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Augmented Reality Media Versus Molymod Media: Comparative Study on Students' Spatial Ability in Chemical Bonding

Yenni Kurniawati[1]*, Handayani Wulandari[1], Faruku Aliyu[2]

[1]Department of Chemistry Education, State of Islamic University Sultan Syarif Kasim Riau, Pekanbaru, Indonesia
[2]Department of Science Education, Sokoto State University, Sokoto, Nigeria

*Corresponding author's email: yenni.kurniawati@uin-suska.ac.id

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Abstract. Spatial ability is a fundamental cognitive skill in chemistry education, particularly in facilitating the visualization of abstract molecular structures, geometric shapes, and spatial relationships among atoms. This research aimed at comparing the uses of augmented reality (AR) media and molymod demonstration media in supporting student spatial ability on chemical bond lesson at the tenth grade of Islamic Integrated Senior High School of Al-Fityah Pekanbaru. Comparative method was used with quantitative approach and pretest-posttest group design in the experimental group I use AR media and the experimental group II use molymod media. Measuring spatial ability was carried out through spatial ability test questions including spatial ability indicators. The research findings showed that the score of significance (2-tailed) was 0.016 lower than 0.05, so there was a significant difference between the experimental groups. In addition, the mean percentage of N-gain score of spatial ability in the AR group was 44% which was in less effective category, and the score of the molymod group was 59.94% which was in quite effective category.

Keywords: Spatial ability, augmented reality, molymod, chemical bond

Introduction

Submicroscopic, macroscopic, and symbolic representations are used for chemistry materials (Kapici, 2023). Effective learning necessitates both conceptual understanding and strong spatial abilities because chemical concepts are abstract (Supriadi et al., 2024). The three levels of representation in chemistry learning can be connected by spatial abilities, claim Waldan et al. (2023). In order to better illustrate submicroscopic events and connect them to macroscopic and symbolic levels, the findings address spatial abilities and chemical understanding that are connected by connecting three levels of representation.

Enhancing pupils' visual comprehension of object shape and location requires spatial skills (Elford et al., 2022). Spatial abilities refer to the capacity to visualize objects in three-dimensional space. spatial ability indicators consist of visual spatial, spatial orientation, and spatial relationships (Dwiningsih et al., 2022). Spatial ability in chemistry learning is necessary for understanding representations of molecular structures, reactions, and chemical theory (Salame & Kabir, 2022). In general, spatial ability in chemistry plays a role in the visualization of abstract concepts, such as atomic and molecular structure, chemical bonding, the theory of electron pair repulsion in the valence shell, and molecular orbital hybridization (Montalbo, 2021). According to (Pawestri et al., 2023) students must be able to combine conceptual knowledge with spatial skills to create, maintain, and manipulate abstract visual images.This ability enables chemistry learning at the high school level to provide a strong foundation for understanding material in advanced courses such as organic chemistry, biochemistry, and physical chemistry. However, many students experience difficulties in learning chemistry due to their low spatial ability (Rahmawati et al., 2021).

According to Dwiningsih et al. (2022), students' spatial abilities can be honed through the implementation of learning media. Educational media assists educators in presenting educational content in a more accessible and comprehensible manner. Research indicates that media can effectively improve spatial skills. Various types of chemistry learning media that support students' spatial abilities include intelligent bonat media developed using a series of colored balls (Winata, 2023), and pipette-based teaching aids (Usman et al., 2020). The demonstration media is designed to suit the needs of chemistry learning. The results obtained from this study showed an increase in visual-spatial intelligence scores after the media was implemented in learning. Considering these results, researchers tested Molymod as a demonstration medium designed to resemble the shape of chemical molecules and show bonded atoms. This demonstration medium was designed to make it easier for students to observe molecular shapes and understand chemical bonding.

In addition to the aforementioned visual aids, technology also provides learning tools that can visualize abstract concepts to enhance understanding and model objects in educational contexts (Fitria, 2023). One of the latest innovations in education is augmented reality (AR) technology, which provides a new approach to the teaching and learning process (Lah et al., 2024). Media AR Research on the use of AR shows positive results in improving students' spatial abilities, based on spatial skill test scores on atomic material, chemical bonds, and the shape of chemical molecules (Montalbo, 2021). These various studies indicate that several learning media are closely related to improving students' spatial abilities.

