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The Effectiveness of Problem-Based Learning Chemistry Modules and Their Impact on Students' Critical Thinking Abilities

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Abstract: The research aims to assess the effectiveness of using problem-based learning-oriented chemical bonding modules in improving students' critical thinking skills. This study falls under the category of Research and Development with a four-D product development model. The research design employs a quasi-experimental approach with a post-test-only control group design using experimental and control classes for comparison. Effectiveness assessment is carried out using interview guidelines, observation sheets, and tests to determine students' critical thinking abilities. The effectiveness analysis technique involves independent sample t-tests and Cohern's effect size. The results of the independent sample t-test indicate a difference in students' critical thinking abilities before and after using problem-based learning-oriented chemical bonding modules. The effect size values suggest a moderate level of effective contribution, ranging from 0.20 to 0.80. Consequently, the research findings conclude that problem-based learning-oriented chemical bonding modules are effective in enhancing students' critical thinking skills.

Keywords: Chemical Bonding; Critical Thinking Skills; Module; Problem-Based Learning

Introduction

The ability to think critically refers to a process in which students are expected to carefully and intelligently formulate reasons systematically. In this process, they are required to use information acquired from various sources such as observation, experience, reflection, reasoning, or communication to conceptualize, apply, analyze, synthesize, or evaluate ideas as a basis for making decisions and taking action. Critical thinking skills are crucial for students as they enable them to effectively address various problems, whether they are social, scientific, or practical (Selviana *et al.*, 2022). Possessing critical thinking skills is crucial for students in the learning process, especially in the study of chemistry, which is often considered challenging by students due to its abstract and complex concepts. These skills, developed through critical, inductive, deductive, and analytical thinking, are essential for solving problems related to the material (Marpaung *et al.*, 2020; Whatoni & Sutrisno, 2022; Kusumah *et al.*, 2020).

The topic of chemical bonding is one of the abstract aspects of chemistry, involving theoretical concepts and mathematical models applied to explain how chemical bonds form. This includes topics such as molecular orbital theory, hybridization theory, understanding molecular shapes, and other aspects of chemical bonding, such as the formation of covalent, ionic, metallic, and hydrogen bonds. These topics require a deeper understanding. Therefore, students need to accurately grasp the basic concepts of chemical bonding and chemical principles (Whatoni & Sutrisno, 2022). This also includes understanding the chemical

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properties of various materials present in the surroundings.

One reason why students are less interested in chemistry is due to its extensive content, which makes them feel difficulty in mastering it. The conventional teaching methods commonly used result in students having difficulty comprehending and delving into the material, leading to challenges in achieving academic success, including high-level thinking skills. This is evident from previous research findings where the limited development of these skills is indicated by critical thinking indicators. Some students are less skilled, with 86% of students showing a weak correlation of 0.26 between academic achievement and critical thinking ability (Rasmawan, 2017). Based on the results of a survey, the critical thinking abilities of students in chemistry learning also indicate a relatively low average (Irwanto *et al*., 2018). Furthermore, a study conducted by Hakim et al. using mini-project laboratory learning also found that there were still low levels of critical thinking abilities among the students (Hakim *et al*., 2016).

While the abilities and skills that students need to possess in facing the demands of the 21st century are crucial, one of these essential skills is critical thinking. Critical thinking plays a significant role in addressing the challenges of the 21st-century world. Therefore, there is a need for efforts to train and develop critical thinking skills, which can be integrated into the learning process (Irwanto *et al*., 2018; Hadisaputra *et al*., 2020). However, the attention given to the importance of critical thinking skills training is not yet aligned with the activities in the school learning process (Hadisaputra *et al*., 2020).

Based on observations conducted at a high school in Yogyakarta, it is evident that students still face limitations in their ability to classify and understand problems. There is a lack of effort in utilizing various references to solve problems, and students show a lack of enthusiasm in providing comments and input during discussions. The learning activities are still teacher-centered or involve passive watching (Ambarwati *et al*., 2021).

