Enhancing Representational Competence: The Impact of Concrete-Media-Assisted Draw to Learning on Molecular Structures for Students with Diverse Spatial Abilities

Masrid Pikoli[1], Thayban Thayban[1,*], Haris Munandar[1], Erga Kurniawati[1], and Astin Lukum[1]

Department of Chemistry, Universitas Negeri Gorontalo, 96554 Bone Bolango, Indonesia
*Corresponding author. thayban@ung.ac.id

Abstract. Representational competence was crucial in supporting the understanding of chemical materials, especially those requiring visuo-spatial abilities, such as molecular geometry. This research aimed to determine the effectiveness of Draw to Learning assisted by concrete media on students' representational competence in the topic of molecular geometry with varying spatial abilities. The study utilized a quasi-experiment. The subjects of this study were sixty-two fourth-semester students majoring in chemistry at Universitas Negeri Gorontalo, divided into two homogenous classes. Research data included students' spatial abilities and their understanding of molecular geometry, measured using test instruments comprising (1) a spatial ability test with a reliability of 0.95 and all questions validated and (2) a test of representational competence in molecular shapes with a reliability of 0.905 and 18 out of 20 questions validated. The data were analyzed descriptively and through statistical tests using two-way ANOVA. The results of the study indicated that students' spatial abilities had developed well and fell into the high category. Draw to Learning assisted by concrete media was more effective than concrete media alone in enhancing students' representational competence in the topic of molecular geometry. Drawing to learning with concrete media developed representational competence across different spatial abilities. The implication of this research was that Draw to Learning, assisted by concrete media in chemistry education, could assist students with low spatial abilities in understanding three-dimensional molecular geometry.

Keywords: representational competence, molecular geometry, spatial abilities

1 Introduction

Representation skills (RC) enhance problem-solving and learning. It is the ability to assess, change, choose, generate, and use representations productively. This talent is termed meta-representational competency [8]. Representational competence significantly contributes to students' success in various STEM disciplines. Several studies indicate that students with poor representational competence struggle to grasp concepts in various STEM disciplines, including mathematics [22], physics [16], biology [39], and chemistry [13, 18, 19, 31, 29, 35, 34].

H. S. Panigoro et al. (eds.), *Proceedings of the 2nd International Conference on Sciences, Mathematics, and Education 2023 (ICOSMED 2023)*, Advances in Social Science, Education and Humanities Research 927,
https://doi.org/10.2991/978-2-38476-410-5_56

To grasp chemical topics, representation skills are needed, especially those demanding visuo-spatial abilities such as molecular geometry, stereochemistry, symmetry, and crystallography. For example, comprehending molecular symmetry entails numerous activities, such as locating the genuine axis of rotation, gazing at a mirror plane, and navigating across a pseudo-axis of rotation. As a result, pupils have to concentrate on many cognitive activities to do so. First, construct a high-quality representation or depiction of a three-dimensional item in space [10, 35]. Second, modifying three-dimensional representational objects in space [37]. Students with inadequate representational skills cannot do this cognitive task successfully.

Students' representational competence can be enhanced through interventions using models in learning. Concrete models [28, 33, 32] can assist students grasp two-dimensional diagrams, interpret diverse representations, and forecast the influence of spatial transformation on the model. When physically conducting spatial changes, concrete models may clearly depict and retain three-dimensional spatial connections. Physically manipulating tangible models is an extra activity that can supplement or replace the mental processes that students can undertake [15], according to Kirsh and Maglio (1995). Consequently, students may enhance their representation abilities by obtaining a better knowledge of how diagrams depict three-dimensional data and how spatial alterations of molecular structures can be mentally recreated through treatments utilizing tangible models.

According to studies done by Thayban et al. (2021) and Kurniawati et al. (2023), students who utilize tangible models are better than students who do not [35, 19]. The researchers discovered that just exhibiting the model to pupils did not ensure successful usage of the physical model. Some students effectively converted the model using alternative representations, but they could not explain the outcomes. According to Chang (2018), students who have representation ability should be able to construct or visualize three-dimensional objects in space with high quality, manipulate representative three-dimensional objects in space, and explain the results of manipulating representative three-dimensional objects [5]. As a result, pupils who cannot correctly describe the effects of manipulation are judged not to have ideal representation competency.

