*Jurnal Pembelajaran Kimia* *OJS*
*Vol. 5, No. 2, Desember 2020, hal. 90-107* *Universitas Negeri Malang*

# Concrete Model VS Virtual Model: Roles and Implications in Chemistry Learning

**Thayban Thayban, Habiddin Habiddin*, Yudhi Utomo**

Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang Jl. Semarang No. 5 Malang, Indonesia

**Abstract** – mastering the topic of symmetry requires a good representational competence to smoothly understand, visualize, and manipulate the movement of three-dimensional objects. This literature study aimed to describe how concrete and virtual media can be utilized in improving students' understanding of the topic. The study implies that the thinking process, cognitive tasks, interactions, mental models, and the completeness features displayed by the two models in identifying all symmetrical operations are the distinguishing factors of the effectiveness of the two formats in affecting students' understanding. The study also implies that the virtual format will contribute to students' understanding better than the concrete format does. However, the empirical study must be explored further to ensure the difference between the two formats.

**Keywords:** Concrete media, virtual media, symmetry, chemistry learning

## INTRODUCTION

Understanding chemistry requires a good representation concept to make it easier to learn. For example, the molecular shape takes a precise representation to visualize the three-dimensional shape of a chemical molecule. As a result, chemistry teaching materials need to cover two-dimensional representations to represent the form's true three-dimensional representations. However, the use of chemistry teaching materials with two-dimensional representations distortions the mental model and can hinder the desired learning process (Stieff, Bateman, & Uttal, 2005). This is because visualizing two-dimensional objects into three dimensions requires several thinking tasks. First, the interpretation and understanding of different charts should be done appropriately before translating them into the three-dimensional form (Abraham, Varghese, & Tang, 2010; Padalkar & Hegarty, 2015; Stull & Hegarty, 2016; Wu & Shah, 2004). Second, converting the abstract object into a real object should be done (Olimpo, Kumi, Wroblewski, & Dixon, 2015). These tasks make it difficult to visualize three-dimensional molecules' movement (Kozma & Russell, 2005) and unable to relate visual information and conceptual representations (Wu & Shah, 2004).

Researchers have addressed this problem by increasing representational competence, namely building two-dimensional visualizations into three dimensions (Robert B. Kozma & Kozma Russell, J., 1997; Stieff et al., 2005; Stull & Hegarty, 2016). Representational competence is part of the ability to visualize representation supported by visual-spatial thinking. This ability can be improved by implementing learning strategies assisted by concrete media or virtual media (Abraham et al., 2010; Ferk, Vrtacnik, Blejec, & Gril, 2003; Kumi, Olimpo, Bartlett, & Dixon,

*Corresponding author: Jurusan Kimia, Universitas Negeri Malang, Malang 65145, Indonesia.

Email: Habiddin_wuni@um.ac.id

**ISSN 2528-6536 (print)/ISSN 2579-5945 (online) @2020 J-PEK**

2013; Olimpo et al., 2015; Stieff et al., 2005; Stull, Barrett, & Hegarty, 2013; Stull & Hegarty, 2016; Wu & Shah, 2004). Concrete media and virtual media catalyze students' understanding of three-dimensional objects and facilitate identifying spatial relationships to translate two-dimensional representations into three dimensions. Concrete media is a physical form used to represent physical phenomena and abstract concepts in mathematics, physics, and chemistry. Meanwhile, virtual media is a form of computerized visualization representing objects (Barrett, Stull, Hsu, & Hegarty, 2015).

Media-assisted learning (concrete or virtual) provides visuospatial information which is better than without using media (Stull & Hegarty, 2016). By using concrete media, students can feel the three-dimensional shape of molecules through sight and touch and make it easier to manipulate molecules because they match what they see. On the other hand, virtual media is different from concrete media. Interactions with molecules in a computer are usually incompatible with the movement of objects that are seen as real, thus requiring additional cognitive effort to adapt virtual media to real objects. Consequently, it affects learning from virtual media. (Patterson & Silzars, 2009).

On the other hand, virtual media offers many advantages over concrete media. Generally, virtual media is more portable because of increasingly sophisticated tablets and smartphones. Molecule shapes with virtual media can be downloaded on the internet, so students do not have to spend time creating them. In terms of flexibility, virtual media can change visually, such as between three-dimensional and two-dimensional representations and can be displayed simultaneously with other representations (Keehner et al., 2008).

Research comparing learning with virtual and concrete media in chemistry has been conducted by Fjeld et al. (2007), Abraham, Varghese, and Tang (2010), and Stull and Hegarty (2016), who indicate an inconsistency in their study. These studies focus on organic chemistry, especially stereochemical materials (the study of the arrangement of atomic spaces that make up molecules) using structural diagrams, concrete media, virtual media, and a combination of concrete and virtual media.

Previous research by Fjeld et al. (2007) found that learning with concrete media was superior to virtual media and concluded that this was due to the difficulty of using the keyboard to rotate virtual media. Besides, Abraham, Varghese, and Tang (2010) yielded different findings. They uncovered that learning using concrete and virtual media showed no significant difference between the treatment groups; however, the virtual media group was better than the concrete media. Furthermore, Stull and Hegarty (2016) found no significant difference between the two media, concluding that organic chemistry on stereochemical material can be studied using two media and suggested combining the two media. Based on these studies, it can be considered that the comparison of concrete and virtual media is still inconclusive. Several researchers such as Al-Balushi and Al-Hajri (2014), Stieff, Bateman, and Uttal (2005), Stull, Barrett, and Hegarty (2013), and Stull and Hegarty (2016) believe that concrete and virtual media learning media can provide different results in their application to learning. Concrete media is very different from virtual media, even though this media aims to help students visualize molecular shapes. However, the cognitive aspect built in using these two media is different. This is supported by Fjeld et al. (2007) stating that virtual media requires more cognitive abilities than concrete media.

The effectiveness of virtual media or concrete media is very dependent on the type of material to be taught (Barrett et al., 2015). For example, in a previous study focused on organic chemistry, especially stereochemistry, students learned to manipulate and control variables or run experimental simulations using concrete or virtual media. If the material is still unable to distinguish media effectiveness between concrete and virtual, then more abstract material is needed. Symmetry material has many operations that must be performed to determine the type of symmetry in molecules so that higher cognitive abilities are needed (Atkins & De Paula, 2006; Effendy, 2017).

In addition, organic chemistry is only limited to the shape of the molecule with the coordination number four, while the molecular symmetry material which includes the shape of the molecule with the coordination number four, five, and six to understand the effectiveness of concrete and virtual media in learning. Therefore, it is necessary to study the literature on the potential of symmetrical material in comparing concrete and virtual media effectiveness.

