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Problem-Based Learning LKPD Assisted by Jmol to Improve Critical Thinking Skills and Understanding of Molecular Shape Concepts

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Abstract:
Learning chemistry on molecular matter faces challenges because the concept is abstract and requires the ability to understand three-dimensional representations and think critically. The initial conditions at MA Al-Ishlah Paciran Lamongan show that students still have difficulty visualizing the shape of molecules, analyzing problems, giving reasons, and drawing conclusions. This research aims to develop LKPD based on Problem Based Learning (PBL) assisted by Jmol software that is valid, practical, and effective to support critical thinking skills and concept understanding. The research uses the Research and Development (R&D) method with the ADDIE Lee and Owens model which includes analysis, design, development, implementation, and evaluation. The research subjects consisted of two material experts, two media experts, two chemistry teachers, and 32 students of class X. Validation results showed that the percentage of material experts was 88.16% and media experts were 95.65%, with an average of 92.26% categorized as very valid. Practicality obtained 90.63% response from teachers and 76.54% from students. Effectiveness was shown through an increase in the average score from 37.97 to 76.56, an N-Gain of 0.626, and 75% of students achieved KKM. Thus, LKPD is declared valid, practical, and effective in supporting chemistry learning based on problem solving and three-dimensional visualization.

Introduction (مقدمة)

The development of science and technology is driving changes in educational practices. Technology no longer only functions as a supporting device, but needs to be appropriately integrated in the design of media and teaching materials so that learning is more relevant, effective, and in accordance with the needs of students (Budiman, 2017); Mukaromah, 2020). These developments also encourage the integration of digital technology in learning as part of the response to changes in educational characteristics in the 4.0 era (Priatmoko, 2018). In science learning, technology integration is becoming increasingly important because students are not only required to master information, but also to analyze, evaluate, solve problems, and build evidence-based understanding.

These challenges are increasingly evident in chemistry learning. Chemistry has many abstract concepts that cannot be observed directly so that learners need the help of representations to build understanding. The understanding of chemical concepts involves the interplay between macroscopic, submicroscopic, and symbolic representations. Macroscopic representations are concerned with observable phenomena, submicroscopic representations are concerned with particles such as atoms, electrons, and molecular structures, while symbolic representations use symbols, formulas, and diagrams (Lestari et al., 2022; Wahdatillah et al., 2022). Difficulties at the submicroscopic level are an important problem because students have to build an image of objects that cannot be directly observed (Sholehah & Azhar, 2019).

Matter in molecular shape is one of the chemical topics that has these characteristics. Students need to master the configuration of electrons, valence electrons, Lewis structures, electron pairs, and the relationship of electron pairs to the shape and angle of bonds. In addition to mastery of concepts, learners need visuospatial skills to build three-dimensional representations of molecules. Research Nisa & Dwiningsih (2021)shows that Mobile Virtual Reality-based molecular geometry visualization can be used to support learning outcomes and visuospatial abilities of learners. Squirrels Rahmawati et al. (2021) It also shows that three-dimensional virtual representation is related to students' spatial abilities in chemistry learning. The findings reinforce the need for media that can help students observe molecular structure from multiple perspectives.

The conceptual problem of molecular matter is not only related to the ability to visualize structures, but also to the potential for misconception. Students may experience difficulties in determining the shape of molecules, estimating bond angles, understanding the influence of free electron pairs and bonding electron pairs, and relating structures to molecular properties. Therefore, learning needs to provide opportunities for students to observe, analyze, compare, give reasons, and evaluate the results of their thinking. Critical thinking skills are an important part of the process because learners need to build conclusions based on information and reasoning that can be accounted for.

The results of the needs analysis in the thesis on which this article is based show more specific conditions at MA Al-Ishlah Paciran Lamongan. Molecular shape learning has not yet used LKPD, which is specifically designed to support problem-based learning. The visualization used is still limited to two-dimensional representations and ball and stick models, while the utilization of three-dimensional molecular visualization software is not optimal. Students also still show passive tendencies in solving problems, lack the opportunity to find solutions independently, and still have difficulty in understanding the concept of molecular shapes. The results of the teacher's interviews showed that the teaching materials used were dominated by package books and PowerPoint presentations. The available LKPD does not display three-dimensional visualization and does not fully direct students to analysis, problem-solving, and strengthening concept understanding activities.

