

Effectiveness of 3D Flipbook Media in Enhancing Students' Visual-Spatial Skills: A Study in Molecular Geometry Learning

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ABSTRACT

Keywords:

3D flipbook,
Molecular geometry,
Visual-spatial skills,
Wilcoxon test

This study examines the effectiveness of 3D flipbook media in improving students' visual-spatial skills in molecular geometry learning. Molecular geometry requires the ability to mentally manipulate complex three-dimensional structures, which often challenges students in understanding abstract concepts. The research was conducted with 32 students of SMA Negeri 7 Surabaya using a quasi-experimental design with pretest and posttest instruments. Because the data were not normally distributed, the Wilcoxon Signed Ranks Test was applied. The results showed that all students achieved higher posttest scores compared to pretest scores, with a significance value of 0.000 ($p < 0.05$). These findings indicate that 3D flipbook media significantly enhance students' visual-spatial skills. Moreover, the study emphasizes the pedagogical value of innovative media in bridging abstract molecular concepts with student comprehension, contributing to the improvement of chemistry education and supporting more effective learning strategies in the classroom.

INTRODUCTION

Chemistry as a discipline is often described as a science of invisible particles. Among its many branches, molecular geometry stands out as a topic that demands not only conceptual understanding but also the ability to imagine and manipulate complex three-dimensional structures. For students at the secondary and tertiary levels, this requirement becomes a significant challenge. Abstract diagrams on a two-dimensional page or static ball-and-stick models often fail to capture the dynamic and spatial nature of molecules. As a result, students frequently struggle to interpret molecular shapes accurately, which can lead to persistent misconceptions and incomplete understanding of chemical bonding (Brown et al., 2021). Spatial ability plays a critical role in this process; students with higher spatial reasoning skills tend to understand molecular geometry and chemical representations more effectively (Stieff & Uttal, 2015). Developing visual-spatial skills is therefore essential, because these skills enable learners to move beyond rote memorization and begin connecting symbolic notations, submicroscopic representations, and real molecular forms in a coherent manner.

Recognizing these difficulties, chemistry educators and researchers have turned to innovative learning media as a way of bridging the gap between abstract chemical concepts and student comprehension. In the past five years, there has been rapid growth in the use of interactive e-modules, augmented reality (AR), and three-dimensional visualization technologies. These tools are designed not only to enrich the learning experience but also to actively cultivate students' spatial reasoning. Research has shown

that such media can significantly improve conceptual understanding, problem-solving ability, and spatial intelligence in chemistry learning (Zakiyah & Dwiningsih, 2022). Unlike conventional approaches, three-dimensional digital media present information dynamically, allowing learners to see structures rotate, transform, and interact in ways that mirror real molecular behavior (Elford, 2022; Singh & Kaur, 2025).

Within this context, the use of digital 3D flipbook media has emerged as a promising pedagogical innovation. A 3D flipbook is structured to present molecular transformations gradually, page by page, so that learners can follow structural changes step by step. This sequential design makes it easier for students to form accurate mental models of molecular geometry, particularly when dealing with VSEPR-based structures or polyatomic molecules. By providing a bridge between abstract textbook diagrams and the mental visualization process, flipbook media can reduce misconceptions and support deeper conceptual learning (Nurhayati et al., 2022).

Beyond cognitive benefits, the adoption of such innovative media also carries important motivational advantages. Studies on the integration of digital media in science classrooms have highlighted that students are more engaged and motivated when learning tools are interactive, visually appealing, and relevant to real scientific practices (Araiza-Alba et al., 2021). Engagement is not a superficial outcome; it plays a central role in sustaining attention, encouraging active participation, and ultimately leading to stronger learning outcomes. Thus, media such as the 3D flipbook not only strengthen cognitive aspects like spatial reasoning but also contribute to building a more stimulating and effective learning environment.

The purpose of this study is to investigate the effectiveness of 3D flipbook media in enhancing students' visual-spatial skills in molecular geometry learning. Through this investigation, the research seeks to provide evidence-based insights into how innovative instructional tools can transform chemistry education. The findings are expected to inform teachers and curriculum developers about the value of integrating digital visualization media into classroom practice, contributing to more innovative, engaging, and effective strategies for 21st-century science education.

