

The Effectiveness of Problem-Based Learning (PBL) and Guided Inquiry Models Assisted by Virtual Lab Media on Students' Critical Thinking Skills

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Abstract: This research aims to determine the effectiveness of the PBL (Problem-Based Learning) model and guided inquiry assisted by virtual lab media in enhancing students' critical thinking skills on reaction rate material. The research design used was a Quasi-Experimental Pretest-Posttest Control Group Design. The experimental class used the PBL and guided inquiry models, while the control class was taught using conventional learning models. Both the experimental and control classes used virtual lab media (Crocodile Chemistry). The data analysis techniques used included descriptive analysis, hypothesis testing using one-way ANOVA to determine differences, and the N-Gain test to determine the effectiveness differences of each learning model used. The results showed significant differences in students' critical thinking skills between those who learned using the PBL model, guided inquiry, and conventional methods. The PBL and guided inquiry learning models assisted by virtual lab media were more effective in improving students' critical thinking skills compared to the conventional learning model assisted by virtual lab media. However, the PBL learning model was more effective than the guided inquiry model in enhancing students' critical thinking skills.

Keywords: PBL, Guided Inquiry, Conventional, Critical thinking, and Virtual lab.

INTRODUCTION

Based on the independent curriculum, the goal of teaching chemistry in high school is broader than merely understanding chemistry concepts. One of the main objectives is to develop students' critical thinking skills, which include the ability to analyse, evaluate, and integrate information from various sources. This ability contributes to students' academic success and prepares them to face the increasingly complex challenges of the workforce. This aligns with the demands of modern or 21st-century learning. According to Redhana (2019), some 21st-century skills that must be prepared include critical thinking and problem-solving, creativity and innovation, communication, and collaboration.

Most chemistry materials have concept complexities, requiring students to develop a deep understanding and analytical skills to comprehend and explain these chemical phenomena. Additionally, in learning, students need to develop skills in using the scientific method, including experiment design, data collection, and result interpretation, which also involves critical thinking processes. Some chemistry contents that can train students' critical thinking include: (1) Redox reactions and electrochemistry, understanding redox reactions and electrochemical concepts require critical analysis of electron transfer, electrode potential, and electrochemical cell applications; (2) Chemical equilibrium, understanding chemical equilibrium and Le Chatelier's principle requires critical thinking in analysing condition changes and their impact on the equilibrium position, (3) Reaction rate, identifying factors affecting reaction rates requires critical thinking in assessing the impact of temperature, concentration, surface area, and the use of catalysts on the reaction rate, (4) Stoichiometry and chemical calculations, analysing and solving

stoichiometry calculations require critical thinking in applying mathematical relationships to real chemical situations.

Education in the 21st century demands changes in learning approaches to prepare students to face the increasingly complex demands of the global society. Critical thinking is one of the essential skills in facing the complexities of the modern world (Paul & Elder, 2006; Halpern, 2014). Santrock (2011) explains that critical thinking is reflective and productive thinking that involves evaluating evidence. Critical thinking is part of the effort to gather, interpret, analyze, and evaluate with the goal of drawing provable conclusions (Fristadi & Bharata, 2015). Critical thinking skills help students solve existing problems, such as real-life questions or issues (Sugrah, et al., 2017). Critical thinking can guide students in connecting learning material with everyday life (Kurniati et al., 2019; Satwika, Laksmiwati, & Khoirunnisa, 2018). However, some research results indicate that students' critical thinking abilities (identifying problems, formulating problems, making hypotheses, processing data, and drawing conclusions) still need to be improved (Muharni & Mustami, 2019).

One alternative to improving students' critical thinking skills is using creative and innovative learning strategies or models. Problem-based learning (PBL) and guided inquiry strategies are used to address issues related to students' critical thinking abilities. PBL and guided inquiry are comparable constructivist learning strategies, both linking learning concepts to everyday life involving critical thinking in solving students' problems. Problem-based learning (PBL) is a student-centred learning method that helps students formulate high-level thinking skills, enhance critical thinking abilities (Aidoo, 2016), and construct knowledge as students learn to solve real-world problems structurally through problem-based learning (Sulistiyani, 2022).