This condition shows that the problem of learning does not only lie in the availability of technology, but in how technology is integrated with pedagogical activities. One relevant approach is Problem Based Learning (PBL). PBL places problems as the starting point for learning and encourages students to investigate, develop solution strategies, test alternatives, and convey the results of thought. This approach corresponds to the characteristics of the material of the molecular shape because learners can use the problem as a context for connecting early knowledge, molecular representation, and chemical concepts. According to Ministry of Education and Culture (2017) placing PBL as a model that can encourage deep understanding, application of knowledge in relevant situations, critical thinking, independence, and cooperation.

Empirical findings Situmorang & Laksono (2025) also shows that the application of PBL is related to improving students' critical thinking skills and active learning.

The use of PBL needs to be supported by teaching materials that are able to direct students to undergo a systematic problem-solving process. The LKPD can serve as a device that provides problems, activity instructions, investigation rooms, analytical questions, and inference activities. Research Wahdatillah et al. (2022) shows that PBL-based e-LKPD with multiple representation in molecular shape materials and intermolecular interactions produces very valid and practical teaching materials. Mufidah and Dwiningsih (2024) also show that PBL-oriented e-worksheets can support the improvement of science literacy. While Lestari et al. (2025), through a systematic literature review, reports that PBL-based teaching materials have the potential to improve critical thinking, creative thinking, problem-solving, learning outcomes, and student competence. Thus, PBL-based LKPD has an empirical basis to be used as a means of connecting problem-solving activities with concept mastery.

However, the use of PBL-based LKPD alone has not fully answered the problem of three-dimensional representation of molecular shape materials. Three-dimensional visualization is necessary because molecular structures have spatial characters that are difficult to adequately represent through two-dimensional images. Research Hoai et al. (2023) It shows that simulation of three-dimensional molecular structure can support the development of chemical competence and the application of spatial knowledge to higher-level concepts. In this study, Jmol was chosen because it can display molecular structures in a three-dimensional format and allows users to rotate models, observe bond lengths and angles, display electron pairs, and explore structures from various perspectives. Thus, Jmol is positioned not as a mere visual addition, but as part of a learning activity that supports the formation of representation and concept analysis.

The integration of PBL, LKPD, and three-dimensional visualization also has support from previous research. Anisa et al. (2026) shows that PBL-based e-modules through a multi-representation approach can improve critical thinking skills. Research R. Rahmawati et al. (2025) shows the importance of *multiple representation* in helping to understand concepts and reduce misconceptions. Research Rose et al. (2025) It shows that digital media that combines text, images, videos, and evaluations can improve understanding of concepts, but their effectiveness remains dependent on indicators and the design of learning activities. Teaching materials developed through ADDIE need to be assessed in terms of validity, practicality, and effectiveness. The series of findings shows that the quality of learning products needs to be looked at as a whole, not just from the existence of the technology used (Duengo et al., 2026)

Based on this description, there is a need to develop teaching materials that integrate the pedagogical orientation of PBL with three-dimensional visualization of molecular shape materials. This study places LKPD as a learning activity structure, PBL as a problem-solving framework, and Jmol as a means of visualizing three-dimensional molecular structures. The integration is directed at two main achievements, namely critical thinking skills and concept understanding. The position of this research is more specific than the previous research because it combines the three components in one LKPD on the molecular shape material of class X MA, based on real problems found through needs analysis at MA Al-Ishlah Paciran Lamongan. Therefore, this study aims to develop LKPD based on *Problem Based Learning* with the help of valid, practical, and effective Jmol software to support critical thinking skills and students' understanding of concepts in molecular shape materials.

Method (منهج)

This research uses the Research and Development (R&D) method to develop LKPD-based *Problem Based Learning (PBL)* Assisted by Jmol software on molecular shape materials. Development is directed to produce products that meet the aspects of validity, practicality, and effectiveness in supporting students' critical thinking skills and concept understanding. In development research, products are not only produced, but also through the stages of needs analysis, design, development, testing, evaluation, and revision so that product quality can be assessed systematically (Setyosari, 2013).