Draw to Learning is utilized as a learning activity in this study to overcome the constraints of utilizing concrete models to improve students' representation abilities. Students produce external visual representations showing any form of content, whether structure, relationship, or process, made in any material in two static dimensions during drawing exercises [25]. In addition, pictorial representations are (a) intentionally created to achieve learning objectives, (b) intended to accurately show the objects represented, and (c) where students are responsible for creating and/or completing the drawings. By providing visual representations that facilitate communication, drawing activities have provided valuable insights for individual scientists and the scientific community [30]. In addition, research by various scholars has revealed that images give a major insight of the growing cognitive models of scientific events seen by learners [21]. Most research on drawing activities focused on the function that drawings serve in facilitating evaluation [5, 7, 10, 14] or to facilitate scientific modeling [7, 25]. As the exercises indicate, visuals give an external representation that helps students to evaluate their increasing comprehension of the scientific paradigm. Most of the photographs depict the final educational paradigm that pupils saw [6].

Harle & Towns, (2011) state that learning molecular geometry heavily involves students' spatial abilities [10]. Spatial abilities are skills that can be trained, honed, and improved [40]. Students' spatial abilities can be enhanced through direct instruction on the meanings of visual codes present in two-dimensional representations [36].

Based on the above description, this study focuses on determining the effectiveness of Draw to Learning assisted by concrete media in improving students' representational competence in the topic of molecular geometry with different spatial abilities.

2 Method

2.1 Research Design

This study used a quasi-experimental design and involved two groups or classes of fourth-year students in the Chemistry Department of Gorontalo State University, who took a chemical bonding course. Each group had 31 students. One of the chemical bonding courses at this university is molecular geometry. Since this study was conducted in a natural setting, the authors were not allowed to randomize the classes. As a result, the convenience sampling technique was used. Student Draw to Learn with Concrete Model (SDtLCM) is referred to as Students with Concrete Model (SCM) i.e. students who undergo learning with concrete models.

2.2 Research Procedure

Before the intervention, a test was conducted on both groups to find out if they had equal abilities. The test covered materials such as atomic structure and prerequisites, especially before the molecular shapes class started. The academic ability of both groups was balanced, according to Levene's homogeneity test (P ¿ 0.05). A spatial ability test was also conducted in both classes to find out which students had good and poor spatial ability. The Process Oriented Guided Inquiry Learning (POGIL) approach was used as an intervention for both groups. Both groups had the same syntax or stages of inquiry learning, which consisted of orientation, exploration, concept formation, and application.

At the orientation stage, the teacher explains the topic to be discussed. At the exploration stage, students investigate the tasks given. For example, when the teacher teaches the Lewis structure, students look at the geometry of the SF4 molecule and predict the Lewis structure. At the concept formation stage, the teacher asks questions to encourage students to understand the concept. The effect of the number of substituents and free electron pairs on the SF4 molecule is an example. With concrete models for SDtLCM and SCM, students are encouraged to use images as learning aids.

During implementation, students talk about their answers in class discussions with the guidance of the teacher. In addition, exercises were conducted to improve students' understanding of the topic. To avoid interaction between the two groups, molecular geometry teaching was conducted on the same day at different times. All other teaching experiences were the same for both groups, except for the media used for the concept formation and application stages. Students' representation competence was assessed through a short answer test consisting of 18 questions after each session was completed. The method is called the Representational Competence Test (RCT).

2.3 Research Instrument

Spatial Ability Test The Purdue Spatial Visualization Test (PVST) test instrument, developed by Hans-Roland Guay (1976), was used to measure students' spatial ability. Translated into Bahasa Indonesia and further refined by Anggriawan, Effendy, and Budiasih (2017) [1]. The spatial ability test consisted of thirty multiple-choice questions with ten questions relating to spatial visualization, spatial relations, and spatial orientation. This instrument is considered to have high reliability, with a value of 0.95. The PVST test was chosen because it can accurately describe students' spatial abilities. This is because it has no relationship with chemistry content, so it does not interfere with students' understanding of chemistry. Figure 1 shows the tool for testing spatial ability.