## METHOD

This study employed a literature review of articles related to concrete and virtual media. The literature review was carried out by discussing previous research on the effectiveness of the use of concrete and virtual media and the characteristics of the symmetrical material. The details of the articles studied are shown in Table 1.

**Table 1.** Reviewed Articles

| Authors (Year) | Title | Publication |
|---|---|---|
| Abraham, M., Varghese, V., & Tang, H. (2010) | Using molecular representations to aid student understanding of stereochemical concepts. | *Journal of Chemical Education* |
| Al-Balushi, S. M., & Al-Hajri, S. H. (2014). | Associating animations with concrete models to enhance students' comprehension of different visual representations in organic chemistry | *Chemistry Education Research and Practice.* |
| Al-Balushi, S. M., & Coll, R. K. (2013) | Exploring Verbal, Visual and Schematic Learners' Static and Dynamic Mental Images of Scientific Species and Processes in Relation to Their Spatial Ability | *International Journal of Science Education.* |
| Anggriawan, B., effendy, & Budiasih, E. (2017) | Kemampuan Spasial dan Kaitannya dengan Pemahaman Mahasiswa terhadap Materi Simetri | *Jurnal Pendidikan.* |
| Antonoglou, L. D., Charistos, N. D., & Sigalas, M. P. (2011) | Design, development and implementation of a technology enhanced hybrid course on molecular symmetry: Students' outcomes and attitudes | *Chemistry Education Research and Practice.* |
| Atkins, P., & De Paula, J. (2006) | Physical Chemistry 8th Edition | In *W.H. Freeman and Company New York.* |
| Barrett, T. J., Stull, A. T., Hsu, T. M., & Hegarty, M. (2015) | Constrained interactivity for relating multiple representations in science: When virtual is better than real. | *Computers and Education.* |
| Cass, M. E., Rzepa, H. S., Rzepa, D. R., & Williams, C. K. (2005) | An Animated Interactive Overview of Molecular Symmetry | *Journal of Chemical Education*, |
| Charistos, N. D., Tsipis, C. A., & Sigalas, M. P. (2005) | 3D Molecular Symmetry Shockwave: A Web Application for Interactive Visualization and Three-Dimensional Perception of Molecular Symmetry | *Journal of Chemical Education.* |
| Craig, N. C. (1969) | Molecular symmetry models | *Journal of Chemical Education.* |
| Ferk, V., Vrtacnik, M., Blejec, A., & Gril, A. (2003) | Students' understanding of molecular structure representations | *International Journal of Science Education*, |
| Fjeld, M., Fredriksson, J., Ejdestig, M., Duca, F., Bötschi, K., Voegtli, B., & Juchli, P. (2007) | Tangible User Interface for Chemistry Education: Comparative Evaluation and Re-Design. | *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 805–808 |
| Flint, E. B. (2011) | Teaching point-group symmetry with three-dimensional models | *Journal of Chemical Education.* |
| Fuchigami, K., Schrandt, M., & Miessler, G. L. (2016) | Discovering Symmetry in Everyday Environments: A Creative Approach to Teaching Symmetry and Point Groups. | *Journal of Chemical Education* |
| Graham, J. P. (2014) | An inquiry-based learning approach to the introduction of the improper rotation-reflection operation, *S*n | *Journal of Chemical Education* |
| Harle, M., & Towns, M. (2011) | A review of spatial ability literature, its connection to chemistry, and implications for instruction. | *Journal of Chemical Education* |
| Harrison, A. G., & Treagust, D. F. (2000) | A typology of school science models | *International Journal of Science Education* |

| Authors (Year) | Title | Publication |
| --- | --- | --- |
| Keehner, M., Hegarty, M., Cohen, C., Cohen, C., Khooshabeh, P., & Montello, D. R. (2008) | Spatial reasoning with external visualizations: what matters is what you see, not whether you interact | *Cognitive Science* |
| Kozma, R., & Russell, J. (2005) | Students Becoming Chemists: Developing Representationl Competence | *Visualization in Science Education* |
| Kumi, B. C., Olimpo, J. T., Bartlett, F., & Dixon, B. L. (2013) | Evaluating the effectiveness of organic chemistry textbooks in promoting representational fluency and understanding of 2D-3D diagrammatic relationships | *Chemistry Education Research and Practice* |
| Mohamed-Salah, B., & Alain, D. (2016) | To what degree does handling concrete molecular models promote the ability to translate and coordinate between 2D and 3D molecular structure representations? A case study with Algerian students | *Chemistry Education Research and Practice* |
| Niece, B. K. (2019) | Custom-Printed 3D Models for Teaching Molecular Symmetry | *Journal of Chemical Education* |
| Olimpo, J. T., Kumi, B. C., Wroblewski, R., & Dixon, B. L. (2015) | Examining the relationship between 2D diagrammatic conventions and students' success on representational translation tasks in organic chemistry | *Chemistry Education Research and Practice* |
| Padalkar, S., & Hegarty, M. (2015) | Models as feedback: Developing representational competence in chemistry | *Journal of Educational Psychology* |
| Patterson, R., & Silzars, A. (2009) | Immersive stereo displays, intuitive reasoning, and cognitive engineering | *Journal of the Society for Information Display* |
| Robert B. Kozma, J. R., & Kozma Russell, J., R. (1997) | Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena | *Journal of Research in Science Teaching* |
| Scalfani, V. F., & Vaid, T. P. (2014) | 3D printed molecules and extended solid models for teaching symmetry and point groups | *Journal of Chemical Education* |
| Schiltz, Holly K., & Oliver-Hoyo, M. T. (2012) | Physical models that provide guidance in visualization deconstruction in an inorganic context | *Journal of Chemical Education* |
| Schiltz, Holly Kristine. (2015) | Promoting visualization skills through deconstruction using physical models and a visualization activity intervention | *Dissertation Abstracts International: Section B: The Sciences and Engineering* |
| Silva, D. D. M., & Ribeiro, C. M. R. (2017) | Analogue Three-Dimensional Memory Game for Teaching Reflection, Symmetry, and Chirality to High School Students | *Journal of Chemical Education* |
| Stieff, M., Bateman, R. C., & Uttal, D. H. (2005) | *Teaching and Learning with Three-dimensional Representations BT* | *Visualization in Science Education* |
| Stull, A. T., Barrett, T., & Hegarty, M. (2013) | Usability of concrete and virtual models in chemistry instruction | *Computers in Human Behavior* |
| Stull, A. T., & Hegarty, M. (2016) | Model manipulation and learning: Fostering representational competence with virtual and concrete models | *Journal of Educational Psychology* |
| Tuvi-Arad, I., & Gorsky, P. (2007) | New visualization tools for learning molecular symmetry: A preliminary evaluation | *Chemistry Education Research and Practice* |
| Wu, H. K., Krajcik, J. S., & Soloway, E. (2001) | Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom | *Journal of Research in Science Teaching* |
| Wu, H. K., & Shah, P. (2004) | Exploring visuospatial thinking in chemistry learning | *Science Education* |
| Zacharia, Z. C., & Olympiou, G. (2011) | Physical versus virtual manipulative experimentation in physics learning | *Learning and Instruction* |