Several studies on the success of implementing PBL have proven to increase student achievement, train communication skills, analysis, and collaboration, enhance creative thinking and problem-solving skills, and boost student learning motivation (Overton & Randles, 2015; Gunter & Alpat, 2016; Baran & Sosbirin, 2017; Argaw et al., 2017; Priyani et al., 2019, Amrilizia et al., 2022, Hamid et al, 2022). According to Gulo (2002), the inquiry learning model is a series of learning activities involving students searching and investigating systematically, critically, logically, and analytically so they can formulate their findings. According to research conducted by Vlassi & Karaliota (2013) in Greek high schools, the guided inquiry learning model is more effective than conventional models. Inquiry learning can improve students' learning outcomes, particularly in problem-solving skills, data explanation abilities, and critical thinking in science learning (Chiapetta & Russel, 1982).

The syntax of the problem-based learning model is divided into several phases: (1) orienting students to the problem, (2) organizing students for learning, (3) guiding students' investigations, (4) developing and presenting the work, (5) analyzing and evaluating the problem-solving process. The use of virtual lab media in this learning strategy can be applied in phase 3, guiding students' investigations. Meanwhile, the syntax of the guided inquiry learning strategy is also divided into several phases: (1) identifying the problem, (2) formulating hypotheses, (3) designing experiments, (4) conducting experiments, (5) analysing data, and (6) concluding. In the guided inquiry learning model, virtual lab media can be used in phase 3, the experiment phase.

The most fundamental difference between guided inquiry learning and Problem-Based Learning (PBL) lies in the type of problems and the goals to be achieved. Problems in guided

inquiry learning are closed-ended, meaning the answers to the given problems are definite. The teacher already knows and understands the answers to the issues studied, but these are not directly conveyed to the students. In contrast, the problems in the PBL model are open-ended, with the answers to these problems being uncertain. Both students and teachers can develop possible answers to the problems faced.

In addition to several advantages, PBL and guided inquiry learning models also have some drawbacks. Ayyildiz & Tarhan (2018) stated that activities implementing the PBL model tend to give students a higher proportion of alternative conceptions (misconceptions), concept difficulties, and lack of knowledge. Kumala & Hartatik (2017) also mentioned that inquiry learning has limitations in studying abstract concepts such as energy, electricity, or particles that students cannot visually see.

Virtual lab media is used to address the weaknesses of these learning models. (Salam et al., 2010). The use of virtual laboratories to support chemistry learning can integrate three levels of chemical understanding (submicroscopic, symbolic, and macroscopic), visualisation and simulation processes (Herga et al., 2012). Lai et al. (2022) stated that inquiry-based virtual laboratories enhance students' understanding of scientific concepts. Therefore, combining a PBL or guided inquiry model with the assistance of virtual lab media allows for a more effective learning process. By applying problem-based learning (PBL) and guided inquiry strategies, assisted by virtual lab media, students' critical thinking skills are expected to improve.

METHOD

The research design used a Quasi-Experimental Pretest-Posttest Control Group Design. This design was utilised to determine differences in students' critical thinking abilities between the experimental and control classes. The experimental classes implemented problem-based learning (PBL) and guided inquiry strategies, while the control class implemented a conventional learning model. All three classes used virtual lab media, including experimental and control groups. The experimental design is outlined in Table 1.

Table 1. Design Experiment

group	Pretest	Treatment	posttest
Experiment (X_1)	Y_1	T_1	Y_2
Experiment (X_2)	Y_3	T_2	Y_4
Control (X_3)	Y_5	T_3	Y_6

Information :

X_1 = PBL class

X_2 = guided inquiry class

X_3 = Conventional class

Y_1 & Y_3 = Pretest scores for experimental classes

Y_2 & Y_4 = Posttest scores for experimental classes

Y_5 & Y_6 = Pretest & posttest scores for control class

The population of this study comprised all 11th-grade students at SMA Negeri 1 Bluto. The 11th grade at SMA Negeri 1 Bluto consists of six classes. The sampling technique used in this study was cluster sampling. The classes selected as research samples were XI.E, XI.F, and XI.G of SMA Negeri 1 Bluto, each with 29 students. The research instrument used was a critical thinking ability test in the form of essay questions using Facione's framework indicators. These indicators

include: 1) Interpretation, 2) Analysis, 3) Inference, 4) Evaluation, and 5) Explanation. The data analysis techniques used in this study were descriptive analysis, one-way ANOVA, and the N-Gain test to measure the effectiveness of the learning models.