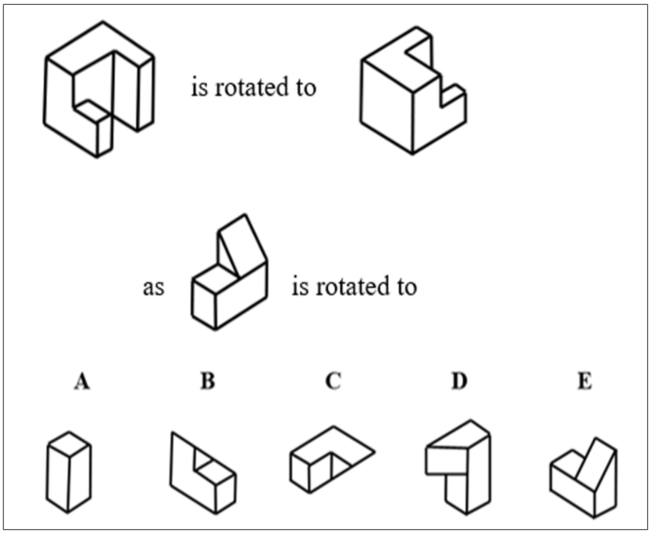

Fig. 1. Example of Spatial Ability Test

Representational Competence Test (RCT) The RCT is designed to measure students' representational competence in the subject of molecular geometry. This test consists of 18 essay questions that represent various coordination numbers of molecular forms. The Representational Competence Test instrument demonstrates a high reliability level of 0.905. The instrument for representational competence can be observed in Figure 2.

Carbon dioxide (CO_2) is a gas naturally present in the Earth's atmosphere and plays a crucial role in the carbon cycle. It is also a greenhouse gas, meaning it can trap heat in the atmosphere and contribute to global warming.

Question:

a. Predict the molecule geometry
b. Illustrate the Lewis structure of molecule
c. Transform the Lewis Structure diagram (2D) into molecular geometry (3D)!
d. Estimate the bond angles between substituents in molecule!
e. Estimate the bond lengths of substituents in molecule!

Fig. 2. Example of RCT

2.4 Data Analysis

Students' Spatial Ability Based on the spatial ability test scores, children were categorized into two categories: students with scores above average were classed as students with good spatial ability, and students with scores below average were labeled as students with low spatial ability [17].

The Relationship Between Spatial Ability and Student Representational Competence in Molecular Geometry The Pearson product moment correlation was employed to examine the association between spatial ability and students' representation ability. Prior to conducting the correlation test, checks for normality and homogeneity were performed. The Kolmogorov-Smirnov test (One-Sample KS) was conducted to assess the normality of the data. The test yielded a P value greater than 0.05, suggesting that the data follows a normal distribution. The homogeneity test using Levene's test yielded a P value greater than 0.05, suggesting that the data is homogenous.

The Effectiveness of Draw To Learning Assisted by Concrete Media and Concrete Media in Enhancing Student Representational Competence in Molecular Geometry Two-way analysis of variance (ANOVA) was used to determine two things: (1) how Draw To Learning using concrete media and concrete media differ in improving students' ability to demonstrate Molecular Geometry materials with different spatial abilities; and (2) how Draw To Learning using concrete media and concrete media work together with spatial abilities of Molecular Geometry materials.

3 Result and Discussion

3.1 Students' Spatial Ability

The results of the spatial ability test for students before the treatment are presented in Table 1.

As shown in Table 1, students have good spatial skills and fall into the high category. The percentage of students who have good spatial abilities is 58%. Therefore,

Table 1. Spatial Ability Test Results of Students

Number of Students	Average Score	Standard Deviation	Category	Percentage of Students (%)
62	10.983	4.422	High	58
			Low	42

it can be concluded that students' spatial abilities have developed well. This is in line with the findings conducted by Anggriawan et al., (2017), Stieff et al., (2018), and Budinoff et al., (2018) [1, 30, 4]. The development of good spatial abilities is influenced by advanced formal thinking skills [30] and experience of studying high quality and quantity three-dimensional objects [2, 36]. In addition, 42% of the students had poor spatial skills. This indicates that these students have not used their spatial abilities well. This result is in line with research conducted by Anggriawan et al., (2017), which found that 40% of students had poor spatial ability, and research conducted by Koutalas et al., (2014), which found that 56% of students had poor spatial ability.

