 6.381, which shows a low level of variation scores from the average. It suggests that most students' post-test scores were close to the average after learning with PyMOL for 3D visualization. The graph is important that the improvement in students' spatial and analytical abilities using PyMOL as a computational chemistry media was higher compared to use Molymod in control class. The advantage of using PyMOL are more realistic and interactive 3D molecule models, allowing students to explore molecular structures from various perspectives. The result was students' spatial and analytical abilities improved significantly after learning with PyMOL. This is supported by the results of quantitative analysis. Quantitative analysis was carried out after obtaining the pre-test and post-test data.

The analysis began by comparing pre-test and post-test scores from both the control and experimental groups. This comparison produced the N-gain values for each group. Before hypothesis testing, a prerequisite test was conducted to determine whether the data met the assumptions for parametric or non-parametric testing. The normality test was used to assess whether the N-gain data in each group were normally distributed. The Shapiro-Wilk test was used to assess normality. A parametric test using the Independent T-test was conducted to determine whether there was a significant difference between the control and experimental classes. The analysis compared the average N-gain scores of both groups to evaluate the improvement in student learning outcomes. This analysis included the calculation of mean scores, standard deviations, and the N-gain values for both the control and experimental classes. The Independent T-test was selected as it aligns with the assumptions of parametric testing and is appropriate for comparing the means of two independent groups.

Table 2. N-Gain Test

Class	Average N-Gain Score	Standard Deviation	T-test (sig)
Control	33.835	10.974	
Experimental	45.663	10.69	0.001

Based on the results in Table 2, a significance value (p-value) of 0.001 was obtained. Since this value is less than 0.05, it indicates a significant difference in the average N-gain scores between students who participated in learning with the PyMOL application as a computational chemistry medium and those who used Molymod. The result demonstrates that the Inquiry-Based Learning model, when supported by PyMOL, is more effective in improving students' learning outcomes compared to Molymod. The use of PyMOL as a visualization tool provided greater support in helping students understand molecular geometry and enhanced their spatial and analytical abilities. Spatial ability was one of the important factors in the study, as referenced by [Aliman et al. \(2024\)](#). The spatial ability indicators used in the research consisted of six components: Analysis, Representation, Scale, Application, Spatial Interaction, and Comprehension. Each indicator has its own characteristics and scope, aiming to assess students' abilities in understanding, interpreting, and applying spatial concepts in the learning process.

The instrument for evaluating spatial ability consisted of 10 questions designed to measure the six spatial ability indicators, distributed as follows: Analysis (2 items), representation (2 items), scale (1 item), application (1 item), Spatial Interaction (2 items), and Comprehension (2 items). This distribution was made to ensure a proportional assessment of spatial ability, allowing the data collected to provide a well-rounded picture of students' spatial skills. The instrument provided a balanced opportunity for students to demonstrate a range of spatial skills, from interpreting and representing molecular forms to applying scale and recognizing interactions between spatial components. Such a structured distribution also enabled the researcher to capture a more holistic

view. The data generated from the test provided a more comprehensive understanding of how students approached tasks that required spatial reasoning within the context of learning about chemical molecules.