The development model used is ADDIE Lee and Owens, which consists of five stages, namely Analysis, Design, Development, Implementation, and Evaluation. This model was chosen because it is designed for the development of multimedia-based learning and is in accordance with the characteristics of LKPD which integrates PBL activity with three-dimensional molecular visualization through Jmol (Lee, W. W., & Owens, 2004). In the Analysis stage, a need assessment is carried out through learning observation, chemistry teacher interviews, and information collection regarding student characteristics, learning objectives, materials, facilities, and available technology. The Design stage includes determining product specifications, material structure, preparation of activities according to PBL syntax, designing instruments, and preparing development schedules. The Development stage produces LKPD which is then validated by material experts and media experts. The Implementation stage is carried out through gradual trials and product effectiveness tests. The Evaluation stage is carried out formatively in each phase to identify weaknesses and determine product revisions.

The research subjects consisted of two material experts, two media experts, two chemistry teachers, and students of class X of MA Al-Ishlah Paciran Lamongan. The subject matter expert assesses the suitability of content, chemical substances, language, presentation, media use, and suitability with PBL. Media experts assess aspects of the appearance, design, graphics, readability, layout, and function of the media. Teachers play the role of practitioners who provide assessments on the practicality of using LKPD, while students become product users as well as effectiveness test subjects. The trial was carried out in stages. A one-on-one trial involved three learners to identify initial errors, material clarity, and usage issues. The small group test involved nine learners to obtain information about the clarity of the material, ease of operation, and completeness of the product. After the revision, an effectiveness test was conducted on 32 students using a one-group pretest-posttest design.

The research data consists of qualitative and quantitative data. Qualitative data was obtained from the results of observations, interviews, comments, criticism, and suggestions from material experts, media experts, teachers, and students. Quantitative data was obtained from expert validation scores, teacher and student responses, and pretest and posttest scores. Data collection instruments include questionnaires and tests. The questionnaire was used to assess the validity of the product by material experts and media experts as well as to find out the response of teachers and students to the practicality of the LKPD. The test instrument consists of critical thinking questions and the Four-Tier Diagnostic Test to measure concept comprehension. The Four-Tier Diagnostic Test measures answers, the level of confidence in the answer, the reason, and the level of confidence in the reason. The preparation and use of questionnaires and tests followed the principles of data collection of development research used in the thesis, with adjustments to the needs of the article (Sugiyono, 2013).

Data analysis was carried out qualitatively and quantitatively. Qualitative data is analyzed through the analysis of comments, criticisms, and suggestions to identify product weaknesses and determine revision strategies. The quantitative data from the questionnaire was analyzed using a Likert scale of 1–4, then converted into a percentage by comparing the score obtained with the maximum score. Percentages are used to determine the level of validity and practicality of the product. Effectiveness was analyzed by comparing pretest and posttest scores using paired-samples t-test and calculating N-Gain. The one-group pretest-posttest design allows changes in learning outcomes to be observed by comparing the condition of students before and after the use of LKPD, but does not provide a control group. Therefore, effectiveness results are interpreted as evidence of improvement after product use, rather than as causal evidence that fully compares the product with alternative learning (Budiman, 2013).

Operationally, the research flow started from the needs analysis, followed by the design and development of the LKPD, expert validation, revision, one-on-one trials, small group tests, revisions, and effectiveness tests on 32 students. All inputs at the validation and trial stages are used as the basis for product improvement.

Result (نتائج)

The development research produced LKPD based on Problem Based Learning (PBL) assisted by Jmol software on molecular shape materials for class X students. The results of the needs analysis show that there is a gap between learning conditions and the needs of students. Based on interviews with chemistry teachers, around 60% of students achieved KKM 70 in molecular shape materials. The main difficulty lies in the ability to describe and visualize the shape of molecules, while the ability to analyze problems, give reasons, and draw conclusions is still low. Previous learning used more publisher worksheets, PowerPoint, and *molymod*. Teachers also reported that students tended to be less enthusiastic about using the available worksheets and were still passive in problem solving. These findings are the basis for the development of LKPD which combines PBL problem-solving activities with three-dimensional molecular visualization through Jmol. The results of the needs analysis also show that the school has a computer laboratory, multimedia room, LCD/projector, internet, and Wi-Fi so that it technically supports the use of the product.