According to Barke & Engida (2001), kids aged 11-16 years have strong spatial ability. At this age, humans have attained the greatest degree of formal reasoning [11], meaning they can think abstractly. Therefore, it can be claimed that spatial ability should be good for students with an average age of 20 to 21 years. There are a lot of variables that might explain for this disparity. Firstly, kids may not have achieved the formal level of reasoning. Abstract thinking skills are essential for spatial thinking, such as visualization, rotation, and viewing objects from diverse points of view. According to Rakhmawan & Vitasari (2016), chemistry students have a concrete-transitional thinking capacity of 37.5% [26]. As a result, students with such thinking abilities may face difficulties in constructing, manipulating and visualizing the movement of an object. As a result, they may face difficulties in spatial ability tests as conducted by Barke & Engida, (2001). Secondly, students may have low spatial working memory capacity. This may be due to object observation that is not accompanied by interpretation or visualization of the object's movement, which makes visual data processing difficult [27]. As a result, students may experience cognitive overload during spatial thinking, leading to difficulties in spatial ability tests [20, 38]. Third, learning experiences with three-dimensional objects may be less significant in visualizing them. Chemistry students learn a lot about three-dimensional things, such as studying molecular shapes and stereochemistry. Research shows that students may not really understand the three-dimensional shape and movement of objects, even though they are exposed to these materials. As a result, students may face difficulties in completing tasks that require spatial ability. Fourth, students may not practice solving high-complexity three-dimensional shape problems [24]. The underdevelopment of spatial abilities may be due to students' lack of exposure to solving complex problems involving three-dimensional objects. For example, in molecular geometry problems, students in this study demonstrated proficiency in solving problems with coordination numbers 2 to 4 but faced difficulties with coordination numbers 5 to 7. Consequently, students struggled with high-complexity spatial ability tasks involving visualization and rotation.

3.2 The Relationship Between Students' Molecular Geometry Representation Ability and Spatial Ability

Based on the findings of the Person-Product-moment correlation test, which reveals a significance value of 0.002 and a r value of +0.395, it is obvious that spatial ability has a positive link with students' ability to exhibit molecular forms successfully. This shows that pupils with strong spatial ability have a higher capacity to exhibit representations of molecular forms compared to those with low spatial ability. A study done by Achuthan et al. (2018) and Tuvi-Arad & Blonder (2010) validated this conclusion, which revealed that students who had good visual-spatial thinking skills were effective in the depiction of molecular forms. In contrast, children that have inadequate spatial skills experience difficulty while completing molecular shape representations. Success in grasping molecular symmetry was enhanced by 15.60% by spatial aptitude. This connection is classed as ”moderate”.

The effect of students' spatial aptitude on their performance in molecular representation, encompassing operations such as rotation, reflection, inversion, and pseudo-rotation, may be stated as follows. First, pupils' spatial ability can successfully employ spatial visualization, spatial orientation, and spatial connection abilities. This enables students execute molecular representation operations such as rotation, reflection, and inversion. Second, spatial relation skills allow students to handle representative three-dimensional objects in space, which helps their knowledge of molecular shapes. Third, spatial orientation skills assist students grasp how molecular things appear from different viewpoints, so that they can appropriately express molecular forms. Fourth, the combination of spatial vision and spatial orientation abilities helps pupils depict molecular forms appropriately.

Despite these explanations, some students with low spatial abilities can still complete tasks describing molecular shapes. This is evidenced by the relatively low percentage of spatial ability contribution to success in understanding molecular shapes. Additionally, this success is categorized as ”moderate.” This suggests that there may be other factors contributing to students' understanding of molecular shapes. These factors may emerge during the learning process, such as the use of learning media. For instance, the use of three-dimensional objects as learning media, well-represented with high quality, can enhance students' spatial abilities during the learning process [23]. Consequently, students acquire good spatial abilities during the learning process, enabling them to solve representational competence tasks in molecular shape. The instructional materials used during the learning process are comprehensive, including concept explanations accompanied by easily understandable three-dimensional images. These materials provide numerous exercises involving three-dimensional objects for determining molecular shapes. As a result, students use their memorization skills to solve molecular shape problems by following the exercises provided in the instructional materials.

3.3 Effectiveness of Draw To Learning with Concrete Media and Concrete Media in Improving Students' Representational Competence in Molecular Shape

Based on the results of the two-way analysis of variance with a significant value of 0.028 and an F-value of 5.049, it is indicated that there is a difference in students' representational competence in the topic of molecular shapes between the use of draw to learning aided by concrete media and concrete media alone. This finding aligns with previous research [3, 33, 32], which suggests that draw to learning aided by concrete media can help students understand molecular shapes better compared to the use of concrete models. This is believed to be due to the following reasons.