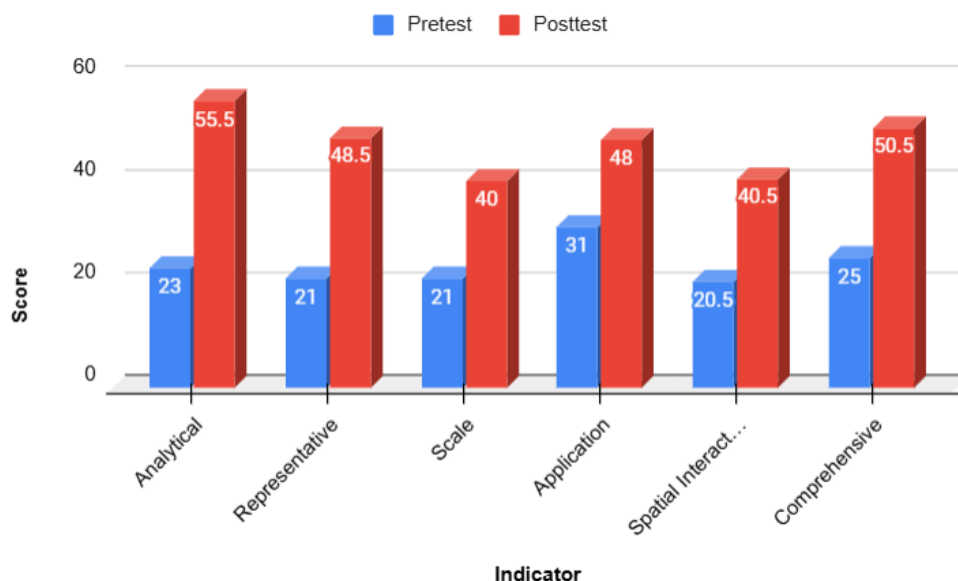


Figure 3. Comparison of the Control Class's Spatial Ability in Pre-test and Post-test

A comparison was conducted between pre-test and post-test scores for each spatial ability indicator in the control class (Figure 3). This analysis aimed to evaluate changes in students' spatial abilities before and after instruction. The comparison determined the extent of improvement for each spatial indicator. The degree of improvement in each indicator provides insight into which specific spatial skills experienced the most significant development as a result of the intervention. The comparison between students' pre-test and post-test scores in the control class indicates a positive impact of the learning process on improving spatial ability across all indicators measured in the study. The control class applied a learning model that utilized Molymod as a 3D visualization tool. The results show an increase in spatial ability for each indicator, suggesting that the learning provided contributed to enhancing students' understanding of spatial concepts. However, the improvement in the control class tended to be general and evenly distributed, with no particular indicator showing a significantly greater increase than the others. The post-test scores in the control class also did not reach the maximum potential, indicating that further development is still possible. This suggests the need for more innovative and hands-on approaches that engage students directly in authentic problem-solving tasks to deepen their spatial abilities. Subsequently, the results from the control class were compared with those from the experimental class.

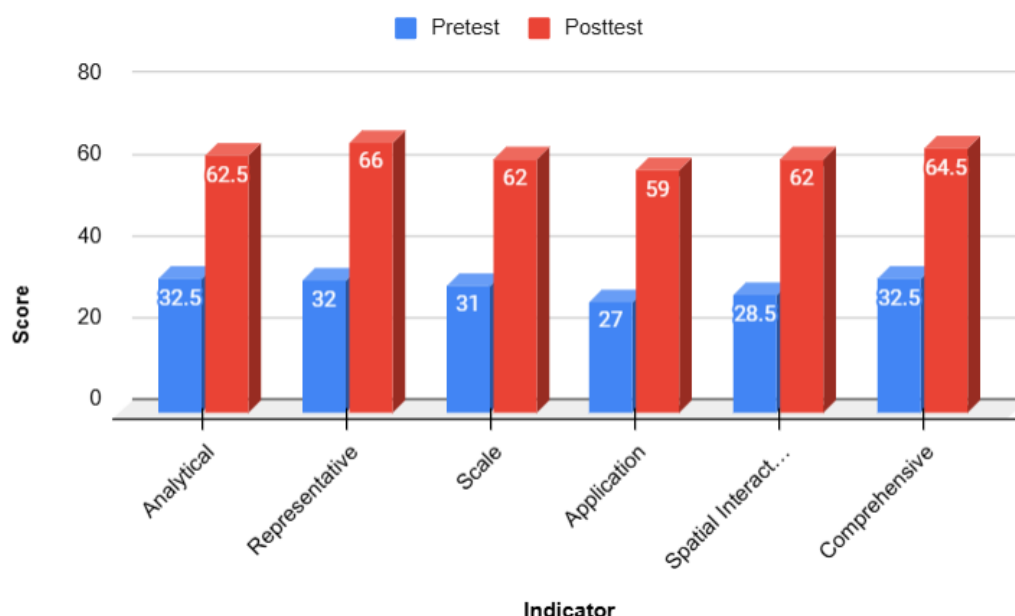


Figure 4. Comparison of the Experimental Class's Spatial Ability in Pre-test and Post-test