Furthermore, educators have not yet developed teaching materials that can support the development and enhancement of students' critical thinking skills, highlighting the need for instructional materials that can provide such support. Therefore, educators should be capable of providing facilities that support students in training and developing their critical thinking or higher-order thinking abilities in chemistry learning (Ramdoniati *et al*., 2018).

In this century, students are also required to respond quickly and effectively to the given learning materials. They are expected to have high intellectual abilities, integrate skills and knowledge to understand the material, and be capable of seeking solutions to problems (Nawawi, 2017; Nurmahasih & Jumadi, 2023; Melawati *et al*., 2022; Asih *et al*., 2022).

Therefore, there is a need for a learning model that can support it. Learning activities that involve active participation of students in developing students' critical thinking skills (Ismiyati *et al*., 2019; Lestari *et al*., 2021). Problem-based learning is a model that can be used because it is designed to acquire essential knowledge and train students to solve a problem by participating in a group (Gandri *et al*., 2019). Implementing this learning model can enhance students' communication skills in the learning process (Isna *et al*., 2018). Identifying problems, analyzing solutions to a problem, applying a solution, evaluating a solution, and drawing conclusions are the five indicators used in this research (Seventika *et al*., 2018).

Based on other research, it is recommended that a problem-based learning model is appropriate and effective for enhancing students' critical thinking skills (Saepuloh *et al*., 2021). Studies utilizing the implementation of a problem-based learning model have shown that it is more effective in making students more active, as evidenced by the improvement in students' higher-order thinking Skills (HOTS) and critical thinking skills (Jailani *et al*., 2017; Paramitha *et al*., 2023). The learning outcomes and self-efficacy of students using problem-based learning also demonstrated an increased difference between the control and experimental classes (Amalya *et al*., 2021).

Learning using a problem-based learning model can be applied in instructional materials that support the implementation of students' learning activities. Using this learning model allows students to actively interact with their peers in a group or with educators and can train their sense of responsibility in solving a problem (Nurmahasih & Jumadi, 2023). Not only that, but the problem-based learning model is also capable of improving other academic skills such as science process skills and problem-solving abilities of students (Witri *et al*., 2023; Asih *et al*., 2022).

Learning media that can guide and train students to be active in learning and independent, including modules that incorporate a learning model such as problem-based learning design (Lestari *et al*., 2021; Retno *et al*., 2018; Ismiyati *et al*., 2019). The use of a learning model in modules has been proven effective in improving students' abilities. For example, research results show that the use of local history modules focused on issues has been effective in enhancing students' critical thinking skills (Mujiyati *et al*., 2019). Modules using the same learning model have a very high level of validity and practicality and can be used as a medium to enhance students' critical thinking skills (Sari *et al*., 2019). Furthermore, other studies also indicate that the implementation of PBL-based living organism interaction modules can improve learning outcomes and students' perceptions (Auly *et al*., 2020; Aufa *et al*., 2020). Learning with problem-based learning-based e-modules can assist educators in delivering materials to achieve learning objectives in enhancing students' scientific literacy (Gusman *et al*., 2022). Learning with problem-based learning-based modules that contain concise materials and important concepts can help students understand the material, thereby improving students' critical thinking skills and cognitive learning outcomes (Rahmatika *et al*., 2020).

The use of modules in learning will train students to study independently, help them simplify their understanding of chemical bonding materials, and support them in building their understanding because these modules include problem-solving learning related to students' daily lives. Therefore, this research was conducted with the overall aim of testing the effectiveness of problem-based learning-oriented chemical bonding modules that have been previously developed on students' critical thinking abilities.

Method

This research is a type of Research and Development (R&D) aimed at producing and testing the effectiveness of a product in learning implementation as an effort to enhance students' critical thinking skills. The method employed by the researcher to generate the previously developed module is by using the four-D development model from Thiagarajan (1974), which consists of the stages of define, design, develop, and disseminate. The module has undergone validity testing by experts, both in terms of content and media, ensuring that the module is valid and practical in terms of readability for use in learning.