Firstly, students taught with draw to learning aided by concrete media are better at predicting molecular shapes, especially in determining bond angles, compared to those taught with concrete models. This is because draw to learning aided by concrete media provides information on both normal and distorted bond angles, similar to experimental data, directly during the learning process. In contrast, using concrete models does not directly provide information on bond angles. Additionally, the angles formed in concrete models are not accurate between different angles. As a result, students may struggle to determine molecular shapes correctly. The availability and accuracy of information on bond angles in molecular shapes make students accustomed to predicting molecular shapes by including bond angles, facilitating them in representing molecular shapes. This is consistent with the statement by Jaeggi et al., (2017) that becoming accustomed to processing information in the learning process forms cognitive training that can enhance cognitive abilities [12].

The research results indicate that students taught with draw to learning aided by concrete media are better at predicting the molecular shape of PFCl4 compared to students taught with concrete models. Students taught using draw to learning with concrete media understand that the Cl(ek)-P-Cl(ek) angle will be distorted $< 120°$ due to the electronegativity difference between the Cl and F atoms in the axial position. On the other hand, students taught using concrete models assume that the electronegativity difference will not affect the molecular shape angle, resulting in them depicting the PFCl4 molecule with a normal Cl(ek)-P-Cl(ek) angle = 120°. This error will affect the determination of rotation and reflection operations since the bond angle in molecular shapes influences the determination of molecular symmetry operations [9]. Therefore, students using virtual models have a better understanding of molecular symmetry compared to concrete models.

3.4 Interaction Between Draw To Learning Assisted by Concrete and Abstract Media with Spatial Ability in Learning Molecular Geometry

Based on the results of the ANOVA test, a Sig value of 0.489 and an F value of 0.484 were obtained, indicating that there is no interaction between draw to learning assisted by concrete and abstract media with students' spatial abilities in learning molecular shapes. This finding is consistent with the research conducted by Stull & Hegarty, (2016), where draw to learning assisted by concrete media is more effective for students with both high and low spatial abilities compared to the concrete model in learning three-dimensional object materials [33].

The difference in the effectiveness of draw to learning assisted by concrete and abstract media on students' spatial abilities in learning molecular shapes can be explained as follows. Abstract thinking ability, draw to learning assisted by concrete media facilitates students in drawing, making them accustomed to determining and representing molecular shapes. Students taught with draw to learning assisted by concrete media must be able to correct and adjust the movement of these molecules. Students who can do this possess abstract thinking abilities, which are developed through good spatial abilities. Thus, it can be said that students with high spatial abilities are more suitable for draw to learning assisted by concrete media in learning molecular shape materials. Meanwhile, students who lack abstract abilities (can only think concretely) are unable to correct and adjust the movements of different molecules.

4 Conclusion

This study confirms that Draw to Learning assisted by concrete media contributes better to the improvement of students' representational competence in molecular shape materials. Furthermore, students' spatial abilities influence their representational competence on the topic. Representational competence increases with their spatial abilities. This study suggests that Draw to Learning assisted by concrete media in teaching molecular symmetry is a beneficial approach. Enhancing students' spatial abilities becomes a solid foundation in learning chemical concepts involving three-dimensional objects, such as molecular geometry.

5 Acknowledgements

The author conveys appreciation to the various persons who aided in the accomplishment of this research. The support provided during the procedure is really appreciated. Appreciation is also conveyed for the financial support that enabled this research.

References

1. Anggriawan, B., effendy, Budiasih, E.: Kemampuan spasial dan kaitannya dengan pemahaman mahasiswa terhadap materi simetri. Jurnal Pendidikan (2017)
2. Barke, H.D., Engida, T.: Structural chemistry and spatial ability in different cultures. Chemistry Education Research and Practice **2**(3), 227–239 (2001). DOI 10.1039/B1RP90025K
3. Barrett, T., Stull, A., Hsu, T., Hegarty, M.: Constrained interactivity for relating multiple representations in science: When virtual is better than real. Computers and Education (2015). DOI 10.1016/j.compedu.2014.09.009. URL https://doi.org/10.1016/j.compedu.2014.09.009
4. Budinoff, H., McMains, S.: Relationships between spatial visualization ability and student outcomes in a 3d modeling course. Engineering Design Graphics Journal (2018)
5. Chang, H.: Students' representational competence with drawing technology across two domains of science. Science Education **102**(5) (2018). DOI 10.1002/sce.21457. URL https://doi.org/10.1002/sce.21457
6. Coll, R., Treagust, D.: Investigation of secondary school, undergraduate, and graduate learners' mental models of ionic bonding. Journal of Research in Science Teaching **40**(5) (2003). DOI 10.1002/tea.10085. URL https://doi.org/10.1002/tea.10085
7. Cooper, M., Williams, L., Underwood, S.: Student understanding of intermolecular forces: A multimodal study. Journal of Chemical Education **92**(8) (2015). DOI 10.1021/acs.jchemed.5b00169. URL https://doi.org/10.1021/acs.jchemed.5b00169