Educational media is consistently utilized in chemistry classes because of the subject's intricate nature (Hidayanti et al., 2020). The use of these media makes it easier for teachers to explain difficult concepts by presenting the material in a simpler way for students to understand. Furthermore, the use of educational media is an effort to enhance active learning in the classroom (Silaban et al., 2023). The use of media helps students learn concepts better (Astuti et al., 2020). Various types of educational media are used, including visual aids designed to meet learning needs and educational media innovated with technology to keep up with current developments. Nevertheless, visual aids also play a crucial role in education, especially in areas without internet access (Mahfuz, 2021).

Therefore, regardless of the type of educational media used, all contribute to helping teachers deliver material and supporting the learning process. Educational media plays a crucial role in supporting learning, such as (AR) developed by (Hurrahman et al., 2022) on molecular material, which allows students to visualize difficult-to-understand chemical concepts such as molecular structure and shape (Karnishyna et al., 2024). Therefore, both types of media play a significant role in supporting chemical representation, and the choice between them should be tailored to the context and needs of the chemistry material being taught.

Chemical bonding is a complex topic in chemistry learning. In this regard, spatial ability is crucial in supporting learning in chemical bonding (Antonucci-Durgan & Abramovich, 2024). Spatial ability here refers to an individual's ability to visualize objects in three-dimensional space relevant to depicting molecules and the relationships between atoms. Based on this background, further studies are needed to analyze the comparative use of learning media that support students' spatial abilities in chemistry.

Methods

The method used in this study was a comparative method with a quantitative approach. The comparative method utilizes a comparative test, namely data analysis to determine differences between two research data sets (Virlando et al., 2022). The quantitative approach involves obtaining numerical data to test hypotheses and identify patterns of relationships between variables objectively and measurably.

The research design used was a pretest-postest group design. This research design uses tests or measurements before administering treatment (pretest) and after treatment (posttest) (Kurniawati, 2019). In this comparative study, the research design used two groups: experimental class I, which implemented AR media by Irene Mugati, and one group, experimental class II, which implemented molymod demonstration media. In these groups, both were given the same treatment, namely using learning media; the only difference was the type of media used. The following pretest-posttest group design is shown in Table 1.

Table 1. Research design pretest-posttest group design

Class	Pretest	Treatment	Posttest
Experiment I	O_1	X_1	O_2
Experiment II	O_3	X_2	O_4

Remark:
O_1 = Pretest of experimental class I
O_3 = Pretest of experimental class II
O_2 = Posttest of experimental class I
O_4 = Posttest of experimental class II
X_1 = AR media
X_2 = Molymod media

The sampling technique used was a saturated sampling technique involving the entire population as the research sample. Both classes, XA and XB Al-Fityah Integrated Islamic High School Pekanbaru, in the research population were included as sample classes. Experimental class I (AR media) and experimental class II (molymod media) were determined after the researcher conducted normality and homogeneity tests as initial analyses and to determine the variance or uniformity of the research sample.

The data collection technique used a written essay test instrument. The spatial ability test consisted of eight questions tailored to spatial ability indicators. The instrument must be tested for content validity, empirical validity, reliability, and difficulty level to produce empirical data in accordance with the research analysis needs. The data analysis technique used is a quantitative analysis technique that includes data processing and presentation based on statistical calculations and data analysis (Soesana et al., 2023). As a prerequisite for initial data processing for statistical tests, normality and homogeneity tests are necessary. Furthermore, data analysis uses a comparative test, namely the independent sample T test to compare interval or ratio data from samples. The normalized n-gain test is also carried out to measure how much change in student scores from the initial test to the final test by knowing the difference in students' posttest and pretest scores. This test can also be used to determine the effectiveness of using a method or treatment (Oktavia et al., 2019).

Results and Discussion

The results of the comparison of the use of AR media and molymod media on chemical bonding material show that the posttest value of students' spatial abilities in experimental class I using AR media is 46.07, while in experimental class II using molymod media it is 61.61. To determine whether the difference in the average increase in spatial abilities of the two experimental classes is statistically significant, a t-test (independent sample t-test) was conducted as the results can be seen in Table 2.