Table 1. Summary of Needs Analysis Results

Aspects Analyzed	Findings	Development Implications
Completeness of learning	Around 60% of students reach KKM 70	Teaching materials are needed that support the improvement of concept understanding
Understanding the shape of molecules	Students have difficulty describing and visualizing the shape of molecules	3D visualization required
Critical thinking	The ability to analyze problems, give reasons, and draw conclusions is still low	PBL-based activities required
Previous teaching materials	Publisher LKS, PowerPoint, and *molymod*	More interactive and targeted teaching materials are needed
Learning activities	Learners are relatively passive in problem solving	LKPD needs to guide the activities of observing, discussing, analyzing, and concluding
School facilities	Computer lab, multimedia room, internet, Wi-Fi, and LCD/projector are available	Jmol can be implemented through school computer devices

The validation results show that the product meets the high eligibility criteria. Material expert validation obtained a score of 67 out of 76 or 88.16%, while media expert validation obtained a score of 88 out of 92 or 95.65%. The average of the two validation results reached 92.26% and was included in the very valid category. The assessment of subject matter experts includes content quality, language, presentation, media use, and conformity with PBL syntax. Media experts assess aspects of appearance, cover design, graphics, content design, readability, image layout, and media functions. The media expert also provided several inputs, including the addition of digital guides to the use of LKPD and barcode tutorials. These results show that the product has met the content and design requirements before use in the trial stage.

Table 2. Product Validation Results

Validator	Scores Obtained	Score Maximum	Percentage	Category
Material Expert	67	76	88,16%	Very valid
Media members	88	92	95,65%	Very valid
Average	155	168	92,26%	Very valid

In terms of practicality, LKPD received a positive response from teachers and students. The teacher's assessment obtained a score of 29 out of 32 or 90.63%, so it is included in the very practical category. Meanwhile, students obtained a score of 248 out of 324 or 76.54%, which is included in the practical category. Teachers assessed that LKPD can help the implementation of PBL, direct students to obtain information through problems and observations, and help understand concepts through 3D visualization and practice questions. From the student's side, the visual aspect received the highest response. The statement that pictures and tables help understand the material obtained a percentage of 83.33%. On the other hand, the aspect of learning spirit and language simplicity obtained 72.22%, so it still needs improvement.

Table 3. LKPD Practicality Test Results

They respond	Scores Obtained	Score Maximum	Percentage	Category
Teacher	29	32	90,63%	Very practical
Students	248	324	76,54%	Practical

Table 4. Important aspects of learner responses

Aspects	Percentage
Pictures and tables help you understand the material	83,33%
Passion for learning	72,22%
Simplicity of language	72,22%

The most important finding was found in the effectiveness test. The test was carried out on 32 students with *a one-group pretest-posttest* design. The average pretest score is 37.97, with a minimum score of 15 and a maximum of 65. After learning using PBL-based LKPD assisted by Jmol, the average posttest increased to 76.56, with a minimum score of 40 and a maximum of 95. Thus, there was an average increase of 38.59 points. The results *of the paired-samples t-test* showed a p value of < 0.001, so there was a significant difference between the pretest and posttest scores. The average N-Gain is 0.626, which is in the medium category. In addition, effectiveness data showed that no students reached KKM 70 in the pretest, while after learning there were 24 out of 32 students or 75% who reached KKM.

Table 5. LKPD Effectiveness Test Results

Indicator	Pretest	Posttest
Number of students	32	32
Minimum score	15	40
Maximum value	65	95
Average	37,97	76,56
Average difference	-	38,59
Participants reach KKM 70	0 (0%)	24 (75%)
N-Gain	-	0,626
Paired t-test	-	p < 0.001

Discussion (مناقشة)

The results of the study show that Jmol-assisted Problem Based Learning (PBL)-based LKPD meets three main aspects of product quality, namely validity, practicality, and effectiveness. These findings need to be read as a series of developments. Needs analysis shows that there are difficulties for students in describing and visualizing the shape of molecules, while problem analysis activities, reasoning, and drawing conclusions also need to be strengthened. Therefore, the product is designed to connect problem-solving activities with three-dimensional visualization. This pattern is consistent with the discussion in the thesis that the product is developed based on the real needs of teachers and students through the stages of analysis, design, development, implementation, and evaluation.