RESULTS AND DISCUSSION

Validity and Reliability of Instrument

The empirical validity of the critical thinking ability test in the form of 7 essay items can be seen in Table 2, and the item validity can be seen in Table 3.

Table 2. Record of Content Validity Results

No.	Validator	Instrument Think Critical
1	Validator I	94%
2	Vakkidartor II	96%
	Average	95%

Table 3. Validity Empirical Item test the ability to think critically student

No. Question	Aspect	r _{count}	r _{table}	Conclusion
1	Interpretation	0.63	0.36	Valid
2	Interpretation	0.64	0.36	Valid
3	Analysis	0.68	0.36	Valid
4	Analysis	0.59	0.36	Valid
5	Evaluation	0.61	0.36	Valid
6	Inference	0.66	0.36	Valid
7	Explanation	0.56	0.36	Valid

Reliability questions test the ability to think critically student, as can seen in Table 4.

Table 4. Reliability Test Instrument Think Critical

r _{count}	r _{Table (α=0.05)}	Information	Conclusion
0.73	0.70	> 0.70	Reliable

The hypothesis test used was a one-way ANOVA, as the prerequisite tests for normality and homogeneity of data distribution were satisfied. This test was used to determine whether the means of the three populations were the same or different.

Table 5. Anova Test Results Ability Think Critical

z	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1070.552	2	535,276	4,636	0.012
Within Groups	9698.966	84	115,464		
Total	10769.517	86			

Based on Table 7, the calculation results for Fo are as follows: F calculated = 4.636 > F table = 3.11. It can be concluded that the null hypothesis (H0) is rejected. This is also evident from the significance value of the calculation, which is 0.012, meaning it is less than 0.05. The critical thinking abilities of students who learn using the Problem-Based Learning (PBL) model, guided inquiry, and conventional methods differ significantly in chemical reaction rates.

The effectiveness analysis of the PBL, guided inquiry, and conventional learning models assisted by virtual lab media was conducted using the N-Gain test. The gain score can be determined as follows.

$$g = \frac{\text{Posttest} - \text{Pretest}}{\text{Ideal Posttest} - \text{Pretest}} \times 100\%$$

Gain the score Then can interpreted based on classification as follows.

Table 6. Criteria N-Gain Effectiveness

Percentage N-Gain score	Criteria
<40	No effective
40 – 55	Less effective
56 – 75	Enough effective
>76	Effective

(source: Hake, 2002)

N-Gain test results from three learning models can seen in Table 6.

Table 7. Summary of N-Gain Test Results

Aspect	% N-Gain Group / class		
	PBL	Inquiry Guided	Conventional
Think Critical	67.19 %	63.43 %	62.61 %

Students' Critical Thinking Skills in Problem-Based Learning (PBL), Guided Inquiry, and Conventional Models

The research results indicate that there are differences in the critical thinking abilities of students who learn using the PBL model, guided inquiry, and conventional methods. Based on the N-Gain scores, the PBL model is more effective than the guided inquiry and conventional models. The N-Gain scores of students' critical thinking skills in the three classes can be seen in Figure 1.

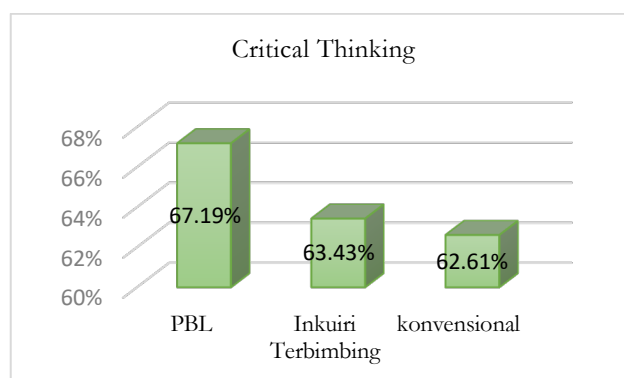


Figure 1. Diagram of Critical Thinking Skills in PBL, Guided Inquiry, and Conventional Models

Based on Figure 1, it can be seen that the percentage value of the N-Gain score for critical thinking skills in the experimental class I, which used the problem-based learning (PBL) model, is higher compared to the N-Gain score for critical thinking skills in the experimental class II, which used the guided inquiry model, and the control class, which used the conventional learning model, has the lowest N-Gain percentage score compared to PBL and guided inquiry. This reality is influenced by several factors that can cause differences in students' critical thinking abilities. This can be observed in the learning activities conducted in the classes using the PBL, guided inquiry, and conventional models.