RESEARCH METHOD

The type of research employed in this study was Research and Development (R&D). The development process in this research used the ADDIE model (Branch, 2010), which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. In addition, the design and development of learning media also considered aspects of creativity and technological collaboration, integrating artistic and visual elements to enhance user engagement (Earnshaw, 2017). Although this study was limited only to the Development stage with limited trials. The research design applied was a one-group pretest-posttest design, in which students were given a pretest before using the 3D flipbook media and a posttest after learning with the media. This design was selected to

determine the effectiveness of the flipbook in improving students' visual-spatial skills in molecular geometry.

The research subjects were 32 students of class XI MIPA at SMA Negeri 7 Surabaya in the odd semester of the 2024/2025 academic year. The sample was selected purposively because the students had previously studied chemical bonding and molecular geometry, making them suitable for the limited trial. The research was conducted on October 7, 2024 at SMA Negeri 7 Surabaya.

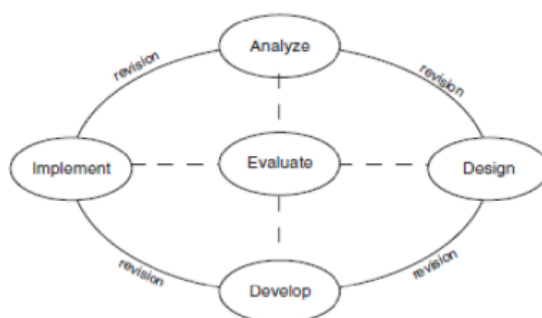


Figure 1. Stages of the ADDIE model. Source (Branch, 2010)

The research instrument consisted of a visual-spatial skill test in the form of pretest and posttest items developed according to molecular geometry indicators. The pretest was administered to identify students' prior ability, while the posttest was conducted after the use of the 3D flipbook to measure the improvement of their visual-spatial skills. The test was designed to assess students' ability to project three-dimensional molecular shapes, determine bond angles, and connect visual models with symbolic representations.

The research procedure began with the analysis stage, which identified students' difficulties in understanding molecular geometry concepts through teacher interviews and student questionnaires. The design stage involved constructing a 3D flipbook storyboard, selecting relevant molecular animations, and preparing pretest and posttest items. The development stage included revising the flipbook according to expert feedback and testing it in a limited trial with class XI MIPA students. In this limited trial, students first completed the pretest, then participated in learning using the 3D flipbook, and finally completed the posttest at the end of the session.

Data from the pretest and posttest of students' visual-spatial skills were obtained through the limited trial using the one-group pretest-posttest design. The effectiveness of the 3D flipbook was analyzed through the following steps:

1. Normality Test

- The normality of pretest and posttest data was tested using the Shapiro-Wilk test, as the sample size was less than 50.
- Decision criteria:
 - If the significance value (p) > 0.05 , the data are normally distributed.

- If the significance value (p) < 0.05 , the data are not normally distributed.
2. Effectiveness Test
- a. If the data were normally distributed, a Paired Sample t-test was applied with the following hypotheses:
 - H_0 : There is no significant difference between pretest and posttest scores.
 - H_1 : There is a significant difference between pretest and posttest scores.
 - Decision rule: If $p < 0.05$, H_0 is rejected and H_1 is accepted.
 - b. If the data were not normally distributed, the Wilcoxon Signed Rank Test was used with the following hypotheses:
 - H_0 : There is no significant difference between pretest and posttest scores.
 - H_1 : There is a significant difference between pretest and posttest scores.
 - Decision rule: If $p < 0.05$, H_0 is rejected and H_1 is accepted.
3. Effectiveness Criteria

The 3D-assisted molecular geometry flipbook was considered effective in improving students' visual-spatial skills if the results of the effectiveness test (Paired Sample t-test or Wilcoxon) showed a significance value of $p < 0.05$.