The research was conducted at one of the high schools in Yogyakarta, with a total sample size of 72 students selected using the simple random sampling technique from 5 classes of X MIPA. The study aimed to assess the effectiveness of using a module and its impact on student's critical thinking skills. The researcher employed a post-test-only control group design within a quasi-experimental research framework.

The study was conducted using two classes: the experimental group and the control group, serving as a comparison to determine the improvement in students' critical thinking skills. The module on chemical bonding oriented towards problem-based learning was utilized in the experimental group, while the control group used a printed chemistry book provided by the school with a conventional learning approach. At the end of the treatment, both the experimental and control groups were given the same critical thinking ability test. The quasi-experimental research design used is outlined in Table 1.

Table 1. Quasi-Experimental Research Design.

Group	Treatment	Post-Test
Experimental	X_1	O
Control	X_2	O

Description:
X_1: Using a PBL-oriented module
X_2: Conventional learning
O: Critical thinking test

Data collection in the research involves using interview guidelines as an instrument to gather information related to the field conditions. Observation sheets are used to observe the characteristics of students, both as a group and individually. The observations cover academic abilities, creativity, and students' motivation. The test instrument consists of essay questions to assess students' critical thinking abilities. The critical thinking test instrument with chemical bonding material comprises 18 essay questions that meet the criteria for test quality in terms of validity and reliability. The indicators for critical thinking include identifying problems, analyzing solutions to a problem, applying a solution, evaluating a solution, and drawing conclusions.

Data analysis techniques involve both qualitative and quantitative analyses. Qualitative analysis is employed to describe the initial conditions of students' critical thinking abilities in chemistry learning activities. Meanwhile, quantitative analysis is utilized to assess the effectiveness of a chemistry bonding module oriented towards problem-based learning using an independent samples t-test with a significance level (α) of 0.05 to determine the difference in students' critical thinking abilities before and after participating in the module-based learning. Before conducting the independent samples t-test, the hypothesis is that if the null hypothesis (H0) value of the significance test is greater than α, it is rejected, and if the H0 value is less than α, it is accepted. Additionally, prerequisite tests for the data, such as normality and homogeneity tests, have been performed.

The next step to determine the effective contribution of the chemical bonding module with problem-based learning orientation on critical thinking skills is to analyze Cohen's d effect size through the following formula (Dunst & Hamby, 2012).

$$d = \left(\frac{X_t - X_c}{S_{pooled}}\right) \quad (1)$$

Description:
d = Effect size value
X_t = Average score of the experimental group

X_c = Average score of the control group
S_{pooled} = Combined standard deviation

Before calculating Cohend's d value, you need to first find the spooled value, and its calculation is done using the following formula:

$$S_{pooled} = \sqrt{\frac{(n_t - 1)S_t^2 + (n_t - 1)\, S_c^2}{n_t + n_c}} \quad (2)$$

Description:
S_{pooled} = Combined standard deviation
n_t = Sample size of the experimental group
n_c = Sample size of the control group
S_t = Standard deviation of the experimental group
S_c = Standard deviation of the control group

The criteria for the magnitude of the effect size are classified as follows:
$d < 0.20$: Considered small
$0.20 < d < 0.80$: Considered moderate
$d > 0.80$: Considered large

Result and Discussion

Based on the results of a study conducted at one of the high schools in Yogyakarta, specifically in the X MIPA class, the researcher obtained information from interviews that the school still implements the 2013 curriculum for the academic year 2022/2023. Regarding the teaching materials used by educators to teach chemistry, the school provides a printed chemistry book published by Erlangga. To measure students' critical thinking skills, educators only assess them based on the level of questions used. Educators have not used additional teaching materials, especially modules oriented towards a learning model, to assess students' critical thinking abilities. Therefore, it becomes one of the strong reasons for the researcher's desire to implement the developed modules. This is aimed at achieving a learning goal that can enhance students' abilities and improve the learning process, supported by teaching materials that incorporate a learning model (Retno *et al.*, 2018).

