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# Enhancing Molecular Geometry Understanding through 3D Visualization-Assisted Intertextual based Learning in Undergraduate Chemistry Students

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**Abstract:** Intertextuality refers to the process of understanding a context by exploring and connecting relationships between different texts or representations. In chemistry education, intertextuality serves as a communication bridge that links the three levels of chemical representation: macroscopic, submicroscopic, and symbolic. This study aims to enhance students' understanding of Molecular Geometry Concepts through Intertextual-based Learning with 3D-visualization. The research employed a quantitative approach with a one-group pretest-posttest design. Participants were selected using purposive sampling from undergraduate chemistry education students. The study involved 26 first-year students majoring in chemistry education who were taking a general chemistry course. Data were collected using student worksheets and pretest-posttest assessments. The data analysis included t-paired test for parametric statistic and evaluating student responses related to learning outcomes. Analysis of the t-paired test results shows that there is a significant difference in the pretest and posttest scores with a significance value of ($p > \alpha 0.05$). The most influenced concept indicator in this study was the concept of molecular geometry types with an increase of 57% in students' correct answers.

**Keywords:** student's understanding, molecular geometry, intertextual based learning, 3d visualization, undergraduate students.

## ▪ INTRODUCTION

Chemistry encompasses three levels of representation that is macroscopic, submicroscopic, and symbolic levels. The macroscopic level involves observable phenomena in the real world, while the submicroscopic level involves explanations of these phenomena at the atomic, ionic, or molecular scale. The symbolic level translates these phenomena into representations such as chemical formulas and equations (Johnstone, 1992; Gilbert, 2005). Using multiple representations can support cognitive development by aiding in the understanding of physical and chemical changes, while also serving as a communication bridge within the field of chemistry (Adadan, 2009; Chandrasegaran, 2011; Corradi, 2012; Pham, 2022).

Molecular geometry is one of the concepts studied in basic chemistry learning. By understanding molecular geometry, we will know the arrangement of atoms in a molecule in 3D space. This concept is very necessary to understand various molecular properties ranging from intermolecular bonds, polarity, electronegativity and other molecular properties (Petrucci, 2011). So far, various visualizations and models have been used to represent the concept of molecular geometry for students because in reality molecular geometry cannot be seen directly by the naked eye. These various forms of representation are models of molecular geometry visualized by researchers based on experimental results. Molecular representations may take the form of reaction equations, Lewis structures, or three-dimensional molecular models. (Kozma, 2012; Kiernan, 2021).

Its undeniable that chemistry relies on visual reasoning on its reasoning process. Chemical concepts are commonly conveyed through visual representations, which

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scientists utilize it to explain various principles of chemistry. In teaching chemistry, representational models both mental and physical play a crucial role, as they are intrinsically linked to visuospatial characteristics. For instance, Lewis structures and 3D visualizations are employed to illustrate fundamental concepts in molecular geometry, while structural models are integral in the study of organic chemistry (Carlisle, 2015).

However, in reality, complexity that confuses learners comes out when using many representations to explain chemical concept (Samon, 2020). Students are unable to connect one representation to another, they consider one representation to be different information with another one. Moreover, at the submicroscopic level, they consider this level to involve something abstract that is invisible so that it is very difficult for them to reason. This difficulty triggers misconceptions among students. These misconceptions can hinder students' understanding of the concept as a whole (Keiner, 2020; Luviani, 2021; Dood, 2022). Many studies have been conducted that assess the misconceptions and difficulties experienced by students in the concept of molecular geometry. Such as students' misconceptions on the concept of bond angles and VSEPR (Uyulgan, 2014). For this reason, it is very important to pay attention to the use of representations in the learning context. Combining various types of information such as text, images, and diagrams can help students understand concepts more deeply (Dicckmann, 2019). Regarding to move from one representation to another, they need to develop representational competencies.

In their study, Kozma and Russel (2005) highlighted that chemistry students should be trained in representational skills. Students who have high representational skills are able to successfully solve spatial problems. They make sketches and drawings to help them explain visual information reasoning. In addition, drawing can also reduce cognitive load by opening working memory space. There are six representational competencies that chemistry students must have (Kozma, 2005). Two of them are 1) the ability to create representations to express a chemical entity and its process; 2) analyzing or identifying features of a representation. Therefore, to face this challenge, instructions are needed to not burden students' cognitive load as well as learning that is able to integrate one representation into another so that understanding chemistry can be complete.