RESULTS AND DISCUSSION

This research aims to describe the effectiveness of a 3D-assisted flipbook on molecular geometry in improving students' visual-spatial skills. The study was conducted using the ADDIE development model (Analysis, Design, Development, Implementation, and Evaluation) but was limited only to the Development stage with small-scale trials. The research design employed was a one-group pretest-posttest design.

Analysis

The analysis stage was carried out to identify students' learning needs and the challenges they encountered in understanding molecular geometry. Front-end analysis was conducted through teacher interviews and classroom observations, which revealed that students often had difficulties visualizing three-dimensional molecular structures, leading to misconceptions. Learner analysis focused on class XI MIPA students, aged 16–17 years, who had previously learned chemical bonding and were entering molecular geometry topics. At this age, students are in the formal operational stage, where they are expected to develop abstract reasoning and mental rotation skills. Task analysis included identifying key learning activities such as determining molecular shapes, predicting bond angles, and connecting symbolic and visual representations. Concept analysis produced a concept map of molecular geometry based on the Valence Shell Electron Pair Repulsion (VSEPR) theory, aligned with the Indonesian high school chemistry curriculum.

Design

The design stage focused on preparing the research instruments and structuring the 3D flipbook as a learning medium. At this stage, pretest and posttest instruments were developed to measure students' visual-spatial skills, particularly their ability to recognize, interpret, and mentally rotate molecular geometries. The test items were

aligned with the learning objectives and indicators in the high school chemistry curriculum, ensuring that they assessed not only conceptual knowledge but also students' spatial abilities.

The design of the flipbook began with the creation of a storyboard outlining the sequence of materials. The content was arranged progressively, starting from simple molecular geometries such as linear and trigonal planar, and then moving on to more complex forms such as tetrahedral, trigonal bipyramidal, and octahedral. Each section was equipped with clear explanations, two-dimensional illustrations, and interactive 3D molecular animations that enabled students to observe and manipulate molecular models directly.

To enhance student engagement, the flipbook included guiding questions and practice exercises that encouraged independent exploration and self-assessment. The visual layout emphasized clarity, with a simple interface, consistent use of colors and labels, and easy-to-navigate menus. The flipbook was developed using Flip PDF Corporate software, which ensured accessibility across multiple devices such as laptops, tablets, and smartphones.

The final product of this stage was referred to as Draft 1, which then served as the prototype for expert validation in the following development stage. The initial appearance of the flipbook can be seen in Figure 1 below.

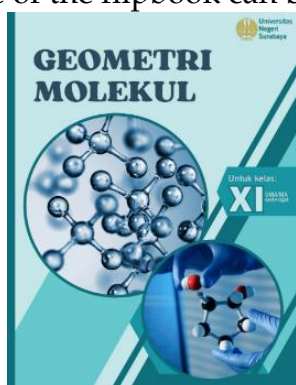


Figure 2. Flipbook Cover Display

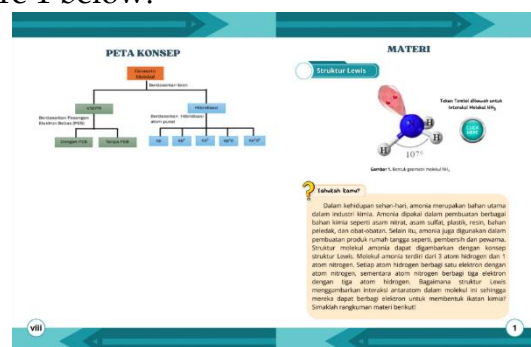


Figure 3. Concept Map and Content in Flipbook

Penerapan konsep	Struktur Elektron	Geometri Molekul	Sudut Ikatan	Sudut Ikatan
1	2	Linear	180°	180°
2	3	Trigonal Planar	120°	120°
3	4	Tetrahedral	109.5°	109.5°
4	5	Trigonal Bipyramidal	120° and 90°	120° and 90°
5	6	Octahedral	90°	90°