The validity of the product which reached an average of 92.26% indicates that the LKPD has met the content and technical requirements before being used in the trial. The validation of the subject matter experts of 88.16% showed the suitability of the content with the curriculum, learning objectives, VSEPR concepts, the use of Jmol, and PBL syntax. Media expert validation of 95.65% shows that the appearance, design, readability, layout, and function of the media are considered very feasible. These results show that the integration of PBL and Jmol is not only done in the visual aspect, but also in the structure of learning activities. The findings are in line with Gabriella & Mitarlis, (2021), which reported that PBL-oriented LKPD on hydrocarbon materials obtained high validity because it conformed to PBL syntax and critical thinking indicators. Research Muchlis (2021) also reported that PBL-based LKPD on electrolyte and non-electrolyte materials met the feasibility in terms of content, language, presentation, and graphics.

The validator's feedback shows that high validity does not mean that the product has been absolutely completed. The thesis noted the need for improvement in the form of digital guides for the use of LKPD and barcode tutorials. This finding is important because technology-assisted teaching materials must consider ease of use. Technically good products still need clear instructions so that students can use the visualization feature appropriately. Thus, the revision process after validation is not just an administrative procedure, but a substantive part of product development.

The practicality of the product shows a different pattern between teachers and learners. The teacher's response reached 90.63% and was in the very practical category, while the students' response reached 76.54% and was in the practical category. The teacher assessed that LKPD helped direct PBL activities, discussions, observation of molecular shapes, and exercises. Students also received the product positively, but scored lower on aspects of learning enthusiasm and language simplicity. These differences show that expert and teacher assessments are not always synonymous with end-user experience. The thesis emphasizes that the language aspects, the variety of activities, and the attractiveness of activities still need to be improved. These findings reinforce the importance of user testing in development research.

The visual aspect obtained the highest response from students, which was 83.33%, to the statement that pictures and tables help to understand the matter of molecular shapes. These findings support the theoretical reasons for Jmol selection. Molecular shape is a concept that requires spatial understanding and three-dimensional representation. In line with Y. Rahmawati et al. (2021) Shows the importance of three-dimensional virtual representation in chemistry learning and its relation to students' spatial abilities. Nisa & Dwiningsih (2021) also showed that the use of Mobile Virtual Reality-based molecular geometry visualization can support molecular geometry learning. Research results Hoai et al. (2023) reports that simulation of three-dimensional molecular structures can help the development of chemical competence through visual experience of molecular structure. Thus, the positive response to the visual elements in this study has support from previous research.

The advantage of Jmol in this study does not only lie in the existence of three-dimensional images. Jmol is used in a series of PBL activities so that students can observe structures, connect electron pairs with molecular shapes, discuss observations, and draw conclusions. The thesis shows that Jmol is positioned as part of the problem-solving, not just a complement to the appearance. This position is important because the use of learning technology needs to be associated with pedagogical goals and learning activities. According to UNESCO (2023) It also emphasizes that educational technology does not automatically produce learning impacts without the support of learning objectives, pedagogy, teacher readiness, and the conditions of students and schools.

The effectiveness of the product can be seen from the increase in the average score from 37.97 in the pretest to 76.56 in the posttest. The average difference was 38.59 points accompanied by paired-sample t-test results with a $p < 0.001$. An N-Gain of 0.626 indicates an increase in the medium category. These findings show an increase in learning outcomes after students use PBL-based LKPD assisted by Jmol. However, because the study used a one-group pretest-posttest design without a control group, the improvement should be interpreted as a change after product use and should not be positioned as causal evidence that fully compares LKPD with alternative learning.

The increase can be explained by the structure of PBL activities that place problems as the starting point of learning. Students are directed to understand problems, seek information, conduct investigations, discuss, present results, and draw conclusions. These activities provide space for interpretation, analysis, inference, evaluation, justification, and reflection. Research results Situmorang & Laksono (2025) found that the application of PBL made a significant difference in students' critical thinking skills and learning activity. Systematic review Yu & Zin (2023) also shows that adaptations of PBL that are oriented towards critical thinking need to consider the design of activities and learning orientations. Mutiara et al. (2024) also strengthened the findings through a systematic study on improving critical thinking skills using PBL.

Changes in thinking ability are also seen in the indicators analyzed in the thesis. In the pretest, students still had difficulty understanding the concept of VSEPR, determining bond electron pairs and free electron pairs, and determining the type of AXnEm. After learning, students are better able to relate PEI and PEB to molecular shapes, provide reasons, evaluate statements, and draw more logical conclusions. This shows that the improvement is not only reflected in the total score, but also in the reasoning process that is part of critical thinking skills. The integration of PBL and Jmol provides different but complementary functions: PBL directs the reasoning process, while Jmol helps provide a visual representation of objects that are difficult to observe directly.