## RESULTS AND DISCUSSION

### Concrete Media

Representation of molecular shape can be visualized in concrete media form. Molecular concrete media is a learning medium used to visualize abstract molecular shape concepts. The use of concrete media in science such as physics (Zacharia & Olympiou, 2011) and chemistry (Niece, 2019; Scalfani & Vaid, 2014; Holly K. Schiltz & Oliver-Hoyo, 2012; Holly Kristine Schiltz, 2015;

Wu, Krajcik, & Soloway, 2001; Wu & Shah, 2004) can be used by users to visualize the movement of three-dimensional objects after being manipulated. The concrete medium of molecular shape follows the ball-and-stick model because it can represent three-dimensional objects well and can show the number of bonds, bond lengths, and bond angles of a molecule. In addition, concrete models are used to examine three-dimensional molecular objects from different angles and can facilitate visualization of the characteristics of the molecular model (Wu et al., 2001; Wu & Shah, 2004).

The development of technology does not directly replace the role of concrete media into virtual media. Recent research uses concrete media as a catalyst in understanding three-dimensional object material (Abraham et al., 2010; Niece, 2019; Scalfani & Vaid, 2014; Holly K. Schiltz & Oliver-Hoyo, 2012; Holly Kristine Schiltz, 2015) because in virtual media there are several deficiencies in displaying three-dimensional objects. Schiltz and Oliver-Hoyo (2012) argue that molecular modeling with virtual media creates distortions to the visualization of the orientation or the user's point of view towards three-dimensional objects. The user's point of view is essential because visualizing a three-dimensional object from a two-dimensional representation should take into account the position of the observation regarding the shape of the molecule (Kumi et al., 2013). The molecular model in the virtual media has been designed by the manufacturer so that the perspective on the shape of the molecule belongs to the maker. As a result, the user does not get his or her own point of view in manipulating the movement of three-dimensional objects. Meanwhile, concrete media allows users to create their own molecular models so that they get their own point of view in visualizing objects. The point of view or spatial orientation to three-dimensional objects is essential to translate the molecular shape after being manipulated (Lohman, 1979).

Furthermore, Fjeld *et al.* (2007) found that the use of virtual media requires more cognitive aspects than the use of concrete media. The use of a keyboard and mouse in manipulating the movement of three-dimensional objects on virtual media causes limited interaction between users and virtual media. As a result, the user requires additional cognitive to translate the visualization of the movement of objects. Based on this fact, a cognitive load will appear where the existing spatial information can no longer be accommodated so that the object's visualization ability is distorted. Meanwhile, concrete media offers unlimited interactions with users in manipulating three-dimensional objects (Barrett et al., 2015). Direct interaction can improve spatial relation capabilities, namely the ability to determine the position of atoms in a molecule after rotation and spatial visualization capabilities, namely the ability to imagine the movement or displacement of atoms in a molecule after being manipulated (Lohman, 1979).

The use of concrete media in symmetry learning has been developed by several researchers (see Craig, 1969; Flint, 2011; Fuchigami, Schrandt, & Miessler, 2016; Niece, 2019; Scalfani & Vaid, 2014; Holly K. Schiltz & Oliver-Hoyo, 2012). They agreed that concrete media can be used as a catalyst in understanding and identifying all symmetrical operations on molecular shapes. For instance, Craig (1969) showed some concrete media to assist in identifying and understanding rotation operations and reflection operations on the mirror plane as shown in Figure 1. Holly K. Schiltz & Oliver-Hoyo (2012) made concrete media to understand the reflection process in the mirror plane. The molecular shape medium is installed with transparent glass to divide the right and left sides symmetrically as shown in Figure 2. Recently, Scalfani and Vaid (2014) created a concrete medium for understanding the symmetry of the molecules of complex compounds with a high degree of complexity. Craig's (1969) media is limited to simple molecular forms, while Scalfani and Vaid (2014) employed a complex molecular shape as shown in Figure 3. Molecular form media is made by using a printer or three-dimensional printing with polylactic acid (filament). Niece (2019) found that there are still difficulties in understanding the operation of reflection on the mirror plane so that he develops concrete media to perfect the media made by Holly K.Schiltz & Oliver-Hoyo (2012) as shown in Figure 4. Effendy (2017) developed simple concrete media but can represent the four previous media. This medium is made of pencil eraser which is round in shape to represent the central atom and pins as bond lengths and substituents as shown in Figure 4.