8. DiSessa, A., Sherin, B.: Meta-representation: An introduction. Journal of Mathematical Behavior **19**(4) (2000). DOI 10.1016/S0732-3123(01)00051-7. URL https://doi.org/10.1016/S0732-3123(01)00051-7
9. Effendy: Molekul, Struktur, dan Sifat-sifatnya. Indonesian Academic Publishing (2017)
10. Harle, M., Towns, M.: A review of spatial ability literature, its connection to chemistry, and implications for instruction. Journal of Chemical Education (2011). DOI 10.1021/ed900003n. URL https://doi.org/10.1021/ed900003n
11. Inhelder, B., Piaget, J.: The growth of logical thinking: From childhood to adolescence. Basic Books (1958). DOI 10.1037/10034-000. URL https://doi.org/10.1037/10034-000
12. Jaeggi, S., Karbach, J., Strobach, T.: Editorial special topic: Enhancing brain and cognition through cognitive training. Journal of Cognitive Enhancement **1**(4), 353–357 (2017). DOI 10.1007/s41465-017-0057-9
13. Karonen, M., Murtonen, M., Södervik, I., Manninen, M., Salomäki, M.: Heuristics hindering the development of understanding of molecular structures in university level chemistry education: The lewis structure as an example. Education Sciences **11**(6) (2021). DOI 10.3390/educsci11060258. URL https://doi.org/10.3390/educsci11060258
14. Kelly, R., Barrera, J., Mohamed, S.: An analysis of undergraduate general chemistry students' misconceptions of the submicroscopic level of precipitation reactions. Journal of Chemical Education **87**(1) (2010). DOI 10.1021/ed800011a. URL https://doi.org/10.1021/ed800011a
15. Kirsh, D., Maglio, P.: On distinguishing epistemic from pragmatic action. Cognitive Science **18**(4) (1994). DOI 10.1016/0364-0213(94)90007-8. URL https://doi.org/10.1016/0364-0213(94)90007-8
16. Kohl, P., Finkelstein, N.: Student representational competence and self-assessment when solving physics problems. Physical Review Special Topics - Physics Education Research **1**(1) (2005). DOI 10.1103/PhysRevSTPER.1.010104. URL https://doi.org/10.1103/PhysRevSTPER.1.010104
17. Koutalas, V., Antonoglou, L., Charistos, N., Sigalas, M.: Investigation of students' ability to transform and translate 2d molecular diagrammatic representations and its relationship to spatial ability and prior chemistry knowledge. Procedia - Social and Behavioral Sciences **152**, 698–703 (2014). DOI 10.1016/j.sbspro.2014.09.265
18. Kozma, R., Chin, E., Russell, J., Marx, N.: The roles of representations and tools in the chemistry laboratory and their implications for chemistry learning. Journal of the Learning Sciences **9**(2) (2000). DOI 10.1207/s15327809jls0902_1. URL https://doi.org/10.1207/s15327809jls0902_1
19. Kurniawati, E., Thayban, T., Alio, L., Sukamto, K.: Virtual vs concrete media: Improving representation competence. Jurnal Ilmiah Kanderang Tingang **14**(1), 102–111 (2023). DOI 10.37304/jikt.v14i1.189
20. Mayer, R.: Multimedia Learning, 2nd edn. Cambridge University Press (2009). DOI 10.1017/CBO9780511811678. URL https://doi.org/DOI:
21. Meter, P., Garner, J.: The promise and practice of learner-generated drawing: Literature review and synthesis. Educational Psychology Review **17**(ue 4)) (2005). DOI 10.1007/s10648-005-8136-3. URL https://doi.org/10.1007/s10648-005-8136-3
22. Nathan, M., Kim, S.: Pattern generalization with graphs and words: A cross-sectional and longitudinal analysis of middle school students' representational fluency. Mathematical Thinking and Learning **9**(3) (2007). DOI 10.1080/10986060701360886. URL https://doi.org/10.1080/10986060701360886
23. Padalkar, S., Hegarty, M.: Models as feedback: Developing representational competence in chemistry. Journal of Educational Psychology **107**(2), 451–467 (2015). DOI 10.1037/a0037516