Figure 4. 3D Molecular Geometry Animation

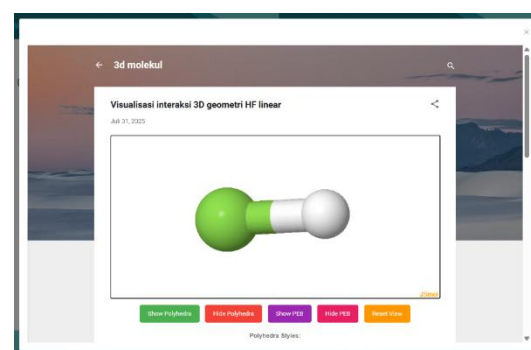


Figure 5. 3D Molecular Geometry Animation in Interaction

Development

At the development stage, the initial flipbook draft from the design phase was validated by experts and tested in a limited classroom trial. Three validators—a chemistry education expert, a media expert, and a chemistry teacher—assessed the content accuracy, clarity of visualization, and usability of the media. Revisions were made based on expert feedback, resulting in an improved prototype (Draft 2).

This prototype was tested with 32 students of class XI MIPA at SMA Negeri 7 Surabaya using a one-group pretest-posttest procedure. The pretest measured initial spatial skills, while the posttest evaluated improvement after using the 3D flipbook. The data showed a significant increase in students' posttest scores, indicating that the 3D flipbook effectively improved students' visual-spatial skills in molecular geometry.

Although the ADDIE model consists of five stages—Analysis, Design, Development, Implementation, and Evaluation—this research was limited to the Development stage, including small-scale trials as preliminary implementation. The evaluation process in this study focused on expert validation and limited field testing, which served as the basis for assessing product feasibility and effectiveness. Further large-scale implementation and summative evaluation are recommended for future research.

Descriptive Statistics

The descriptive analysis of students' pretest and posttest scores is presented in Table 1. The table shows the mean, minimum, maximum, and standard deviation values. The results indicate that the mean posttest score is higher than the pretest score, suggesting an improvement in students' visual-spatial skills after learning with the 3D-assisted flipbook.

Table 1.

Statistik	Pretest	Posttest
Mean	35.00	91.88
Std. Deviation	15.24	9.98
Minimum	20.00	80.00
Maximum	60.00	100.00

The difference in the mean scores of the pretest and posttest can be seen more clearly in Figure 1. The chart illustrates the improvement in students' visual-spatial skills after learning with the 3D-assisted flipbook.

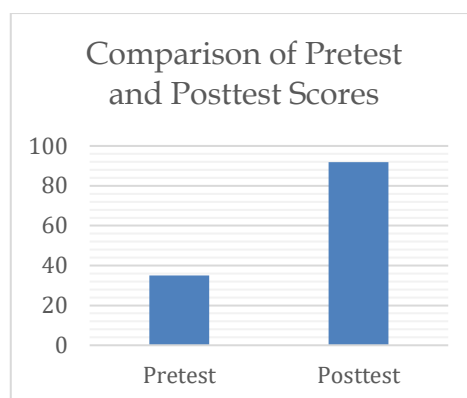


Figure 6. Comparison of Pretest and Posttest Scores

Normality Test

Before testing the effectiveness, a normality analysis was first conducted to determine whether the pretest and posttest data on students' visual-spatial skills were normally distributed. Conducting a normality test is essential because the results determine the appropriate type of statistical test to be used in the analysis, whether parametric or non-parametric. Since the number of samples in this study was less than 50, the Shapiro-Wilk test was applied. The results of the Shapiro-Wilk test are presented in Table 2.

Table 2. Results of Shapiro-Wilk Normality Test

	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
pretest visual spasial	.275	32	.000	.784	32	.000
posttest viusal spasial	.386	32	.000	.625	32	.000

a. Lilliefors Significance Correction

Based on the results of the normality test, both pretest and posttest data were not normally distributed (Sig. < 0.05). Therefore, the effectiveness of the 3D-assisted flipbook was tested using the Wilcoxon Signed Rank Test.