Formulation of questions (Problem statement)

The ability of students to formulate questions or problem statements was obtained from the student worksheets. In the PBL class, the problem was formulated in phase 1, which is orienting students to the problem. It was observed that most of the questions created in the PBL

class were analytical questions that connected the given problem with the concept to be studied. Examples include: “How does collision theory influence the course of a reaction? and do all collisions cause substances to react?” Meanwhile, In the guided inquiry class, the problem was formulated in phase 1, focusing students on the problem. Most of the questions or problem statements created in the guided inquiry class were still related to the given problem without directly linking it to the studied concept. Examples include: “What is collision theory and how is it related to the reaction rate? Give examples of collisions in everyday life.” In the conventional class, questions were formulated at the beginning of the learning activity after the teacher's introduction. An example of a question given by a student in the conventional class is: “What is meant by effective collision in the reaction rate?” Evidence of the problem statements from the PBL, guided inquiry, and conventional classes is provided in Figure 2.

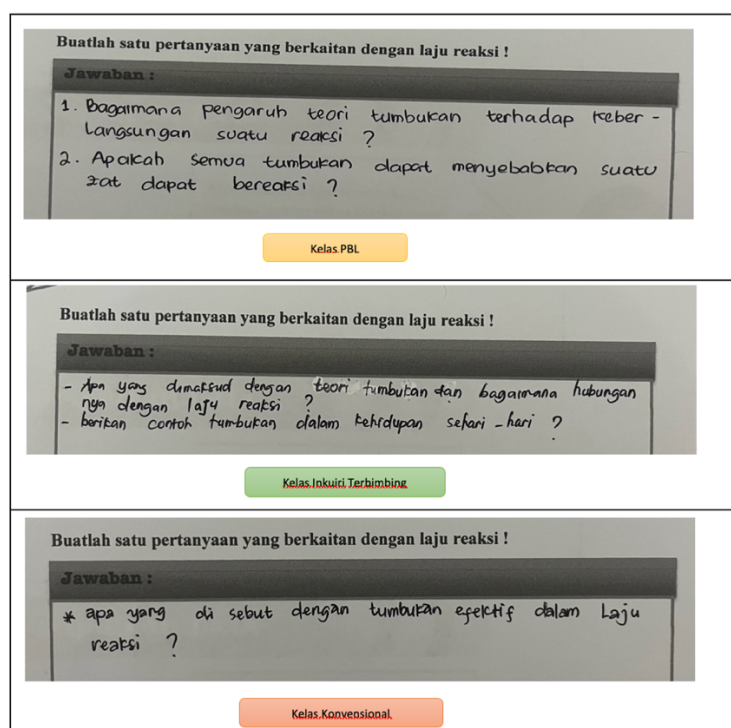


Figure 2. Problem Statements in PBL, Guided Inquiry, and Conventional Classes

Based on Figure 2, it is evident that to answer the problem statements given in the PBL class, students need to apply the concept of collision theory in a more complex context, solve problems, and make connections between concepts. This involves higher-level critical thinking skills. In the guided inquiry class, the questions aim to provide definitions and examples of collisions in everyday life. This involves a basic understanding of concepts and the ability to relate them to real-life situations, although more complex than the questions in the PBL class. Meanwhile, questions in the conventional class appear simpler, requiring only a basic understanding of collisions. Although these questions are also important, their complexity and depth level are lower than those in the PBL and guided inquiry classes. Therefore, the PBL class likely focuses more on critical thinking skills because it involves solving more complex problems and applying concepts to deeper situations.

The Depth of Questions Posed (Critical Thinking Skills)

In addition to the ability to analyze and formulate problem statements, evidence of the effectiveness of the PBL class over the guided inquiry and conventional classes can be seen from the depth of questions posed by students. Data on the questions posed by students were obtained from the teachers' daily journals. Below are some examples of questions from students in the PBL class, guided inquiry class, and conventional class, presented in Figure 3.