24. Pribyl, J., Bodner, G.: Spatial ability and its role in organic chemistry: A study of four organic courses. Journal of Research in Science Teaching (1987). DOI 10.1002/tea.3660240304. URL https://doi.org/10.1002/tea.3660240304
25. Quillin, K., Thomas, S.: Drawing-to-learn: A framework for using drawings to promote model-based reasoning in biology. CBE Life Sciences Education **14**(1) (2015). DOI 10.1187/cbe.14-08-0128. URL https://doi.org/10.1187/cbe.14-08-0128
26. Rakhmawan, A., Vitasari, d.M.: Kemampuan berpikir logis sebagai prediktor keberhasilan mahasiswa dalam perkuliahan kimia dasar. Jurnal Penelitian Dan Pembelajaran IPA **2**, 99–109 (2016)
27. Salthouse, T.: Working memory as a processing resource in cognitive aging. Developmental Review **10**(1), 101–124 (1990). DOI 10.1016/0273-2297(90)90006-P. URL https://doi.org/https://doi.org/10.1016/0273-2297(90)90006-P
28. Stieff, M., Bateman, R., Uttal, D.: Teaching and Learning with Three-dimensional Representations BT - Visualization in Science. Springer Netherlands (2005). DOI 10.1007/1-4020-3613-2_7. URL https://doi.org/10.1007/1-4020-3613-2_7
29. Stieff, M., DeSutter, D.: Sketching, not representational competence, predicts improved science learning. Journal of Research in Science Teaching **58**(1) (2021). DOI 10.1002/tea.21650. URL https://doi.org/10.1002/tea.21650
30. Stieff, M., Origenes, A., DeSutter, D., Lira, M., Banevicius, L., Tabang, D., Cabel, G.: Operational constraints on the mental rotation of stem representations. Journal of Educational Psychology (2018). DOI 10.1037/edu0000258. URL https://doi.org/10.1037/edu0000258
31. Stieff, M., Ryu, M., Dixon, B., Hegarty, M.: The role of spatial ability and strategy preference for spatial problem solving in organic chemistry. Journal of Chemical Education (2012). DOI 10.1021/ed200071d. URL https://doi.org/10.1021/ed200071d
32. Stull, A., Barrett, T., Hegarty, M.: Usability of concrete and virtual models in chemistry instruction. Computers in Human Behavior (2013). DOI 10.1016/j.chb.2013.06.012. URL https://doi.org/10.1016/j.chb.2013.06.012
33. Stull, A., Hegarty, M.: Model manipulation and learning: Fostering representational competence with virtual and concrete models. Journal of Educational Psychology (2016). DOI 10.1037/edu0000077. URL https://doi.org/10.1037/edu0000077
34. Thayban, T., Habiddin, H., Utomo, Y.: Concrete model vs virtual model: Roles and implications in chemistry learning (2020). DOI 10.17977/um026v5i22020p090
35. Thayban, T., Habiddin, H., Utomo, Y., Muarifin, M.: Understanding of symmetry: Measuring the contribution of virtual and concrete models for students with different spatial abilities. Acta Chimica Slovenica **68**(3), 736–743 (2021). DOI 10.17344/acsi.2021.6836
36. Tuckey, H., Selvaratnam, M.: Studies involving three-dimensional visualisation skills in chemistry: A review. Studies in Science Education **21**(1), 99–121 (1993). DOI 10.1080/03057269308560015
37. Tuvi-Arad, I., Gorsky, P.: New visualization tools for learning molecular symmetry: A preliminary evaluation. Chemistry Education Research and Practice (2007). DOI 10.1039/B6RP90020H. URL https://doi.org/10.1039/B6RP90020H
38. Tversky, B.: Visualspatial reasoning. Cambridge University Press (2005)
39. Wilder, A., Brinkerhoff, J.: Supporting representational competence in high school biology with computer-based biomolecular visualizations. Journal of Computers in Mathematics and Science Teaching **26** (2007)
40. Wu, H., Shah, P.: Exploring visuospatial thinking in chemistry learning (2004). DOI 10.1002/sce.10126. URL https://doi.org/10.1002/sce.10126. In Science Education.