On the other side to gain a complete and in-depth understanding of a concept requiriing ability to structure and link various subconcepts both hierarchically and through cross- relationships between subconcepts (Novak, 1984). Intertextual strategy in chemistry provides connectivity between chemical phenomena and concept through three level representation, which is macroscopic, submicroscopic and symbolic. (Wu, 2003). Meanwhile, according to cognitive load theory, students get effective instruction when the information obtained is not separated. An example is integrating "text" statements with "visualization" diagrams (Cai, 2019). Springer's research (2014) suggests the use of 3D molecular structures in addition to 2D representations because it provides significant benefits for students' understanding of the concept of molecular geometry. In previous studies (Wardani, 2018; Zulfahmi, 2022), learning with intertextual-based strategies has been developed to improve students' understanding of geometric concepts. Other research in the context of molecular geometry focuses on the use of various 3D learning tools such as AR and VR. The study stated that there are still limitations in terms of learning instructions that need to be further developed. So, this study uses intertextual-based learning with the help of 3D visualization where learning instructions are presented in a unified manner between multiple representations and step by step, minimizing the cognitive load that students may face, maximizing students' ability to understand each feature of the representation and making it easier for students to connect one representation to another.

## ▪ METHOD

### Research Design

This study used a quantitative pre-experimental approach to answer the research questions with a one group pretest-posttest design. In the one-group pretest-posttest design, a single group is measured or observed not only after being exposed to a treatment of some sort, but also before treatment (Salkind, 2010). In this study, a one-group pretest-posttest design was used to determine changes in students' mastery of concepts after the implementation of intertextual-based molecular geometry learning.

| *O* | *X* | *O* |
|---|---|---|
| *Pretest* | Treatment | *Posttest* |

**Figure 1**. One group pretest postest design

### Participants

A total of 26 first-year students majoring in chemistry education were involved as samples of this study. The selection of this study sample was based on a purposive sampling strategy on students who were contracting the Basic Chemistry course. This study will asses students' understanding of the concept of molecular geometry after conducting intertextual based learning. At the college level, the concept of molecular geometry is taught in basic chemistry courses so this strategy was used because first-year chemistry students contract basic chemistry courses and will study the concept of molecular geometry.

### Instruments

Quantitative data in this study were collected through pretest and posttest instruments on molecular geometry material consisting of 10 multiple-choice questions. These questions have been developed based on 5 sub-indicators on the concept of molecular geometry, 1) definition of Molecular Geometry, 2) Types of Molecular Geometry, 3) Relationship between molecular geometry and polarity, 4) VSEPR Theory & 5) Valence Bond/Hybridization theory. Each sub-indicator contains 2 questions. The validation of the construct of this instrument is based on the learning competency achievement indicators. After the validation process, there were slight revisions made to the question instrument according to the input given by the experts. The pretest questions are different from the posttest questions but have the same sub-indicator construct. Students answer the pre-test questions before carrying out learning and answer the post-test questions after carrying out learning. The indicators described in table 1 below.

**Table 1.** Indicator concept of molecular geometry

| No | Concept | Indicator |
|---|---|---|
| 1 | Molecular Geometry | Define molecular geometry |

| | | |
|---|---|---|
| 2 | Types of Molecular Geometry | Classified the types of molecular geometry based on it features |
| 3 | Relationship between molecular geometry and polarity | Connect polarity with molecular geometry |
| 4 | VSEPR Theory | Predict molecular geometry using VSEPR theory. |
| 5 | Valence Bond/Hybridization theory | Predict molecular geometry using Valence Bond theory. |

Each question indicator is presented in 2 questions. The construct validity and content of each question item were validated by three expert lecturers in the field of chemistry. The validation CVI value of 0.667 indicates that this instrument is valid for use. Then the reliability of this instrument was tested using the KR-20 test, which is a reliability test for multiple-choice questions with a result of 0.680, which indicates high reliability results.