The research findings are also in line with research on the development of other PBL-based teaching materials. Develop e-LKPD based on PBL and multiple representation on molecular shape materials and intermolecular interactions. The study shows the potential of LKPD in combining problem-solving with chemical representation (Wahdatillah et al., 2022). Mufidah & Dwiningsih (2024) shows that PBL-oriented e-worksheets on chemical equilibrium materials can support science literacy. The similarity of these studies lies in the use of structured teaching materials to direct student activities. The difference is that this study specifically integrates PBL with three-dimensional visualization of Jmol in molecular shape materials and tests the validity, practicality, and effectiveness of the product in a series of developments.

The comparison clarifies the contribution of this research. Previous research has shown the benefits of PBL in the development of critical thinking and the benefits of three-dimensional visualization in supporting spatial understanding. This study integrates the two components in one LKPD that follows the PBL syntax. Thus, the added value of the product is not solely in the use of Jmol or PBL separately, but in the design of activities that connect problems, investigations, molecular visualizations, discussions, analysis, and conclusions. The thesis findings also confirm that the linkage between initial needs, product design, validation, practicality, and field test results form a consistent development flow.

The findings also show that the improvement in learning outcomes does not appear uniformly in all students. The thesis shows that there are still students who are in the low N-Gain category, while the majority are in the medium and high categories. Differences in initial abilities, speed of understanding concepts, skills in using technology, and activeness in discussions can be factors that affect the results. Therefore, the use of JMOL-assisted LKPD needs to be accompanied by teacher assistance and instruction that is in accordance with the student's abilities. The product also needs to be developed with step-by-step examples, glossaries, additional instructions, or remedial exercises for learners who need more support.

Facility factors also need to be considered in interpreting the results. MA Al-Ishlah has a computer laboratory, multimedia room, LCD/projector, internet, and Wi-Fi that supports the implementation of Jmol. However, not all students have laptops or personal computers and the use of smartphones is not allowed in learning. Therefore, the success of the application of the product in the context of this research is supported by the readiness of school facilities. This condition is the limit for the transfer of results to other schools. Implementation in schools with limited facilities requires alternative strategies, such as group use of devices or the provision of visualizations that can be used without individual device access.

The findings of this study can also be strengthened from the perspective of misconception diagnosis. Sudiatmika et al. (2025) suggests that misconceptions can be persistent and need to be identified as a basis for designing appropriate learning. The four-tier instrument they developed was found to be very valid, very practical, and very effective at identifying misconceptions. Its relevance to this research lies in the abstract character of molecular shape material and has the potential to give rise to conceptions that are not in accordance with scientific concepts. Therefore, the increase in scores after the use of Jmol-assisted LKPD should not only be understood as an increase in scores, but also as an indication that learners are receiving representational assistance to reconstruct the relationship between electron pairs, structures, and molecular shapes. The integration of diagnostic assessments into follow-up research can provide stronger evidence of changes in students' conceptions.

The next strengthening came from the study Malau et al. (2024) about critical thinking skills in project-based chemistry learning. The study emphasized that it is not enough to learn chemistry through memorization, but it is necessary to develop the skills of identifying, analyzing, evaluating, reasoning, and drawing conclusions. Project-based learning can also be reported to encourage learner engagement, problem-solving, collaboration, and the relationship between theory and practice. Although this study used PBL instead of PjBL, the findings are still relevant at the cognitive process level. PBL activities in this research LKPD direct students to understand the problem, conduct investigations, analyze information from Jmol visualizations, provide reasons, and draw conclusions. Thus, the improvement of critical thinking skills found in this study has the support of the literature that places active learning activities as a means of developing high-level thinking.

Research results Mahardika et al. (2022) provide additional support for the use of LKPD combined with simulation media. The study found significant differences between learning using PhET-assisted LKPD and LKPD from package books on students' motivation and cognitive learning outcomes. The author explained that simulation media helps students visualize concepts and explore abstract phenomena. The same principle is seen in this study, although the media used is different. Jmol provides a three-dimensional representation that can be observed and explored to help learners understand the shape of molecules. Therefore, the results of this study strengthen the argument that LKPD becomes more functional when combined with interactive media that directly helps students observe objects or phenomena that are difficult to represent through static text and images.