In addition to obtaining information through interviews with educators, the researcher also conducted classroom observations to gather information related to the conditions and facts that occur during the learning process. This information is useful to support the implementation of the use of a chemical bonding module oriented towards problem-based learning, which the researcher had previously developed for use in learning activities. The observation of student characteristics is based on critical thinking abilities, taking into account academic abilities, activeness, and motivation of students toward chemistry lessons. Based on the observations obtained, it is known that students are less able to categorize and understand problems, lack effort in utilizing various references to solve problems, and lack enthusiasm in providing responses and comments during discussions.

To address all existing issues, the researcher utilizes teaching materials in the form of a problem-based learning-oriented chemical bonding module that has been previously developed. This is done to conduct an experimental study to test the effectiveness of the module on students' critical thinking abilities. The use of a problem-based learning model in instructional activities can assist in enhancing students' critical thinking skills, encouraging their active participation in learning, and improving their problem-solving abilities (Adhelacahya *et al.*, 2023; Ismiyati *et al.*, 2019; Nurmahasih & Jumadi, 2023).

The following problem-oriented chemical bond module products are used in research as in the image below

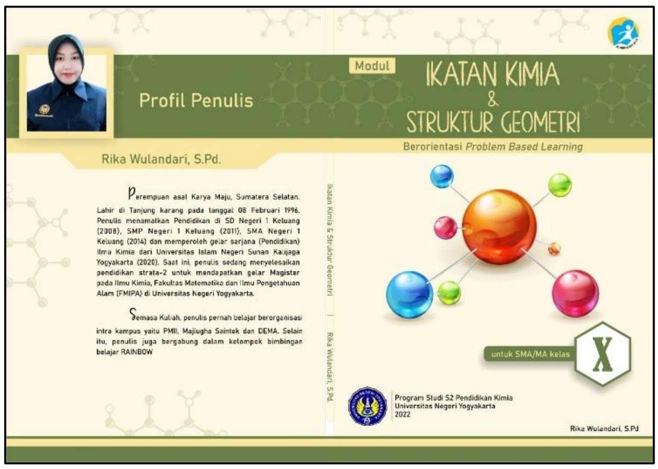

Figure 1. Module cover

The Results of The Data Normality Test for Students' Critical Thinking Abilities.

The critical thinking abilities of students on the topic of chemical bonding were subjected to a normality test using the Shapiro-Wilk and Kolmogorov analyses with IBM SPSS version 25. The significance level used was 5% or 0.05. A summary of the normality test results can be found in Table 2.

Table 2. Test of Normality for Students' Critical Thinking Abilities.

Class	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
Experimental	0.12	36	0.15	0.95	36	0.15
Control	0.11	36	0.20	0.95	36	0.12

Based on the data, it indicates that the normality test results for the critical thinking abilities of students in the experimental and control classes have significance values greater than 0.05. This implies that H0 is accepted, and H1 is rejected. Therefore, it can be concluded that the data for the critical thinking abilities of students in both the experimental and control classes are normally distributed.

The Results of The Homogeneity Test for Students' Critical Thinking Abilities Data

The homogeneity test was conducted using the Levene test in the SPSS program, version 23, with a significance level of 5% or 0.05. A summary of the Levene test results can be seen in Table 3.

Table 3. Test of Homogeneity of Variances for Students' Critical Thinking Abilities.

Levene Statistic	Df 1	Df 2	Sig.
0.25	1	70	0.62

Based on the data, it indicates that the homogeneity test resulted in a Levene test statistic of 0.25 with a significance value of 0.62, which suggests that the critical thinking abilities of the students have homogenous variances because the significance value is greater than 0.05, which means H0 is accepted.

The Results of The Independent Samples T-Test for Students' Critical Thinking Abilities Data

Understanding whether there is a difference in the critical thinking abilities of students who use a problem-based learning-oriented chemical bonding module compared to those who do not use a problem-based learning-oriented chemical bonding module.