**Procedures**

Before learning begins, students are given a pretest in mastering the concept of molecular geometry first. After that, the treatment process is carried out by carrying out intertextual-based molecular geometry learning. Lectures for 3 credits (150 minutes) were carried out to provide an introduction to the topic, learning instructions, and data collection from learning activities. Initially, an introduction is given using presentation slides on the topic of molecular geometry, including learning objectives and an overview of learning activities. In the introductory material, students are introduced to molecular geometry and the properties of a molecule that it influences. Then as a macroscopic representation, the experimental data from the XRD experiment is presented which shows data on bond angles and molecular bond lengths. To connect the macroscopic (bond length and angle) with the submicroscopic (molecular geometry), from the experimental data students are instructed to create 2D sketches of molecular geometry from the experimental data.

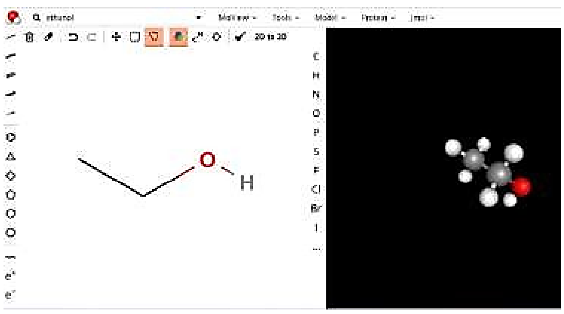


**Figure 2**. Molview, software for creating 3D visualizations of molecules

In the next activity, students are instructed to create a 3D visualization of molecules using molymod and visualize them using the 3D molecular visualization application, molview. Students are instructed again to create 2D sketches of molecular geometry from the 3D visualization results that have been created. Student worksheets are used to collect image sketch data. After the drawing activity, students are instructed to write down the differences between the first activity drawing and the second activity drawing based on features. Student participants were given approximately 50 minutes to complete the assignment (drawing and creating 3D visualizations). After applying the intertextual approach-based geometry learning, the students were given a posttest.

**Data Analysis**

To answer the first research question related to the impact of intertextual learning on students' mastery of molecular geometry concepts, statistical tests were used. The data were tested for normality first using the Saphiro Wilk test because the data sample size was less than 50 ($n \leq 50$). The Saphiro Wilk test is a method that is suitable for small sample sizes because it is more sophisticated in detecting data distribution abnormalities (Mishra, 2019). The appropriate statistical test will be determined after the normality is known. If the data is normally distributed, statistical tests are carried out parametrically using the paired t-test to determine the significance of the two groups of data. Meanwhile, if the data is not normally distributed, statistical tests are carried out nonparametrically using the Wilcoxon test to determine its significance. Furthermore, to answer the second research question related to which concept indicators are most influenced by learning, the results of students' answers are presented descriptively in the form of Mean, Maximum Value, Minimum Value, Standard Deviation. Then the increase in students' correct answers from each indicator is analyzed.

## ▪ RESULT AND DISSCUSSION

**The Impact of Intertextual Learning on Mastery of Concepts**

In this study, the mastery of the molecular geometry concept was assessed using pretest and posttest instruments, which had been developed based on competency achievement indicators. The pretest and posttest scores of students were analyzed for normality using the Shapiro-Wilk test. The W-calculated value was found to be greater than the W-table value at a 95% confidence level with df = 25, leading to the acceptance of the null hypothesis, indicating that the data is normally distributed in the differences between the

two groups. A parametric paired t-test was used for statistical analysis to determine the significance of the treatment's effect on the sample. Descriptive data from the pretest and posttest results are presented in Table 2.

**Table 2.** Descriptive data of pretest and posttest of mastery of molecular geometry concepts

| Data | Pretest | Postest |
|---|---|---|
| Number of Students | 26 | 26 |
| Minimum score | 20 | 60[R1] |
| Maximum score | 90 | 100 |
| Mean | 65.38 | 90.77 |
| Deviation Standard | 18.60 | 11.29 |
| Normality test (Wilk, p > 0,05. n=26) | 0,97 | |
| Interpretation | Normal Distribution | |
| t- paired test (t>t0.05), | T = ABS (-7.938), | |

| | |
|---|---|
| df=25 | sig. (2-tailed) 0.000 |
| Interpretation | There is a significant difference |
| Effect Size Cohen' d | 1.650 |
| Interpretation | Large effect |