The Figure 4 shows a comparison of pre-test and post-test scores for spatial ability indicators in the experimental class. Based on Figure 4, there is a differentiation between the pre-test and post-test scores of students' spatial abilities in the experimental class across all measured indicators. The increase observed in the experimental class is significantly higher than that in the control class. This indicates that the innovative learning model, which utilizes the PyMOL application as a computational chemistry tool, implemented in the experimental class, had a more substantial positive impact on improving students' spatial abilities. The data demonstrate that applying an innovative learning approach with PyMOL in the experimental class resulted in a more substantial improvement in spatial skills compared to the traditional learning approach used in the control class. Each spatial ability indicator showed a considerable gain, reinforcing the effectiveness of an activity-based, problem-solving-oriented, and student-centered learning process in facilitating the optimal development of spatial thinking. The learning model applied provided students with opportunities to explore, think critically, and connect spatial concepts to gain a deeper understanding. To support these findings, quantitative analysis was conducted to compare the spatial ability improvement between the control and experimental groups.

The analytical ability indicators used in this study, as referenced by [Setraksa and Namvan \(2024\)](#), encompass the following components: Identification, Evaluation, Contextual Understanding, and Analysis. These indicators were utilized to assess students' analytical thinking abilities in solving problems. The instrument used to measure analytical skills consisted of 5 questions, designed to evaluate four indicators: Identification (1 item), Evaluation (1 item), Contextual Understanding (1 item), and Analysis (2 items). This distribution was intended to assess analytical ability proportionally, ensuring that the data collected could provide a comprehensive overview of students' analytical skills. A comparison of pre-test and post-test scores for each analytical indicator was also conducted for both the control and experimental groups. This analysis aimed to measure the changes in students' analytical ability before and after instruction. The comparison helped to determine the extent of improvement in each analytical indicator.

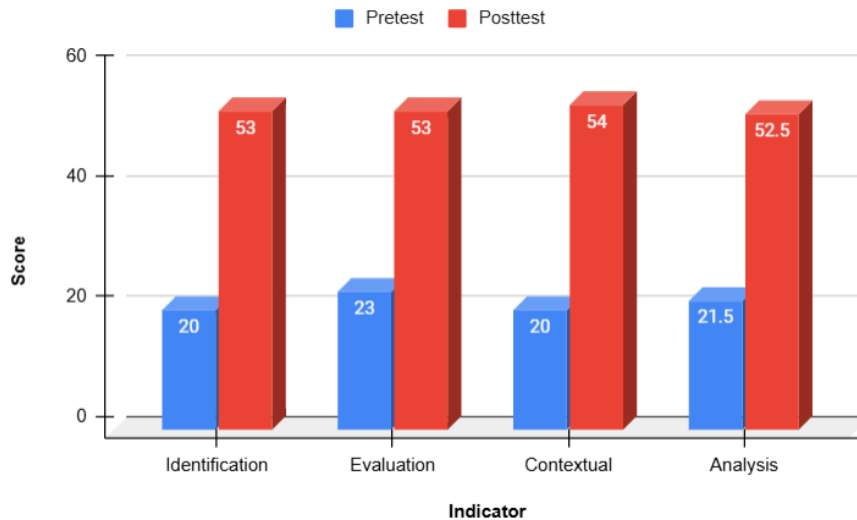


Figure 5. Comparison of the Control Class's Analytical Ability in Pre-test and Post-test

Figure 5 illustrates that the comparison between students' pre-test and post-test scores in the control class shows a positive impact on the improvement of analytical abilities across all measured indicators. The control class implemented a learning model using Molymod as a 3D visualization tool. The figure indicates an overall increase in students' analytical skills in each indicator. This improvement suggests that the implemented instruction contributed to enhancing students' understanding of analytical concepts. However, the observed increase in the control class tended to be general and evenly distributed, without any specific indicator showing a significantly higher gain than the others. This moderate improvement suggests that the learning model used in the control class was effective in improving students' basic analytical abilities, but was not yet sufficient to foster more advanced analytical thinking. Furthermore, the post-test scores of the students in the control group did not reach the maximum level, indicating further potential for improvement. This highlights the need for more innovative, activity-based, and real-world problem-solving approaches to enhance students' analytical skills more effectively. The results from the control group are then compared with those from the experimental group.