Effectiveness Test

The results of the effectiveness test using the Wilcoxon Signed Rank Test are presented in Table 3. The obtained significance value was 0.000 ($p < 0.05$), which indicates that there is a significant difference between students' pretest and posttest scores. In other words, the use of the 3D-assisted flipbook had a positive effect on improving students' visual-spatial skills in molecular geometry.

Table 3. Results of Effectiveness Test Using Wilcoxon Signed Rank Test

Test Statistics ^a	
	posttest viusal spasial - pretest visual spasial
Z	-5.011 ^b
Asymp. Sig. (2-tailed)	.000

Furthermore, the results of the Ranks analysis presented in Table 4 reinforce these findings. All students ($n = 32$) showed an improvement in their scores after the learning process. This is evident from the negative ranks value of 0, which means that no student obtained a lower posttest score compared to the pretest. The ties value was also 0, indicating that no student maintained the same score. On the other hand, all students achieved higher posttest scores, with 32 positive ranks, a mean rank of 16.50, and a sum of ranks of 528.

Table 4. Results of Ranks Analysis from Wilcoxon Signed Rank Test

Ranks		N	Mean Rank	Sum of Ranks
posttest visual spasial - pretest visual spasial	Negative Ranks	0 ^a	.00	.00
	Positive Ranks	32 ^b	16.50	528.00
	Ties	0 ^c		
	Total	32		

a. posttest visual spasial < pretest visual spasial

b. posttest visual spasial > pretest visual spasial

c. posttest visual spasial = pretest visual spasial

An analysis of the effectiveness of the Wilcoxon Signed Rank Test showed that all students experienced an improvement in scores after using the 3D-assisted flipbook, with a significant difference between the pretest and posttest results. None of the students experienced a decrease or a fixed score, which indicates that the improvement in visual-spatial skills is happening across the board. These results provide a solid basis for further discussion of the role of 3D-assisted flipbooks in supporting molecular geometry learning.

The results of this study show that the use of 3D-based flipbooks is effective in improving students' visual-spatial skills in learning molecular geometry. The increase in posttest scores compared to the pretest proves that interactive visual-based learning media is able to help students understand abstract concepts through more concrete three-dimensional representations. These media facilitate students to perform mental rotation and connections between macroscopic, microscopic, and symbolic representations, which were previously often the main difficulties in chemistry learning.

These findings are consistent with the results of research by Malik et al. (2020) who stated that the use of interactive and contextual digital media can strengthen conceptual understanding while improving students' higher-order thinking and spatial reasoning skills. Furthermore, Brown et al. (2021) emphasized that immersive and interactive digital visualization helps reduce misconceptions in abstract chemical concepts because students can directly observe and manipulate molecular structures in three dimensions. This aligns with broader research showing that virtual reality-based learning environments consistently improve students' conceptual understanding and engagement across different education levels (Merchant et al., 2014).

Effective signaling and focus cues in virtual reality can help direct learners' attention and reduce unnecessary cognitive load (Albus, Vogt, & Seufert, 2021). This finding is also consistent with the study of Zakiyah & Dwiningsih (2022), which revealed that interactive e-modules not only improve students' conceptual understanding of chemical bonding but also enhance their spatial reasoning skills. In addition to the aspect of conceptual understanding, students' learning motivation is also strongly influenced by the use of technology-based media. Araiza-Alba et al. (2021) demonstrated that immersive and interactive learning environments can enhance motivation and provide a more engaging learning experience. Similarly, Cheng, Chen, & Chang (2021) found that effective integration of digital media in chemistry instruction improves students' learning outcomes, interest, and confidence.

Overall, the results of this study confirm that 3D-assisted flipbooks are an effective learning medium for improving students' visual-spatial abilities, especially in abstract topics such as molecular geometry that demand three-dimensional imagination. In line with the growing trend of digital innovation, recent developments in web-based molecular modeling platforms also show the potential for collaborative and immersive chemistry learning environments that connect learners in real time (Rodríguez et al., 2025). Thus, 3D flipbooks can be considered one of the relevant innovations supporting chemistry learning in the digital era and aligned with the demands of twenty-first-century education.