According to the data in Table 1, the average pretest score of students was 65.38, with minimum score of 20 and maximum score of 90. In contrast, the average posttest score was 90.77, with a minimum score of 60 and a maximum score of 100. In the pretest, the minimum score was 20, while in the posttest, the minimum score was 60. This indicates that the implementation of learning was successful in increasing the scores of students whose initial ability scores were low. The paired t-test results showed a significance value of 0.000, which is less than $\alpha = 0.05$. The obtained t-test value exceeded the two-tailed t-table value at a 95% confidence level with df = 25, leading to the rejection of the null hypothesis. There is a notable difference in the averages of the two groups. This indicates that there is a significant difference in students' concept mastery before and after receiving intertextual-based molecular geometry learning. The 35.39-point difference in the average pretest-posttest scores suggests an improvement in students' understanding of molecular geometry concepts after the intertextual-based learning treatment. Cohen's d effect size shows a value of 1.650, which means that the implementation has a large impact on improving student grades. The results of the paired t-test, the increase in the average score and cohen' d effect size demonstrate that intertextual-based molecular geometry learning has a significant impact on enhancing students' mastery of molecular geometry concepts.

Overall, the findings of this study align with previous research on the use of intertextual strategies in chemistry education (Wu, 2003; Varelas, 2006; Ryu, 2018). The concept explored in this study is molecular geometry, with 3D visualization software integrated into the learning process. The goal of using visualization models is to serve as an external representation that helps clarify the connection between unseen representations and students' real-life experiences (Baldwin, 2019). Molecular geometry learning based on intertextuality enhances students' conceptual understanding because the intertextual relationships in the instructional materials support students in deeply understanding and connecting different representations. Once students acquire this skill, they are more capable of understanding chemistry in its entirety, as they can utilize the connections between different representations to explain the cause-and-effect relationships of chemical phenomena. (Treagust, 2009; Ryu, 2018).

**Student Concept Mastery per Indicator**

The students' mastery of the subject matter involved five key concepts: defining molecular geometry, identifying different types of molecular geometry, understanding the link between molecular geometry and polarity, grasping the VSEPR Theory, and comprehending the Valence Bond Theory/Hybridization.

Overall, there was an improvement in students' correct answers on the concept mastery test after the implementation intertextual based learning. The highest correct answer in the pretest was on the VSEPR theory indicator, which was 88,9% and the lowest correct answer was on the type of molecular geometry indicator, which was 27.8%. After the implementation, the highest increase in students' correct answer was observed in the

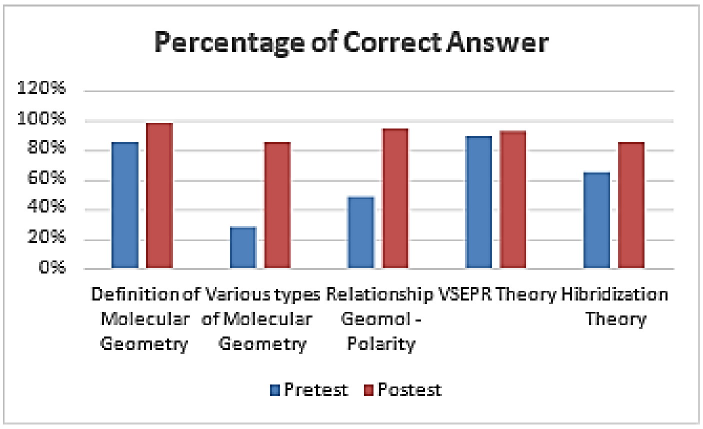


**Figure 2.** Percentage of students' correct answers for each indicator

type of molecule indicator, which was 57%. To determine the type of molecular geometry, the ability to analyze the features of a molecule is required. This is one of the representation competencies mentioned by Kozma (2005). As suggested in Carlisle's research (2015), training can improve students' reasoning abilities. Showing 3D features makes students familiar with each feature of molecular geometry. The lowest increase occurred in the VSEPR theory indicator which only 3,7%. For this VSEPR theory questions, the initial score was already high so the increase was not too significant, indicating that students' initial understanding of this theory was already high.