Fatemah et al., (2020) strengthening the foundation of the use of three-dimensional visualization in chemistry learning. They explain that learning chemistry demands an integration between spatial abilities and conceptual knowledge. Conventional 2D visualization has not fully helped learners understand molecular structures, while interactive 3D models can help with the spatial visualization process. The study also showed that virtual models can help narrow the performance gap between students with different levels of spatial ability. The findings are relevant to the students' responses to this study, especially in the aspect of images and tables which obtained a percentage of 83.33%. The visual support of Jmol can be seen as a bridge between symbolic or two-dimensional representations and three-dimensional spatial representations, so that learners have a more concrete basis for analyzing the shape of molecules. Thus, Jmol's contribution in this study is not only related to the appeal of the media, but also to the cognitive needs in studying molecular structure.

If synthesized, the four additional journals reinforce the four dimensions of this study's findings. Sudiatmika et al. (2025) reinforcing the importance of diagnosis of conception and misconception; Malau et al. (2024) strengthen the link between active learning and critical thinking skills; Mahardika et al. (2022) strengthening the function of LKPD combined with simulation media on learning outcomes; whereas Fatemah et al. (2020) reinforcing the role of 3D visualization in science-demanding learning of spatial abilities. These four perspectives make the interpretation of research results more comprehensive because the improvement in learning outcomes can be understood as the result of the interaction between PBL activity design, LKPD function, visual technology support, and the need of students to build a conceptual understanding of abstract chemical objects.

Theoretically, the results support the idea that learning abstract chemical concepts requires integration between cognitive activity and visual representation. Pedagogically, PBL provides a structure for developing thought processes, while Jmol provides a three-dimensional representation that supports the observation of molecular structure. Practically, LKPD provides activity guides that can help teachers manage problem-based learning in a more targeted manner. However, the results of the study still have limitations on the number of subjects, the context of the facilities, the materials developed, and the design of the one-group pretest-posttest. Therefore, follow-up research needs to involve a more diverse sample and school, using control groups or quasi-experimental designs, testing learning retention, and developing products on other abstract chemical materials.

Table 6. Synresearch Results and Interpretation

Components	Key Results	Interpretasi
Needs analysis	±60% reach KKM 70	There are problems with initial understanding
Material validation	88,16%	Contents are valid
Media validation	95,65%	Very valid media
Average validation	92,26%	Highly valid products
Teacher practicality	90,63%	Very practical
Practicality of learners	76,54%	Practical
Pretest	37,97	Relatively low initial capability
Posttest	76,56	Improved post-learning ability
Average increase	38.59 points	There is an increase in learning outcomes
Paired t-test	$p < 0.001$	Significant pretest-posttest differences
N-Gain	0,626	Moderate category upgrades
Completeness of KKM	0% → 75%	Increased completeness after learning
Critical thinking	Interpretation, analysis, inference, evaluation, justification, and	PBL and visualization support the analytical thinking process

	metacognition are increased	

Research Limitations and Implications

The results of the study need to be read by considering several limitations. The field test only involved 32 students of class X-H MA Al-Ishlah Paciran Lamongan so the results could not be generalized to the wider population. The one-group pretest-posttest design also does not provide a control group. In addition, the application of Jmol depends on computer facilities and school readiness, new products are tested on molecular shape materials, and studies have not measured long-term retention of comprehension.

The implications of the study cover three levels. For teachers, LKPD can be an alternative teaching material to guide problem-based learning and visualization of molecular shapes. For students, the product provides observing, discussing, analyzing, and concluding activities with three-dimensional visual support. For schools, products can take advantage of the computer laboratory facilities and multimedia rooms available. Subsequent developments need to improve language and instruction, provide digital guidance, expand test subjects, use control groups, and test learning retention.

Conclusion (خاتمة)

This study developed a Jmol-assisted Problem-Based Learning LKPD for molecular shape learning and evaluated its validity, practicality, and effectiveness. The product achieved very high validity, with an average expert validation score of 92.26%. Teachers rated it very practical at 90.63%, while students rated it practical at 76.54%. Effectiveness testing showed significant improvement, with mean scores increasing from 37.97 to 76.56, an N-Gain of 0.626, and 75% of students reaching the KKM. The LKPD therefore supports critical thinking and concept understanding through structured problem-solving and three-dimensional molecular visualization. However, broader trials and controlled studies are needed.

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