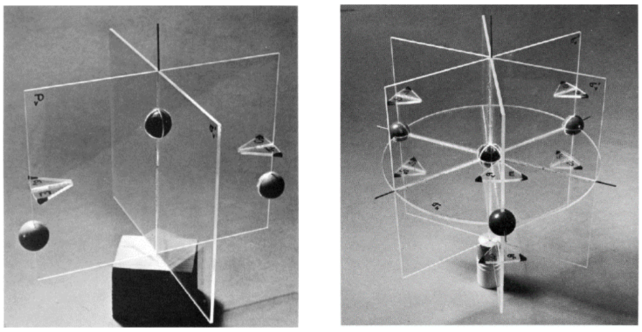


**Figure 1.** Craig's (1969) Concrete Media

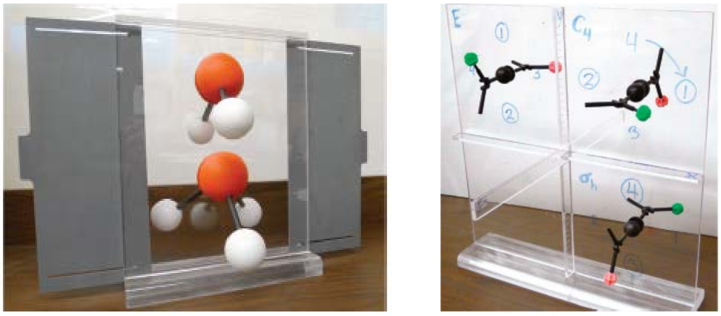


**Figure 2.** Holly K. Schiltz & Oliver-Hoyo's (2012) Concrete Media

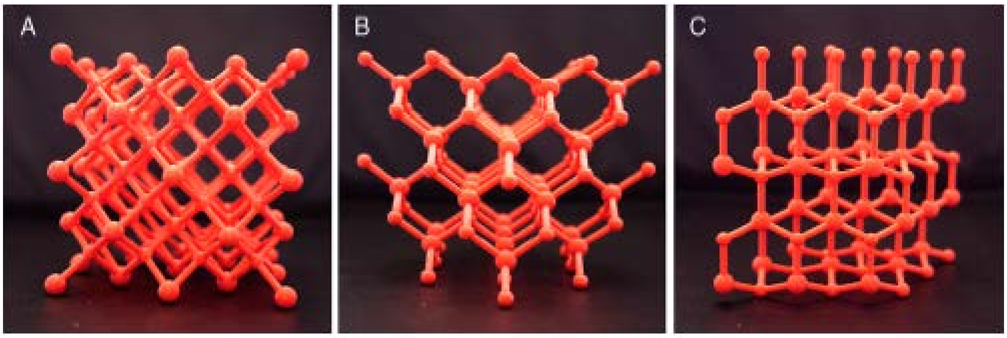



**Figure 3.** Scalfani and Vaid's (2014) Concrete Model

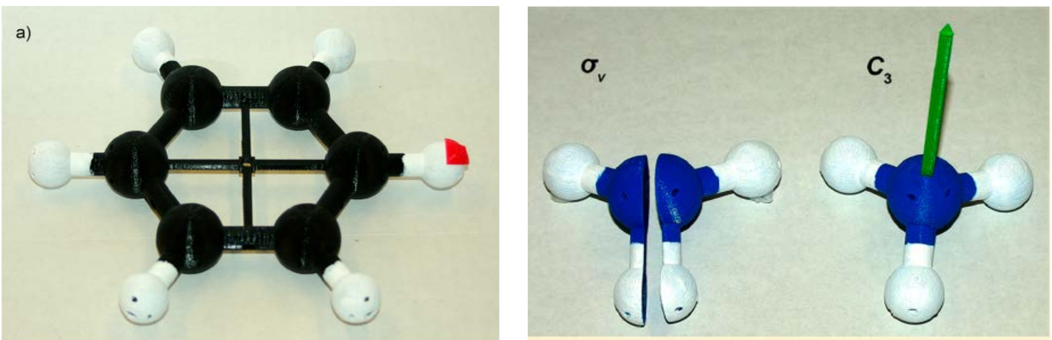
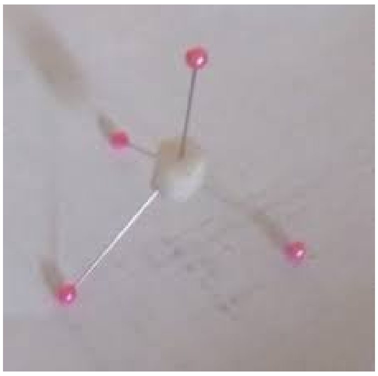


**Figure 4.** Niece's (2019) Concrete Model



**Gambar 5.** Effendy's (2017) Concrete Model

The concrete media developed by the researchers offers excellence and effectiveness to support the learning of symmetry material. However, the use of concrete media can result in misconceptions about the bonds associated with the central atom (Harrison & Treagust, 2000) and cannot show an overlap of electron clouds from atoms that form covalent bonds (Effendy, 2017). In addition, concrete media has limitations in making molecules that are more complex (Stieff et al., 2005). Good concrete media are those that can provide a variety of colors and sizes and can represent molecular models in particular such as the molecular shape of barium hydroxide. As a result, users experience failure in the visualization of chemical processes, namely the dynamic interaction between submicroscopic particles.

### Virtual Media

Virtual media is a computerized three-dimensional visualization medium. This media emerged as a result of technological developments that support chemistry learning (Al-Balushi & Coll, 2013; Antonoglou, Charistos, & Sigalas, 2011; Barrett et al., 2015; Stull et al., 2013). The use of virtual media supports the understanding of the process of manipulating one or more representations into another, visualizing the forces or interactions between molecules during a chemical process, and predicting the products resulting from a reaction (Al-Balushi & Al-Hajri, 2014; Stieff et al., 2005). As a result, the understanding of modeling using virtual media can be coherent with chemical phenomena.

Virtual media exists to replace concrete media in visualizing three-dimensional molecular shapes. The use of concrete media is considered to be no longer relevant to the times that demand a clearer, wider, and faster visualization of three-dimensional objects. (Al-Balushi & Coll, 2013; Anggriawan, effendy, & Budiasih, 2017; Antonoglou et al., 2011; Barrett et al., 2015; Cass, Rzepa, Rzepa, & Williams, 2005; Charistos, Tsipis, & Sigalas, 2005; Mohamed-Salah & Alain, 2016; Stull & Hegarty, 2016; Tuvi-Arad & Gorsky, 2007). Virtual media can cover many shortcomings of concrete media. Stieff et al. (2005) argued that the concrete media cannot display more than one representation of the three-dimensional molecular shape causing no interconnection between two-dimensional and three-dimensional representations. If the interconnection between the two representations is not well developed and the media is not present, there will be difficulties in visualizing the shape of the molecule. In addition, the visualization of molecular shape retention is not long. Meanwhile, virtual media offers multiple representations of molecular shapes. Virtual media displays two-dimensional and three-dimensional representations so that users can immediately see changes in the representation of the molecular shape. As a result, students who are taught with virtual media can maintain their visualization results in their retention for longer.

Previous research by Stull et al. (2013) prove that students who are taught with concrete media cannot show good performance compared to students who are taught with virtual media in visualizing the three-dimensional molecular shape given after the test without media and the test delay for seven days.

Furthermore, Barrett et al (2015) argued that concrete media has flaws in appearance. Concrete media cannot visualize the shape of a molecule with different substituent atoms. As it is observed, the size of one atom with another atom causes different repulsion of electron clouds from atoms of different substituents. This condition will create a misunderstanding of the shape of the molecule, for example, in the CHFClBr molecule. The use of concrete media will cause students to predict that the shape of the CHFClBr molecule is normal tetrahedral. Meanwhile, considering the difference in electronegativity of each different atom, it causes the repulsion between the atoms to be different so that the angle formed is a distorted tetrahedral (Harle & Towns, 2011; Harrison & Treagust, 2000; Wu et al., 2001; Wu & Shah, 2004). In addition, the incomplete availability of molecules with high complexity leads to limited representation of three-dimensional molecular shapes by users (Stieff et al., 2005).