From the data collected, molecular geometry indicator has 85,2% percentage of students' correct answer. This indicates that before the implementation of intertextual learning, majority of students had mastering the definition of molecular geometry which is a representation of molecules in three-dimensional space so that they were not fooled by other answers involving 2D representations such as line structures and chemical formulas. After the learning was implemented, there was 12.9% increase of, so the average correct answer on this indicator became 98.1%

For the type of molecular geometry indicator, it has 27.8% of the correct answer percentage in the pretest. This result indicates that initially the majority of students from the class have not been able to classify the type of molecular geometry correctly based on the features of the molecule such as the size of the bond angle and the number of atoms bound to the central atom. In the implemented intertextual learning, molecular geometry visualization was carried out using the molview molecular visualization software which presents a 3D model of molecular geometry. As mentioned above, to be able to classify the type of molecular geometry, students need the ability to analyze the features of a representation. This is in line with the representational competence that is important for students to become chemists that is generating representations (Rau, 2017). The ability to visualize is an important skill in chemistry. With visualization, students can be more familiar with representations and better understand the particulate nature of matter because they can directly observe it through external representations, either through physical models or computer models (Kozma, 2012; Carlisle, 2015). After the learning was implemented, the results of students' correct answers increased by 57% become 85.2% correct answer. In this study, students were asked to pay attention to 3D models through computer applications so this may be one of the factors which makes the indicator of the type of molecular geometry the biggest improvement. This indicates that the implementation of intertextual learning has succeeded in training students in the indicator of classifying types of molecules. Learners improve their ability in terms of analyzing the features possessed by molecules so that they can distinguish the types of molecular geometry based on their features.

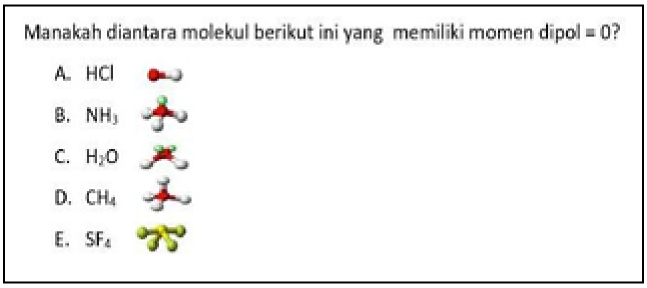


**Figure 3.** Example of polarity - molecular geometry questions

In the indicator of the relationship between molecular geometry and polarity properties, students must be able to explain experimental data on polarity from a molecular geometry perspective. This requires the ability to connect one representation-read: polarity to another-read: molecular geometry as Novak (1984) said regarding understanding chemistry required the ability to structure and link various subconcepts, both hierarchically and through cross-relationships between subconcepts. The pretest showed that 48.1% of students answered correctly on this indicator. These results indicate that the majority of students in the class have not been able to connect and explain polarity properties with molecular geometry. The implementation of learning using intertextual instructions trains students to connect the two. Students are instructed to identify the bond polarity of each bond in the molecule and then determine the geometry of the molecule. Furthermore, students are directed to connect properties based on polarity and geometry with clear instructions and steps. The posttest results showed an increase of 46.3% of students' correct answers so that 94.4% of students answered correctly after the implementation of learning. This implementation successfully improved students' ability to explain the polarity of molecules from a molecular geometry perspective.

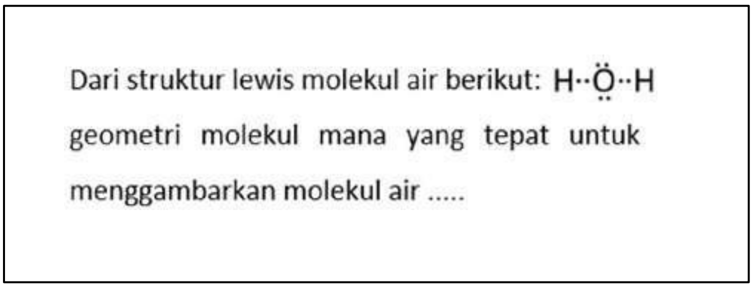


**Figure 4.** Example of VSEPR theory questions

The VSEPR Theory indicator has the most correct answers from students compared to other indicators. To understand this indicator, students must be able to determine the amount of PEI and PEB in a molecule, transform a 2D Lewis structure into a 3D structure, and understand the repulsion between electron pairs. 3D visualization using molview software provides a feature for transforming 2D structures into 3D structures. By demonstrating this 3D visualization, students transform a 2D Lewis structure into a 3D molecular model and analyze the repulsion between electron pairs seen in the 3D model visualization. According to Carlisle (2015) this requires students to visualize spatial relationships among the atoms in the molecule. The posttest results showed an increase of 3.7% of students' correct answers so that 92.6% of students answered correctly after the implementation of learning.