Table 2. T-test results of post-test data

Data	df	Sig (2-tailed)	explanation
Post-test	50	.016	Sig (2 tailed) < 0.05 (there are significant differences)

Based on the results of the t-test (independent sample t-test) on the post-test data, a significant value (Sig. 2 tailed) of 0.016 was obtained, this significant value is smaller than the established significance level of 0.05. The T-test results indicate a performance disparity between the two groups within the tested material and population context. In the context of educational research, such as comparing learning outcomes between two experimental classes, a significant t-test confirms that the AR and molymod educational media treatments have different impacts on student abilities. Significant t-test results serve as the basis for decision-making in educational contexts by linking the t-test results to the average value to assess the magnitude of the treatment (Salsabila & Marsofiyati, 2025).

The following comparative examination of spatial ability can be assessed using the percentage of indicators related to spatial skills, which include spatial visualization, spatial orientation, and spatial relations. Spatial ability itself is an ability that involves understanding and manipulating objects in three-dimensional space, including the ability to visualize shapes, orient oneself to objects from various perspectives, and understand the relationships between objects in space (Carlisle et al., 2024).

Table 3. Division of questions based on spatial indicators

Indicators of spatial ability	Question number
Spatial Visualization	1,2
Spatial Orientation	3,7,8
Spatial Relations	4,5,6

To understand the improvement in spatial ability indicators in more depth, an analysis of students' answers was conducted by calculating the average score for each question and spatial indicator in both experimental classes. The following presents the percentage of spatial ability indicators against spatial ability questions in both experimental classes, as shown in Figure 1.

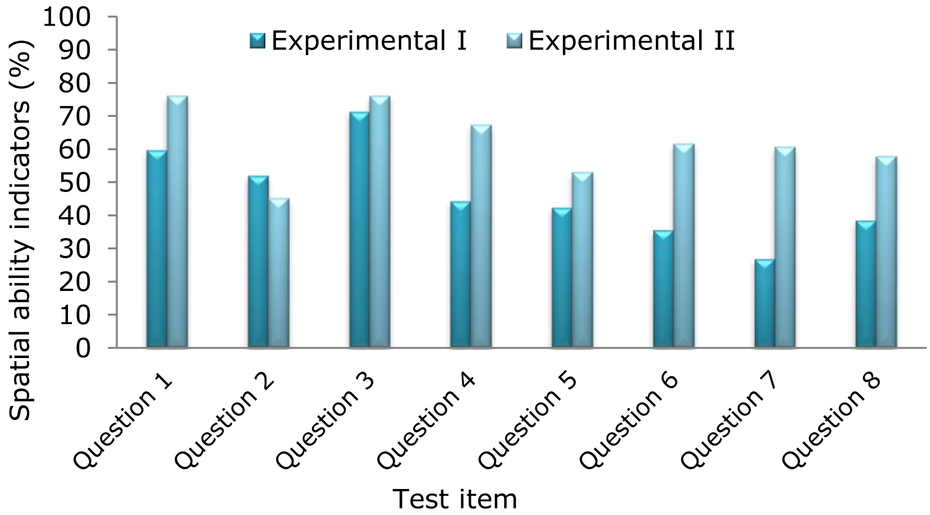

Figure 1. Graph of spatial indicators in relation to spatial ability test items

The graph illustrates that in experimental class II, questions 1 and 3 achieved the highest percentage of 75.96%, whereas question 2 recorded the lowest percentage at 45.19%. On the other hand, in experimental class I, question 3 had the highest percentage of 71.15%, while question 7 noted the lowest percentage, standing at 26.92%. The percentage outcomes suggest that the variance in spatial ability regarding the visual-spatial indicators in questions 1 and 2 for the two classes was almost identical. Meanwhile, for other questions, the comparison between the two experimental classes showed visibly different results. To further understand the comparison of the percentages of the spatial ability indicators, the following is a comparison of the percentages of three spatial ability indicators in experimental class I and experimental class II to understand the differences in the improvement of students' spatial abilities using AR media and molymod visual aids, as shown in Figure 2.