Some chemistry learning experts have innovated to develop virtual media in learning symmetry material to overcome learning difficulties experienced by students, among others are Cass et al. (2005), Charistos, Tsipis, and Sigalas (2005), Tuvi-Arad and Gorsky (2007), Johnston D. H (2009) and Antonoglou, and Charistos and Sigalas (2011). The virtual media developed by these researchers is able to visualize molecular shapes and the application of the concept of molecular shapes to learning dynamic three-dimensional symmetry operations through virtual molecular media features and animation. Besides, virtual media provides several advantages. First, free websites in the media are accessed; second, virtual media has the form of molecules with various coordination numbers; and third, virtual media has updated websites. In addition, virtual media has several features that can improve students' understanding of symmetry material, including, (1) Symmetry Tutorial, providing interactive point groups that can guide users through all symmetrical elements and operations with interactive displays and animations, (2) The Symmetry Gallery, a collection of more than hundreds of unique molecules with interactive views of all the elements of symmetry and animation of symmetry operations. The molecules are arranged by groups of points, so the user can select samples to show a particular element of symmetry, and (3) The Symmetry Challenge, in the form of a detailed flow chart of the process of determining the point group of each molecule.

Virtual media related to symmetrical material developed by several experts in the form of multimedia and online applications are, among others, (1) Molecular Symmetry: An Inteactive Guide developed by Cass *et al.* (2005) as shown in Figure.6; (2) Molecular Symmetry on the Web developed by Antonoglou, Charistos and Sigalas (2011) as indicated by Figure.7; and (3) Symmetry @ Otterbein developed by Johnston D.H (2009) as indicated by Figure 8.