Hypothesis testing was conducted using an independent sample t-test with SPSS version 23 and a significance level of 5% or 0.05. The result of the independent sample t-test showed a significance value of 0.01, which is less than 0.05. Therefore, the null hypothesis (H0) is rejected, and the alternative hypothesis (H1) is accepted. Thus, it can be concluded that there is a difference in the critical thinking abilities of students before and after participating in learning using a problem-based learning-oriented chemistry module. The research results using the problem-based learning model, as conducted by other studies with indicators focusing on developing strategies and tactics, also showed a significant difference between the two groups used (Rahmat *et al*., 2020).

The critical thinking abilities of the students were assessed using a test instrument consisting of 18 essay questions. This instrument was employed to identify the differences in the critical thinking abilities of students who used the problem-based learning-oriented chemistry module in the experimental class compared to the critical thinking abilities of students in the control class who did not use the problem-based learning-oriented chemistry module but instead utilized printed books provided by the school. The test instrument was administered at the end of the treatment during the learning activities.

Based on the test results, it is evident that the experimental class performed better than the control class. This indicates a significant difference in the critical thinking abilities of students before and after participating in learning using the problem-based learning-oriented chemistry module. The research findings align with other studies that have implemented similar module-based approaches, showing their effectiveness in enhancing students' critical thinking abilities. Students become more adept at understanding problems deeply, expanding their analytical understanding to find solutions to existing issues (Mujiyati *et al*., 2019). Furthermore, the results are supported by other research indicating that the use of a problem-based learning model with the assistance of Mentimeter media significantly contributes to improving students' critical thinking and collaboration skills (Anggriani *et al*., 2022). Additionally, modules have proven to be effective tools for teachers and students, supporting learning outcomes and enhancing their metacognitive abilities and problem-solving skills (Damayanti & Yohandri, 2022; Ramdoniati *et al*., 2018; Saputri *et al*., 2023).

The results of this research are also supported by other findings stating that modules using problem-based learning have proven effective in supporting materials and assisting learners in improving critical thinking skills (Rubini *et al*., 2019). Furthermore, modules with problem-based learning are also effective in enhancing the creative abilities of learners, demonstrating a moderate level of effectiveness (Selviana *et al*., 2022). Then, the research results of developing trigonometry modules based on problem-based learning prove to be effective. This is evidenced by the module's ability to be used in improving the understanding of concepts for learners classified in the high criteria. Additionally, this model is capable of enhancing academic achievement, leading to improved learning outcomes for learners (Bazuri & Arliani, 2022; Gurses *et al*., 2015; Melawati *et al*., 2022).

The result of The Effect Size, Cohen's-d, is

Understanding the effective contribution provided by problem-based learning-oriented chemical bonding modules to students' critical thinking abilities by examining the effect size. The effect size value was obtained using Cohen's d effect size analysis. The effective contribution provided in the use of problem-based learning-oriented chemical bonding modules to students' critical thinking abilities, based on the results of Cohen's d effect sizes, indicates a value of 0.59.

If we consider the interpretation categories of data based on Cohen's d effect size, the range of 0.20 – 0.80 indicates a moderately effective contribution (Dunst & Hamby, 2012). This supports the research findings indicating that the implementation of problem-based learning modules with authentic assessment provides a high gain in students' critical thinking abilities (Suastra *et al*., 2019; Seruni *et al*., 2020). Furthermore, the implementation of modules using a problem-based learning model is also effective, showing a high effect size (Nurmasyitah *et al*., 2023).

Conclusion

Based on the research results, it can be concluded that problem-based learning-oriented chemical bonding modules are effective in improving students' critical thinking abilities. The independent sample t-test results indicate a difference, showing that the average improvement in critical thinking abilities of students in the experimental class is greater than that in the control class. The use of problem-based learning-oriented chemical bonding modules also contributes to critical thinking abilities with a Cohen's d effect size value of 0.59, indicating a moderate category.

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The authors declare no conflict of interest.

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