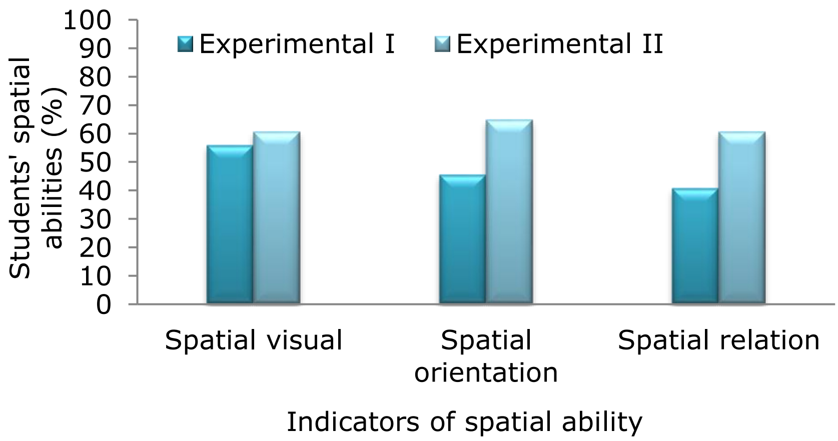

Figure 2. Graph of students' spatial abilities based on indicators

The analysis of the spatial ability indicators' percentages in both experimental groups revealed that the class utilizing molymod media outperformed the class that employed AR media. The following will present a further analysis regarding the comparison of students' spatial ability results for each spatial ability indicator against AR media and molymod demonstration media applied to chemistry learning in class.

1. Spatial Visual Indicator

The comparison of the percentages of visual spatial indicators for both classes was nearly identical. Thus, both AR and molymod media were able to support students' spatial abilities, particularly in visual spatial indicators. This aligns with research (Asri & Dwiningsih, 2022) and research (Winata, 2023) which found that AR and visual aids can visualize molecular shapes and support visual spatial abilities in chemistry. Visual spatial indicators can be trained through AR media, allowing students to view three-dimensional molecular models virtually, significantly improving their visual spatial abilities. However, classes using molymod as a physical demonstration medium showed better results than classes using AR media. This may occur because students encountered technical obstacles and errors in implementing AR media.

The obstacles experienced by students included slow processing devices, applications that could not run properly, and devices that quickly overheated during AR use. Due to these obstacles, students were required to use devices by sharing with other students. Visually, students were limited in observing objects while using AR. This statement is in line with research (Trisnawati et al., 2025) which discussed obstacles such as devices overheating, applications frequently exiting automatically, the need for high smartphone specifications, and limited visualization due to shared use. Furthermore, research by (Marell-Olsson & Broman, 2020) also stated that other technical obstacles such as limited devices and technology adaptation were the main obstacles to maximizing AR utilization in the classroom.

2. Spatial Orientation Indicator

The spatial orientation indicator showed that the molymod media class performed better than the AR media class. This indicates that students' understanding of molecular orientation and rotation was further enhanced through direct interaction with the physical molymod model. Physical interaction is crucial in developing spatial orientation skills because students can actually feel changes in the position and orientation of objects. Direct manipulation of physical models provides a concrete and multisensory learning experience, significantly improving students' spatial orientation skills. This aligns with research (Spassiani et al., 2017) showing that physical manipulation of models can improve orientation accuracy. Molymod demonstration media provide a realistic and concrete three-dimensional physical representation, making it easier for students to grasp the concept of chemical bonding visually and tactilely (Sumer & Vanecek, 2024).

Conversely, AR, while capable of presenting dynamic and interactive three-dimensional visualizations, has limitations in providing the physical tactile experience essential for developing spatial orientation. This results in less optimal spatial orientation skills through AR compared to physical demonstrations, as students lack the kinesthetic experience that helps them understand the rotation and position of objects more deeply.This factor suggests that AR application design may not fully accommodate students' learning needs, particularly in terms of physical interaction and the multisensory experiences required for spatial orientation skills. (Sari et al., 2023) AR applications focus on visualizing three-dimensional objects without providing more comprehensive interaction features. In addition to limitations in physical manipulation and multisensory experiences, there are limitations in the hardware used by students.