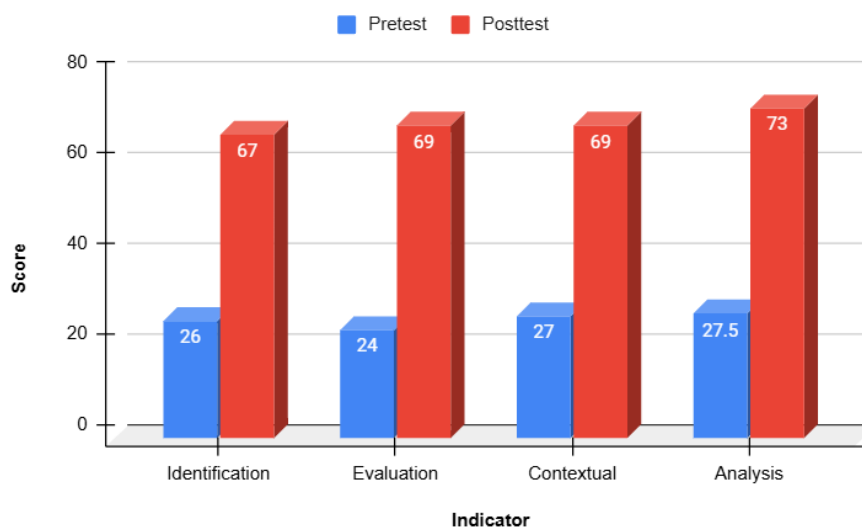


Figure 6. Comparison of the Experimental Class's Analytical Ability in Pre-test and Post-test

Figure 6 shows a significant difference between the pre-test and post-test scores of students' analytical abilities in the experimental class across all measured indicators. The improvement in the experimental group demonstrates higher results compared to the control group. This suggests that the innovative learning model, which utilizes PyMOL as a computational chemistry visualization tool, applied in the experimental class, has a significantly positive impact on enhancing students' analytical skills. The data suggest that the implementation of this innovative learning approach using PyMOL significantly enhances students' analytical abilities more effectively than the traditional approach used in the control group. The substantial gains across all indicators confirm this. This is further supported by the nature of the applied learning model, which emphasizes activity-based learning, problem-solving, and active student engagement. Such a model facilitates optimal development of students' analytical skills by providing opportunities to explore, think critically, and connect analytical concepts with a deeper understanding.

The integration of computational chemistry visualization through PyMOL enables students to better understand abstract molecule structures, thereby enhancing their learning performance. Spatial and analytical abilities are two essential components that contribute to higher-order thinking skills. Spatial ability enables students to visualize, manipulate, and comprehend the relationships between objects in three-dimensional space. This skill is crucial for comprehending abstract scientific concepts, such as molecule shapes, atomic structures, or concept maps. Meanwhile, analytical ability refers to the capacity to identify problems, evaluate information, and analyze data in order to make well-informed decisions. Therefore, it is essential to investigate the relationship between spatial and analytical abilities in students. This analysis aims to determine the extent of the relationship between the two skills within the learning context and whether an improvement in spatial ability has a positive impact on students' analytical skills.