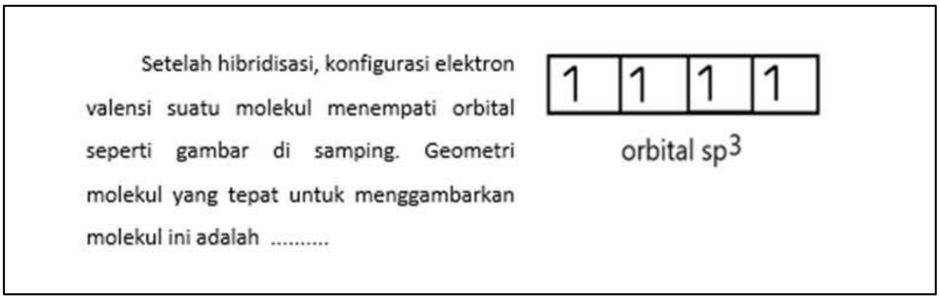


**Figure 5.** Example of vallence bond theory questions

The pretest in valence bond theory indicator results showed that most students 64.8% already understood the valence bond theory before learning. To predict the shape of a molecule using this theory, students need to be able to count valence electrons, draw orbitals, and determine which orbitals form bonds. This means that students must be able to convert information from electron configurations into orbital images. According to Dickmann (2019), combining various types of information such as text, images, and diagrams can help students understand concepts more deeply. Therefore, in this learning, students are trained to connect electron configurations with the shape of molecular orbitals. They are asked to draw orbital diagrams and the shape of bonded orbitals. The goal is for students to understand where the shape of the molecule comes from. After learning, there was a significant increase. Now, 85.2% of students can answer questions correctly.

Overall, the question indicator experienced an increase in students' correct answers. This shows good results from the implementation of 3D visualization assisted – intertextual based learning. The 3D visualization in this study is used as training so that students can clearly see the features in molecular geometry in 3D and will be familiar with the arrangement of atoms in molecules in 3D space. In Carlisle's study (2015), training was highlighted as an effort to improve students' visual reasoning. One of the suggestions for chemistry instruction adapted from Harle (2011) is Explicitly articulate 3D cues. Molview is a software application that can be accessed publicly. In its application, we can easily transform the molecular structure of 2D images into 3D molecular visualizations. Here it also presents complete information related to the size of the angle and the length of the molecular bond. This 3D visualization demonstration helps students to imagine what the shape of the molecule is in real 3D space. Whereas if only presented with a 2D image, students may not be able to imagine it.

In this intertextual learning, beside observing 3D visualization activities, there is also an activity of drawing molecular geometry sketches based on experimental data and visualization data. This activity actually aims to reduce students' cognitive load. Because as Kozma (2005) said that drawing is one of the activities that can reduce the cognitive load experienced by students. Drawing activities open up memory space so that the many representations used do not burden students and confuse them. In addition, presenting intertextual relationships between representations can make it easier for students to connect information between one representation and another (Wu, 2003). So in this case students will get a complete understanding of chemical concepts without burdening their cognitive load.

## ▪ CONCLUSION

As explained above, this study aims to determine the impact of the implementation of intertextual learning on the mastery of molecular geometry concepts. From the research conducted, it is known that there is a significant difference between before and after the implementation of intertextual learning. Regarding the concept indicators that are most influenced by learning, the highest increase occurred in the molecular geometry type indicator, which was 57%. This increase can be associated with an increase in students' representation competence due to training using intertextual learning. From learning instructions, students are trained to understand the features of each representation and are directed directly to make connections between representations. This study is in line with previous studies related to the use of intertextual strategies to improve student learning outcomes (Wu, 2003; Varelas, 2006; Ryu, 2018; Zulfahmi, 2022).

Intertextuality refers to the process of understanding a context by exploring and connecting relationships between different texts or representations (Salloum, 2021). In this study intertextual is used as a training tool for students to be able to connect one representation to another. the use of this strategy is efficient in reducing students' cognitive burden due to the many chemical representations used to explain a phenomenon. For further research, intertextual learning instructions can be further explored according to the topic of the material used. Intertextual strategies are very suitable for connecting between representations and supporting a complete understanding of concepts.

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