3. Spatial Relation Indicator

The spatial relations indicators in molymod classroom demonstration media are superior to those in AR. The use of physical demonstration media helps students understand the relationships between molecules. The experience of connecting and positioning atoms using Molymod helps students understand the distances and bond angles between atoms according to VSEPR theory. While AR media can visually and interactively display three-dimensional molecular models, it only provides visual representations without direct physical manipulation, making it difficult for students to estimate actual bond distances and angles. Research (Casselman et al., 2021) suggests that learning involving physical manipulation of objects and direct interaction can enhance understanding of spatial concepts, helping students construct mental representations of spatial relations. This study found that manipulating models, both virtual and physical, supports students' spatial learning. However, physical models, which require hands-on construction and manipulation, significantly impact spatial abilities in chemistry learning. This hands-on experience encourages the active construction of mental spatial relations that aid understanding of complex spatial structures in chemistry.

Spatial relation refered to the ability to understand the relations between objects in space, which can be improved through more intensive practice and familiarization. The reason for the lower performance of AR media classes is the challenges of using AR, which require further training. AR media students require more direction and guidance in using AR applications compared to students using molymod. This lack of training affects the ability to support spatial relationship indicators. Research (Porat & Ceobanu, 2023) shows that without adequate training, students' spatial abilities tend to stall or fail to progress, especially in the aspect of spatial relations. Without ongoing training involving students in manipulating and interacting with media, students may not develop the essential spatial abilities needed to understand molecular geometry, chemical bonding, and other abstract chemistry concepts. Porat and Ceobanu's research reinforces the need for instructional interventions that intentionally develop these spatial relational skills to avoid stagnation in spatial ability development.

The following results and discussion relate to the comparison of AR media and molymod media based on normalized N-Gain calculations. The data of students' spatial abilities was categorized based on N-Gain scores, following the classification established (Oktavia et al., 2019) as described in Table 4.

Table 4. Category N-Gain score

N-Gain score	Category	Experiment I	Experiment II
		Student	Student
$G > 0.7$	High	12	19
$0.3 \leq G \leq 0.7$	Medium	-	-
$G < 0.3$	Low	14	7
Total		26	26

The following is the percentage increase in the N-Gain score of students' spatial ability, categorized as high, and low.

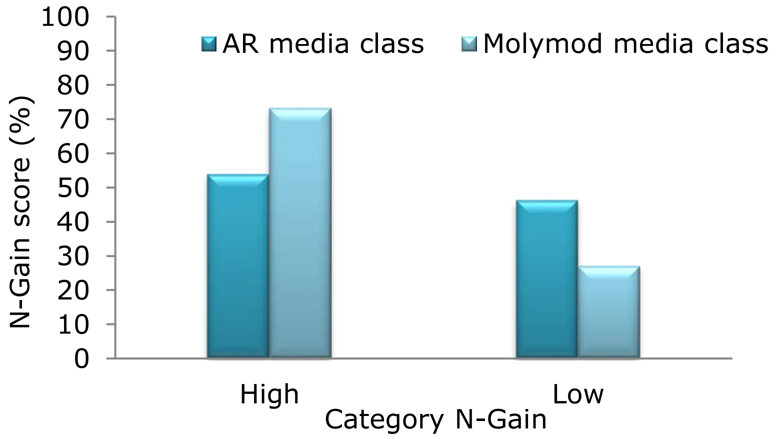

Figure 3. Graph of student N-Gain scores

Based on the distribution of N-Gain values in the two experimental classes, findings indicated that experimental class I, 53.84% fell into the low category, while 46.15% were in high category. These results are consistent with previous research suggesting that AR media is effectively enhances spatial abilities. However, obstacles like limited devices and need for technological adaptation persist (Marell-Olsson & Broman, 2020). The experimental class II show 26.92% in low category and 73.07% in high category. This demonstrates implementation of molymod visual aids is more effective and consistent in supporting students' spatial skills, as supported by research (Casselman et al., 2021) which indicates that physical visual tools significantly improve understanding ini chemistry.

The physical manipulation of molecular models is easier for students to understand, especially in supporting spatial abilities. Although, AR still managed to encourage some students to achieve high-level improvements, as supported by research (M. Sharhabilu et al., 2025) that found AR can improve motivation and spatial visualization skills, especially in students with low spatial abilities. Student motivation and readiness are also important factors influencing learning outcomes with AR. The following is a description of the effectiveness of AR and molymod media according to research data conducted by the author.