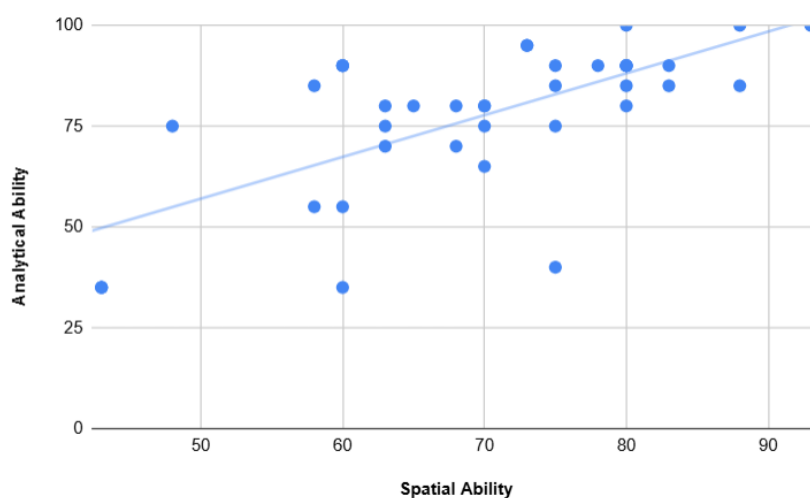


Figure 7. Distribution of the Correlation Test Between Students' Spatial and Analytical Abilities

Based on Figure 7, the data points tend to form an upward trend. This pattern indicates a positive correlation between spatial and analytical abilities. In other words, the higher a student's spatial ability, the higher their analytical ability tends to be. Furthermore, the distribution of the results of the spatial and analytical ability tests was analyzed using the Pearson correlation test. Based on the results of the Pearson correlation test, the correlation coefficient (Pearson Correlation) was found to be 0.641 with a significance value (2-tailed) of 0.001. This significance value is lower than 0.01, indicating that the relationship between spatial and analytical abilities is statistically significant at the 1% level of confidence. The Pearson correlation coefficient of 0.641 suggests that the strength

of the relationship between spatial and analytical abilities falls within the strong positive correlation category. This implies that the higher the students' spatial ability, the higher their analytical ability is likely to be.

These findings support the visualization in Figure 7, which shows a distribution pattern of data points forming an upward trend. This suggests that spatial ability may be a good predictor of enhanced students' analytical skills. Figure 4.17 illustrates the results of student evaluations regarding the use of computational chemistry media in the learning process. The learning response instrument consisted of 10 questionnaire statements distributed to students. Each item represented a different aspect, such as clarity of the material, media attractiveness, student engagement, ease of concept understanding, and perceived benefits of the lesson in improving understanding of chemistry. The percentage of student satisfaction responses indicated positive outcomes, ranging from 87.5% to 93.75%. The highest percentages (93.75%) were recorded for statements 2, 3, and 10, indicating a very positive student response toward these specific aspects. Meanwhile, the lowest percentages (87.5%) were found in statements 5 and 7, which, although still categorized as high, suggest areas that may require further attention and improvement. Overall, the data in Figure 4.17 show that the use of computational chemistry media in the learning process was well-received by students. This suggests that the approach was effective in enhancing student engagement, interest, and understanding of the topic of molecule shape in chemistry.

CONCLUSION

The implementation of the Inquiry-Based Learning model supported by computational chemistry media through the PyMOL application significantly enhanced students' spatial and analytical abilities in learning chemical molecule concepts. By enabling interactive 3D visualization of molecule structures and bond angles, PyMOL allowed students to manipulate, visualize, and accurately represent molecular geometry, thereby improving their ability to analyze problems and understand cause-and-effect relationships within molecule structures. Compared to Molymod models, 3D visualization using PyMOL provided clearer connections between abstract concepts and concrete representations, resulting in a notable increase in students' understanding, as reflected by the high N-gain scores in the experimental class. Student responses further confirmed the effectiveness of this approach, with high levels of engagement, motivation, and satisfaction reported, particularly in terms of content clarity and participation. Overall, learning chemistry using the inquiry-based model, integrated with PyMOL as a computational chemistry tool, demonstrates strong potential as an innovative teaching strategy for improving spatial and analytical skills, while making chemical molecules more meaningful and accessible to students.

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