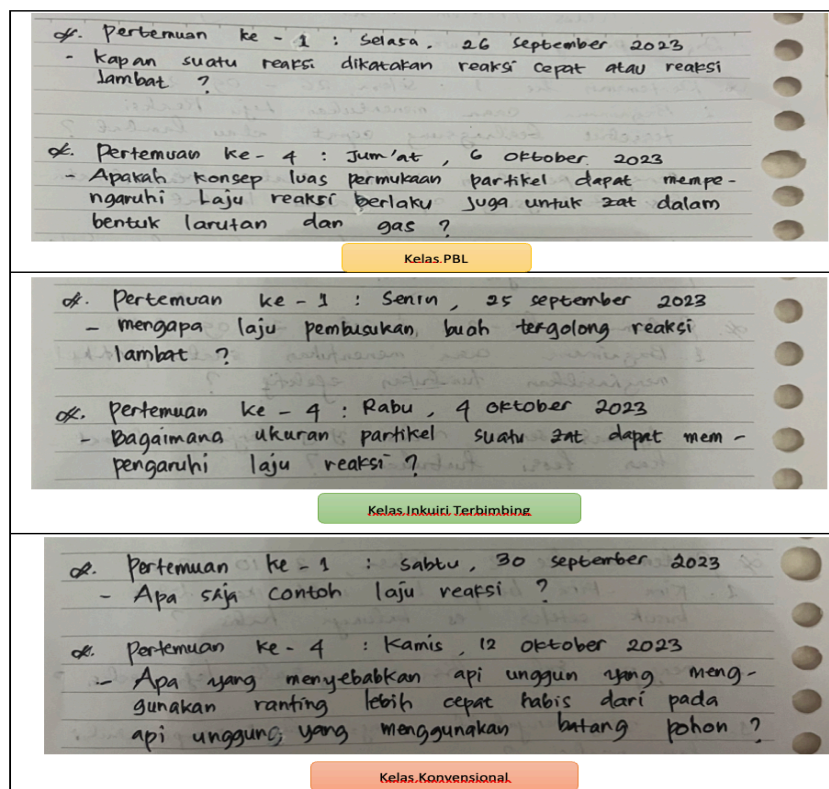


Figure 3. Example of Student Questions

Based on Figure 3, it can be seen that in the PBL class, the questions posed become more focused in touching upon the material concepts. This is evident from the questions in the initial meetings where students were merely asking about the given problem, such as: "When is a reaction considered fast or slow?" These questions are still relatively basic, but by the fourth meeting, deeper questions about chemical concepts emerged. "Can the concept of surface area of particles affect reaction rate also apply to substances in the form of solutions and gases? How do you explain the surface area of molecules in solutions and gases?"

These questions demonstrate the development of students' thinking. Students are asked about the factors affecting reaction rates in general and explore the concept of the surface area of particles and how it applies to substances in the form of solutions and gases. This indicates that students have deepened their understanding of chemical concepts and are trying to relate them to more complex situations. It also shows that students have begun to formulate questions critically, asking about concepts and attempting to apply them to more specific chemical contexts. The questions in the guided inquiry class are still limited to basic concepts. The presence of more comprehensive guidance from the teacher results in students less frequently asking their critical questions. From the initial meetings, students more often ask about the given problem, such as: "Why is the rate of fruit decay classified as slow?" By the fourth meeting, questions are more

directed towards basic chemical concepts. They are explorative, and they can help students build a basic understanding of concepts related to reaction rates and influencing factors. However, these questions are not as critical as those in the PBL class, which requires a more complex understanding. For example: "How can the particle size of a substance affect the reaction rate?"

Meanwhile, the questions posed by students in the conventional class usually only consist of basic questions about what has been explained by the teacher. For example: "What are examples of reaction rates, and what causes a bonfire using branches to burn out faster than a fire from a tree trunk?" From the first to the fifth meeting, there was a noticeable development in the questions in the PBL class, with some questions becoming more focused and deeper in their chemical concepts. Whereas the questions posed by students in the guided inquiry class still revolve around basic concepts. Different from PBL and guided inquiry classes, direct instruction by the teacher in the conventional class leads to students rarely asking questions. The questions asked are limited to simple questions when prompted by the teacher.

Drawing conclusions

Withdrawal data conclusion student obtained from sheet Work student Good PBL class, inquiry-guided, nor class conventional ones can be seen in Figure 4.