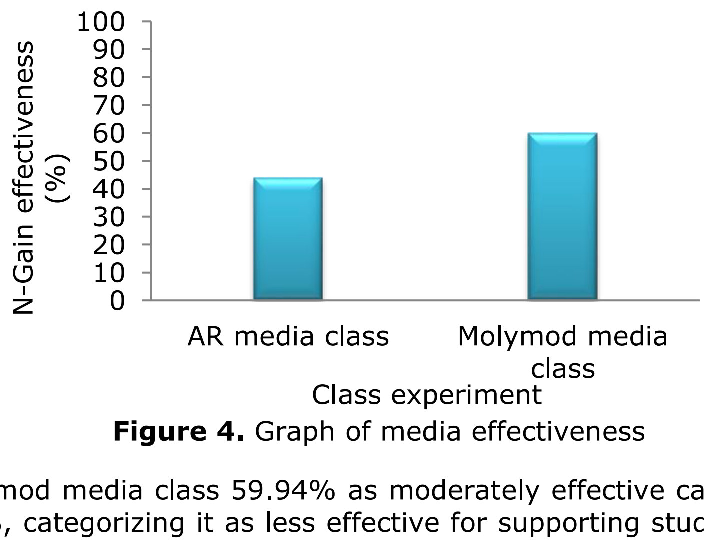

Figure 4. Graph of media effectiveness

The molymod media class 59.94% as moderately effective category, while the AR media class 44%, categorizing it as less effective for supporting students' spatial abilities in chemical bonding. Each type of media offers distinct learning experiences. Molymod's concrete multisensory approach enables students to physically hold, rotate, and observe molecular models in 3D. In contrast, AR allows students to visualize virtual objects.

Nevertheless, the characteristics of the learning media employed ini both classes still create an interactive and immersive educational experience, leading to a notable boost in student motivation and engagement in chemistry studies (Radianti et al., 2020).

Based on the comparison of the results of using AR and molymod learning media, it is confirmed that learning media play a crucial role in developing students' spatial abilities, particularly in the context of chemistry learning. Both learning media have similarities in improving students' spatial abilities in chemical bonding. The following is a more detailed explanation of the advantages and disadvantages of AR and molymod media.

Table 5. Advantages and disadvantages of augmented reality and molymod

Aspect	Augmented Reality	Molymod Physical Model
Advantages	Interactive and innovative virtual visualization (Rodriguez et al., 2022)	Real physical manipulation experience: holding, rotating, and observing 3D molecular models (Novemly et al., 2022)
	Increases learning motivation and is accessible anytime and anywhere via mobile devices (Rita & Guspatni, 2024)	Simple media, easy to assemble, reusable, and supports collaborative learning (Sulhajir et al., 2013)
	Helps students with low spatial ability to improve spatial visualization (M. Sharhabilu et al., 2025)	Improvement in visual-spatial ability, spatial orientation, and spatial relation is more consistent
Disadvantages	Technical obstacles: incompatible devices, unstable applications, and technology learning curve (Abutayeh et al., 2022)	Less appealing to students who are more interested in digital technology (Mukama & Byukusenge, 2023)
	Requires training and adaptation for both students and teachers (Marell-Olsson & Broman, 2020)	Relatively expensive and limited in number, so not all students can use it simultaneously
	Relatively expensive and limited in number, so not all students can use it simultaneously	Static visualization and limited to the physical models that can be assembled

Based on the table, both media have advantages and limitations that influence the effectiveness of chemistry learning, particularly in supporting students' spatial abilities. When implementing learning, media selection must consider the appropriateness of the media and the desired learning objectives to optimize learning outcomes. Based on the findings of this study, molymod is quite effective, but it also has limitations.

Therefore, the most effective solution is to collaborate on the use of AR and molymod. Integrating these two media can overcome their limitations. This approach is expected to optimize spatial abilities and maintain student motivation and engagement in the chemistry learning process. Thus, the collaboration of AR and molymod media not only enriches students' multisensory learning experiences but also supports more comprehensive and adaptive learning that accommodates students' needs.

Conclusion

The conclusion of this study shows a difference in spatial ability between students who used AR media and students who used Molymod media. Post-test results showed that students who used molymod media scored higher and were considered quite effective, while AR media was considered less effective in supporting students' spatial abilities related to the topic of chemical bonds.

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