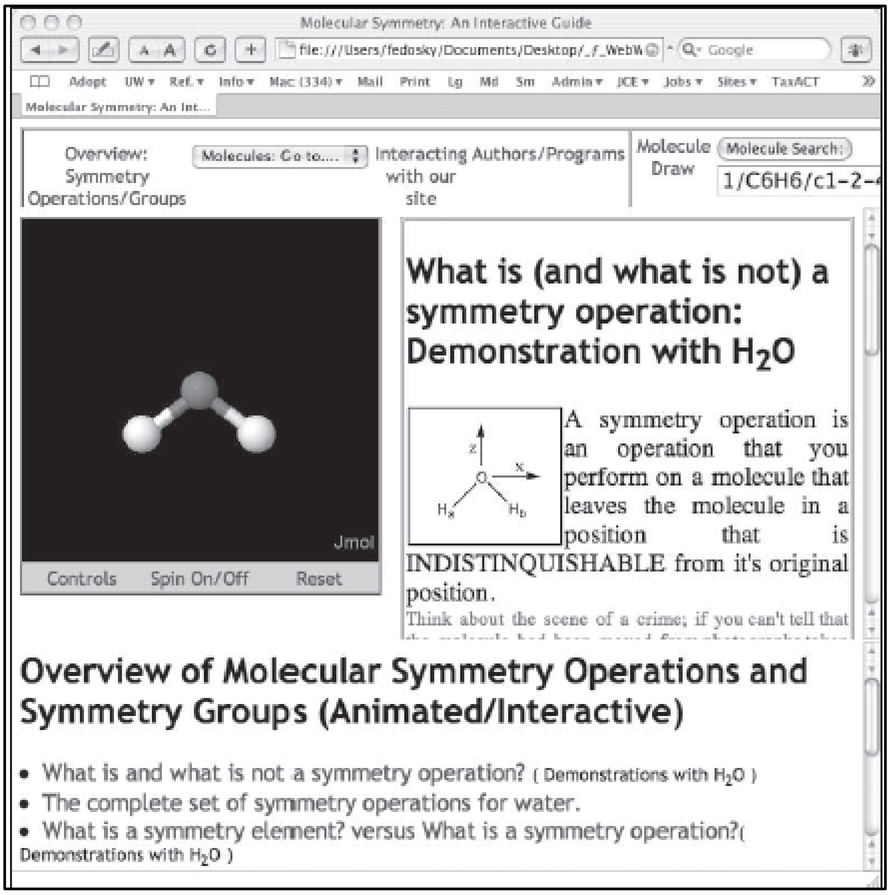



**Figure 6.** Virtual Media on Molecular Symmetry : An Inteactive Guide developed by Cass *et al.* (2005)

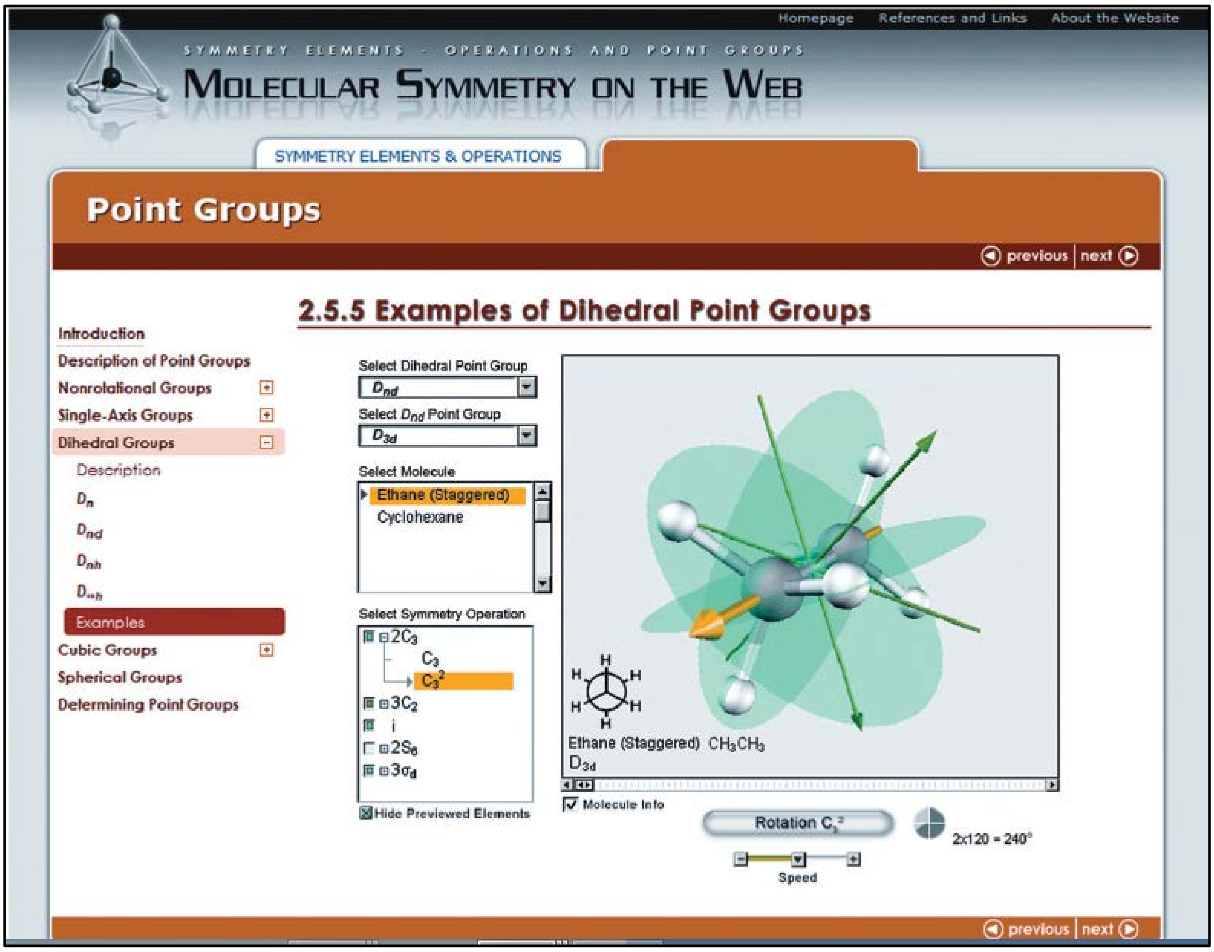



**Figure 7.** Virtual Media on Molecular Symmetry on the Web developed by Antonoglou, Charistos and Sigalas (2011)

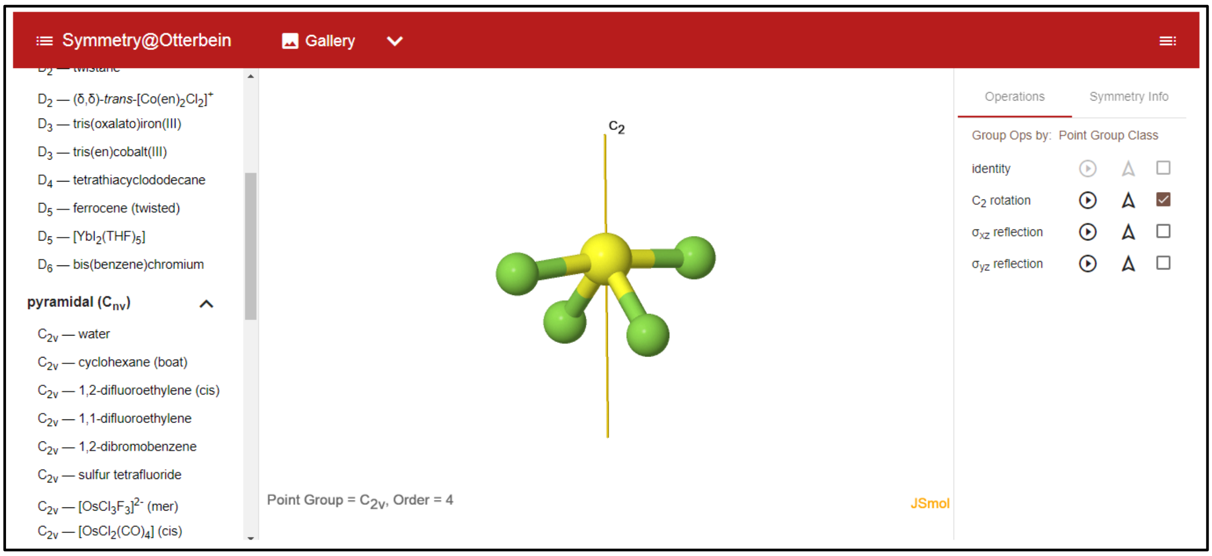



**Figure 8.** Virtual Media on Symmetry @ Otterbein developed by Johnston D.H (2009)

## Symmetry

"Treasure, Throne, and Symmetry", this expression shows the uniqueness of chemical materials, namely symmetrical matter. The three elements in the phrase describe a test or temptation for humans. Among the three elements, what attracts attention is Symmetry. Why symmetry can be a temptation for humans? This is answered as follows. Symmetry is material that deals with objects and images with two- and three-dimensional representations. In other words, all objects and images have a certain symmetry operation (Atkins & De Paula, 2006; Effendy, 2017; Flint, 2011; Fuchigami et al., 2016). For example, butterfly objects, certain brand logos, bowls, prayer mat patterns, etc. have certain symmetrical properties and can identify their symmetry. Symmetry learning material includes two concepts that need to be understood, namely the operation of symmetry and the elements of symmetry as shown in Table 2. Symmetry operation is the rearrangement of the atoms in a molecule based on several manipulations including rotation through true axis, mirror plane reflection, inversion through center, and pseudo axis rotation. Symmetry elements can be lines, planes or points. The element of symmetry operating the rotation through the true axis is the line; while the symmetry element of the reflection operation in the mirror plane is the plane; and the element of symmetry operating the center of symmetry is a point (Atkins & De Paula, 2006; Effendy, 2017).

**Table 2.** Operations and elements of symmetry

| Symmetry operation | The element of symmetry | Definition | Symbol |
|---|---|---|---|
| Element of symmetry | Not any | Symmetry operations that do not change the orientation of an object. | $E$ |
| Rotasi | Line based on n through true axes | The rotation of an object, with a rotation angle of 3600 / n | $C_n$ |
| Reflection | Mirror plane | The reflection or reflection of an object on the mirror plane | $\sigma_v$, $\sigma_h$, $\sigma_d$ dan $\sigma$ |
| Center of symmetry | Point | Project an object at the same distance from the center of symmetry but in the opposite direction | $i$ |
| Rotation via a pseudo rotation axis | Line based on n through the pseudo axis of rotation | The axis of rotation of the reflection or axis alternates | $S_n$ |

Based on the two concepts of symmetry, humans who have understood the material of symmetry will provide the operation of symmetry and elements of symmetry in each object they see. All objects that are passed and viewed will be identified with their operations and elements of symmetry. This will be a temptation for Muslims who pray using a patterned or patterned prayer mat. A Muslim who understands and can identify the operation of symmetry and the elements of symmetry will not be immersed in his prayer because he will be tempted to identify all the symmetrical operations on the pattern or pattern on the prayer mat. As a result, Muslims will not get anything in their worship.