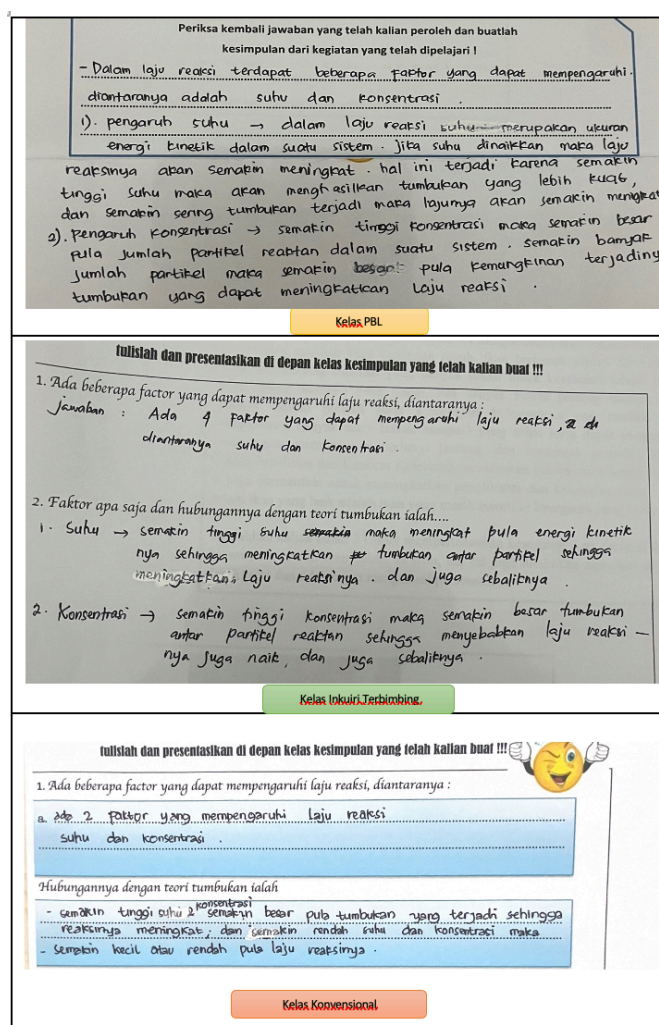


Figure 4. Student Conclusion Drawing in PBL and Guided Inquiry Classes

Based on Figure 4, it is evident that, in conclusion, the worksheets used in the guided inquiry class are directed towards providing conclusions on basic concepts. Students follow the steps outlined in the worksheet to conclude, enabling guided inquiry students to make conclusions easily. The conclusions made by each group are relatively similar according to the problem formulation and hypotheses made earlier. In the PBL class, students determine their own conclusions based on the questions or problem formulations they have previously made. This requires higher-order thinking skills compared to the guided inquiry class. To conclude the PBL class, students need to adapt to the problem formulation, resulting in conclusions that may vary between groups and tend to be more complex. Meanwhile, in the conventional class, students draw conclusions with the teacher, so the conclusions align with the teacher's preferences and lead towards the learning objectives being pursued.

Ability to analyse problems

The differences in the effectiveness of the PBL, guided inquiry, and conventional learning models are further observed from the observer notes during the learning activities. In the PBL class, observers note that students find it easier to understand the given problems and are able to analyze their relationship with chemical concepts. In the guided inquiry class, students still need help to independently connect the given problems with the chemical concepts being studied. Teacher guidance remains a significant factor in assisting students in their analytical activities. Meanwhile, in the conventional class, observers note that students' ability to analyse problems has yet to be evident, as the lecture method restricts students' analytical activities. The teacher directly transfers learning, so students rarely engage in analytical activities. This can be seen from the observer notes in Figure 5.