CONCLUSION

improving students' mastery of abstract chemical concepts, particularly molecular geometry. By demonstrating a significant increase in visual-spatial skills through the use of a 3D-assisted flipbook, this research affirms that technology-enhanced learning tools can bridge the gap between symbolic representations and concrete mental models. The completeness of the evidence—from descriptive statistics to the Wilcoxon test and ranks analysis—underscores the reliability of the results, while the consistent improvement across all participants leaves a compelling impression of the product's effectiveness. Ultimately, the 3D flipbook not only proves to be a valid instructional innovation but also stands as a meaningful step toward advancing chemistry education in the 21st century.

REFERENCES

- Albus, P., Vogt, A., & Seufert, T. (2021). Signaling in virtual reality influences learning outcome and cognitive load. *Computers & Education*, 166, 104154. <https://doi.org/10.1016/j.compedu.2021.104154>
- Araiza-Alba, P., Keane, T., Chen, W. S., & Kaufman, J. (2021). Immersive virtual reality as a tool to learn problem-solving skills. *Computers & Education*, 164, 104121. <https://doi.org/10.1016/j.compedu.2020.104121>
- Branch, R. M. (2010). *Instructional design: The ADDIE approach*. Springer Science & Business Media.
- Brown, C. E., Alrmuny, D., Williams, M. K., Whaley, B., & Hyslop, R. M. (2021). Visualizing molecular structures and shapes: A comparison of virtual reality,

- computer simulation, and traditional modeling. *Chemistry Teacher International*, 3(1), 69–80. <https://doi.org/10.1515/cti-2020-0013>
- Cheng, S. L., Chen, S. B., & Chang, J. C. (2021). Examining the multiplicative relationships between teachers' competence, value and pedagogical beliefs about technology integration. *British Journal of Educational Technology*, 52(2), 734–750. <https://doi.org/10.1111/bjet.13052>
- Earnshaw, R. (2017). *Art, design and technology: Collaboration and implementation*. Cham: Springer International Publishing. <https://doi.org/10.1007/978-3-319-58121-7>
- Elford, D. (2022). *Augmented reality in chemistry higher education* (Doctoral dissertation, University of East Anglia). <https://ueaeprints.uea.ac.uk/id/eprint/90630/>
- Malik, A., Yuliani, Y., Rochman, C., Zakwandi, R., Ismail, A., & Ubaidillah, M. (2020). Optimizing students' critical thinking skills related to heat topics through the model of content, context, connection, researching, reasoning, reflecting (3C3R). *Journal of Physics: Conference Series*, 1521(2), 022001. <https://doi.org/10.1088/1742-6596/1521/2/022001>
- Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education*, 70, 29–40. <https://doi.org/10.1016/j.compedu.2013.07.033>
- Nurhayati, N., Linda, R., & Anwar, L. (2022). E-module using FlipHTML5 application on chemical bond material. *Jurnal Pendidikan Kimia Indonesia*, 6(2), 133–141. <https://doi.org/10.23887/jpki.v6i2.49542>
- Rodríguez, F. C., Krapp, L., Meireles, F. T. P., Dal Peraro, M., & Abriata, L. (2025). MolecularWeb democratizes web-based, immersive, multiuser molecular graphics and modeling. *ChemRxiv Preprint*. <https://doi.org/10.26434/chemrxiv-2025-46p89>
- Singh, S., & Kaur, A. (2025). Implementing an enhanced AR-based application for chemistry teaching and learning practice. *AIP Conference Proceedings*, 3227(1), 040003.
- Stieff, M., & Uttal, D. (2015). How much can spatial training improve STEM achievement? *Educational Psychology Review*, 27(4), 607–615. <https://doi.org/10.1007/s10648-015-9304-8>
- Zakiyah, W. I., & Dwiningsih, K. (2022). The effectivity of interactive e-module to increase the students' visual-spatial intelligence on ionic. *Jurnal Inovasi Teknologi Pendidikan*, 9(1), 91–100. <https://doi.org/10.21831/jitp.v9i1.46561>