## The potential of symmetrical material as a differentiating factor for the effectiveness of concrete and virtual media

Research comparing the effectiveness of concrete and virtual media has been carried out by several researchers, and the results show inconsistencies (Abraham et al., 2010; Al-Balushi & Al-Hajri, 2014; Barrett et al., 2015; Fjeld et al., 2007; Stull et al., 2013; Stull & Hegarty, 2016; Zacharia & Olympiou, 2011). Fjeld et al. (2007) found that learning with concrete media was superior to that of virtual media. The use of a keyboard and mouse in manipulating the movement of three-dimensional objects on virtual media causes limited interaction between users and virtual media. as a result the user requires additional cognitive to translate the visualization of the movement of objects. This can trigger a cognitive load where the existing spatial information can no longer be accommodated so that object visualization abilities are distorted. Therefore, learning related to three-dimensional objects such as organic chemistry is recommended to use concrete media. Meanwhile, with the same conditions Barrett et al. (2015) argue that the limited interaction of using virtual media has a good impact on understanding the movement of three-dimensional objects after being manipulated. The limited interaction of virtual media makes users more careful and careful in manipulating three-dimensional objects so that there are not many cognitive forms. This is different from concrete media, which provides unlimited interactions, which can make users not careful in manipulating objects. As a result, users will experience mental distortion of the model on the concrete media.

Besides, Abraham, Varghese, and Tang (2010) found different findings namely learning using concrete and virtual media showed no significant difference between the treatment groups. The virtual and concrete media groups show similar performance in visualizing the movement of three-dimensional objects. Furthermore, the effectiveness of concrete and virtual media is differentiated by giving the two groups more tasks to manipulate the movement of three-dimensional objects. The results show that the virtual media group is better than concrete media. Furthermore, Stull and Hegarty (2016) found no significant difference between the two media, thus concluding that the understanding of organic chemistry on stereochemical material can be studied using two media and suggested combining the two media.

This study concluded that the comparison of the effectiveness of using concrete and virtual media in teaching is not significant. The debate between concrete and virtual media has led to alternative thoughts, namely it is better to combine the two media together in learning (Al-Balushi & Al-Hajri, 2014). Despite this, combining the two media does not necessarily become a solution in learning. Some researchers remain in the opinion that concrete media is better than virtual media (Flint, 2011; Fuchigami et al., 2016; Niece, 2019; Scalfani & Vaid, 2014; Holly K. Schiltz & Oliver-Hoyo, 2012; Silva & Ribeiro, 2017) or vice versa, the use of virtual media is better than concrete media (Anggriawan et al., 2017; Antonoglou et al., 2011; Barrett et al., 2015; Cass et al., 2005; Stull et al., 2013).

Previous research by Barrett et al. (2015) proposed that aspects of the types of material being taught need to be considered in comparing the effectiveness of using concrete media and virtual media, for example, in previous studies (see Abraham et al., 2010; Al-Balushi & Al-Hajri, 2014; Barrett et al., 2015; Fjeld et al., 2007; Stull et al., 2013; Stull & Hegarty, 2016) focusing on organic chemistry, students learn to manipulate and control variables or run experimental simulations using concrete or virtual media. If the material is still unable to distinguish the effectiveness of media between concrete and virtual, then more abstract material is needed. Symmetry material has many operations that must be performed to determine the type of symmetry in the molecule so that higher cognitive abilities are needed to cause a high level of molecular visualization representations (Atkins & De Paula, 2006; Effendy, 2017). In other words, symmetry has the potential to differentiate the effectiveness of concrete and virtual media.

The effectiveness of the concrete and virtual media can be distinguished on the concept of rotational symmetry operations on the true axis, reflection on the mirror plane, and rotation on the pseudo rotation axis. The following is an explanation of the three material concepts of symmetry. First, it identifies the rotation symmetry operation of the true axis of rotation. The rotational symmetry operation of the true rotational axis is the rotation of an object through the axis of rotation Cn with an angle of rotation of 360/n in order to obtain an equivalent orientation (Effendy, 2017). The molecule SF6 with C4 as shown in Figure 9.

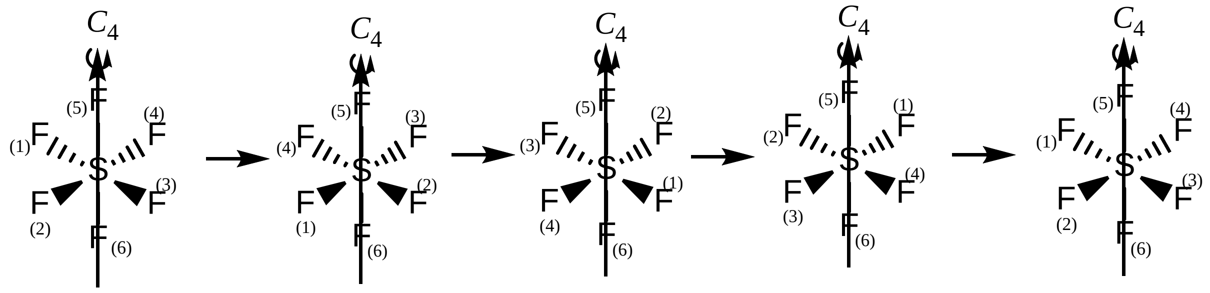


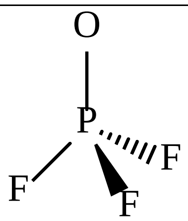
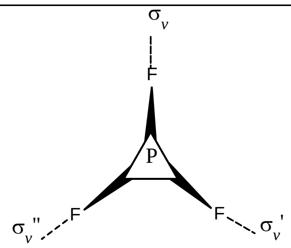
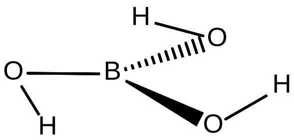
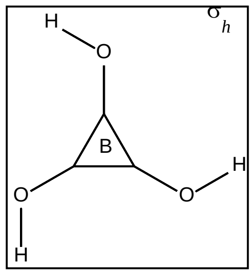
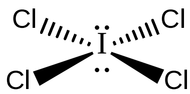
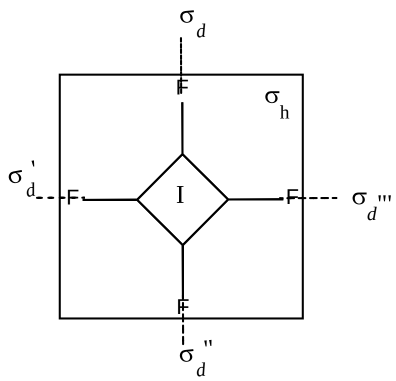

**Figure 9.** Rotational symmetry operations on molecule $SF_6$

Identifying the rotation operation of the true axis on the SF6 molecule the student had to perform cognitive tasks. First, the interpretation and understanding of different charts must be done properly before translating them in three-dimensional form (Abraham et al., 2010; Padalkar & Hegarty, 2015; Stull & Hegarty, 2016; Wu & Shah, 2004). Second, converting the abstraction object into a real object is necessary (Olimpo et al., 2015). Third, building a representation or visualization of three-dimensional objects in space with good quality is essential (Harle & Towns, 2011). Fourth, manipulating representative three-dimensional objects in space should also be done (Tuvi-Arad & Gorsky, 2007). Students with low visuo-spatial and representational competence thinking skills will have difficulty identifying them. Therefore, the use of concrete and virtual media is needed to help understand rotation operations.

Concrete and virtual media have the same quality in representing three dimensions. However, there are several aspects of the border in its use. Concrete media offers users to interact directly or infinitely as opposed to virtual media that uses a keyboard and mouse so that there are limited interactions in manipulating the rotational movement of the molecular model. This condition can lead to different levels of accuracy in manipulating molecular shapes (Barrett et al., 2015). In addition, the represented concrete media is not precise in the placement of molecular atoms because the angles formed are slightly deviated from the experimental results, whereas, virtual media presents molecular shapes with precise angles and precession according to the reference. This results in mental model abilities of the user. If the media represented has angles and shapes that do not match the experimental results, it will create distortions in the mental model (Stieff et al., 2005). Based on this case, it can be assumed that identifying rotational symmetry operations on the true axis virtual media is superior to concrete media.

Second, the mirror plane reflection symmetry operation reflects an object on the mirror plane through the object in order to obtain an equivalent shape. There are reflection operations in several mirror planes, including (1) the vertical mirror plane through the main axis is symbolized by $\sigma_v$. The number of vertical mirror areas in an object is equal to the value of n on the main axis $C_n$ owned by the object; (2) the plane of the horizontal mirror perpendicular to the principal axis is symbolized by σh. There is only one horizontal mirror plane in an object; (3) the diagonal mirror plane through the main axis and dividing the angle formed between the two axes $C_2$ into two equal parts is symbolized by $\sigma_d$. The sum of the diagonal mirror areas in an object is equal to the value of n on the main axis $C_n$ owned by the object; and (4) the mirror plane on an object that does not have a major axis is symbolized $\sigma$ (Effendy, 2017). The mirror plane reflection symmetry operation can be seen in Table 3.

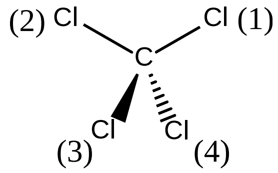
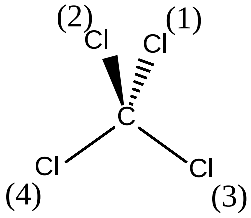
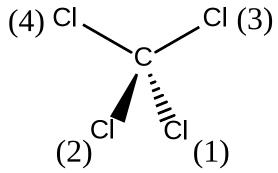
**Table 3.** Reflection operation on the mirror plane

| Operation Reflection | Molecular shape | After manipulation |
|---|---|---|
| Vertical pine plane ($\sigma_v$) |  |  |
| Horizontal mirror plane ($\sigma_h$) |  |  |
| Diagonal mirror plane ($\sigma_d$) |  |  |

Identifying the reflection symmetry operation on a particular mirror plane on various molecules the student has to perform the same cognitive tasks such as identifying the rotational symmetry operation over the true axis is important. However, there is a cognitive addition that must be done by students, namely imagining the movement or displacement of an object that is observed through a different point of view (Harle & Towns, 2011; Lohman et al., 1979; Wu et al., 2001; Wu & Shah, 2004). Concrete and virtual media have the same role in visualizing objects with observations from different points of view. In addition, both models offer mirroring features to assist in identifying the symmetry operation of the molecular reflection. The effectiveness of these two media in the process of identifying the reflection operation lies in how well it is in visualizing the reflection of a molecule. Concrete media has inflexible mirroring as shown in Fig. 1 and Fig. 2 which causes an inoptimal understanding of the reflection symmetry operation (Niece, 2019). In contrast, virtual media offers high flexibility with good visualization as shown in Fig. 7. Based on this case, it can be assumed that virtual media is superior to assisting students in identifying the reflection symmetry operation in the mirror plane.

Third, the operation of rotational symmetry through a pseudo rotation axis is also called the reflection axis of rotation or the axis alternately symbolized by $S_n$. Rotation through the axis of rotation $S_n$ involves the rotation of an object through an axis $C_n$, followed by a reflection through a mirror plane whose position is perpendicular to the axis $C_n$ (Effendy, 2017). Rotational symmetry operation through pseudo rotation axis can be seen in Table 4.

**Table 4.** Rotational symmetry operation through pseudo rotation axis

| **Rotation via a pseudo rotation axis** | **Initial molecular shape** | **Rotation through axes $C_n$** | **Reflection through the mirror plane** |
|---|---|---|---|
| $S_4$ |  |  |  |

Identifying the rotational symmetry operation via the pseudo-axis of rotation requires a combination of cognitive tasks of rotational symmetry operation on true axis and mirror plane reflection symmetry operation. Identifying this symmetry operation is very difficult because it requires a high level of representational competence to perform two manipulations of movements simultaneously. This is proven by a previous study which finds students have difficulty even experiencing errors in identifying this symmetrical operation (Graham, 2014). Concrete and virtual media can help solve this problem (Antonoglou et al., 2011; Niece, 2019). However, there are differences in the accuracy when manipulating the molecules. The use of concrete media directly often causes errors in manipulating objects. The boundless interactions offered by the concrete media cause positional errors after rotation and reflection. In contrast, virtual media with limited interaction uses the object movement simulation feature appropriately so that there will be no errors in identifying the symmetry operation $S_n$ (Anggriawan et al., 2017; Antonoglou et al., 2011; Cass et al., 2005; Tuvi-Arad & Gorsky, 2007). Based on this case, it can be assumed that the use of virtual media is superior to concrete media in identifying rotational symmetry operations through the pseudo-axis of rotation.

## CONCLUSION

The present study uncovers that symmetry material has a very good potential to distinguish the effectiveness of using concrete media and virtual media. The thought processes, cognitive tasks, interactions, mental models, and the completeness features created by the two models in identifying all symmetrical operations are the distinguishing factors of the effectiveness of the use of these two media and it can be assumed that the effectiveness of virtual media is better than concrete media.

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