<p>Catatan Observer: Jumat, 29 September 2023</p> <ol style="list-style-type: none"> Sebagian besar siswa sudah mampu memahami masalah yang di berikan mampu menghubungkan masalah yang diberikan dengan konsep kimia yang diharapkan masih sedikit membutuhkan bimbingan guru. <p style="text-align: center;">Kelas PBL</p>
<p>Catatan Observer: Rabu, 27 September 2023</p> <ol style="list-style-type: none"> Sebagian besar siswa masih bergantung terhadap bimbingan guru dalam melakukan analisis membutuhkan bantuan guru dalam menghubungkan masalah terhadap konsep kimianya <p style="text-align: center;">Kelas Inkuiri Terbimbing</p>
<p>Catatan Observer: Kamis, 5 Oktober 2023</p> <ol style="list-style-type: none"> Pembelajaran berpusat pada guru Siswa jarang melakukan analisis karena guru menjelaskan secara langsung konsep yang dipelajari <p style="text-align: center;">Kelas Konvensional</p>

Figure 5. Observer Notes for PBL, Guided Inquiry, and Conventional Classes

Based on Figure 5, it is evident that the student's ability in PBL classes to analyze problems is superior to that of guided inquiry and conventional classes. However, in conducting analyses in PBL classes, students still require some guidance from the teacher, as this type of learning activity is still relatively new and unfamiliar to them, leading them to ask the teacher questions often when analyzing problems during the learning activities. In guided inquiry classes, students receive full guidance during the learning activities, so they do not face much difficulty in analyzing problems even though the learning model used is still relatively new. The presence of teacher guidance causes students to rely more on the directions given by the teacher, resulting in them tending to involve less of their own thinking abilities. In contrast, in the control classes of both experiments, students do not engage in problem analysis activities; instead, the teacher directly presents the concepts to be taught without providing problems first, thereby not involving the students' thinking abilities in analyzing a problem.

Use of Virtual Lab Media

The effectiveness of the virtual lab media used (Crocodile Chemistry) in enhancing critical thinking skills is seen from the students' ability to answer questions or quizzes given by the teacher from the first to the fifth meeting. The use of virtual lab media in PBL, guided inquiry, and conventional classes is carried out in the third and fourth meetings for material on factors influencing reaction rates. The summary of students' ability to answer questions or quizzes is presented in Figure 6.

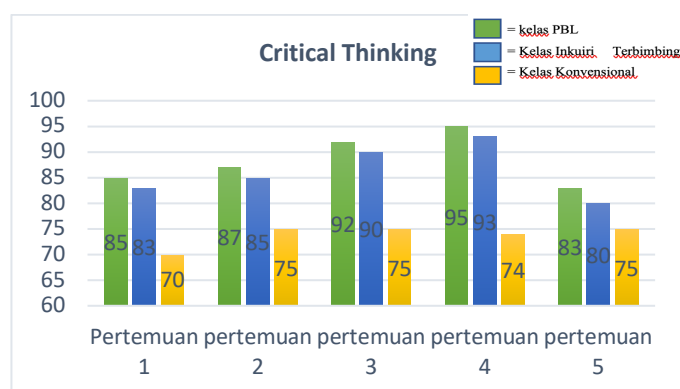


Figure 6. Average Quiz Scores of PBL, Guided Inquiry, and Conventional Classes

Based on Figure 6, it can be seen that from the five conducted meetings, the third and fourth meetings show a significant improvement both in PBL and guided inquiry classes but not in the conventional class. The highest increase in critical thinking skills occurred in the PBL class. Thus, using virtual lab media has an impact on enhancing the effectiveness of the learning model used. Learning with virtual laboratories makes learners more independent and can improve their thinking skills and the ability to communicate their ideas. This is consistent with the research conducted by Hastuti et al. (2016), which states that PBL models assisted by virtual media affect students' mastery of physics concepts. Furthermore, Kumala & Hartatik (2017) also stated that inquiry-based learning assisted by virtual laboratory simulation can improve thinking skills. Inquiry-based learning models assisted by virtual laboratories can be an alternative learning model that can

be applied in education because they can improve students' thinking abilities (Kusdiastuti et al., 2016).

Problem-based learning (PBL) results in better conceptual understanding and demonstrates consistency in developing students' critical thinking skills. This development can be observed from the first to the fifth meeting, where students gradually acquire skills in applying critical thinking to chemical contexts. Students start with more general questions or statements at the beginning of the learning process. However, over time, students begin to sharpen their abilities to formulate more detailed and specific problems. This reflects the development of students' abilities in identifying the essence of a problem and formulating more focused questions. Additionally, in making conclusions, students not only conclude but also can relate them back to the chemistry concepts they have learned. This indicates their ability to understand information separately and see relationships and connections between various concepts in chemistry.

From the initial to the fifth meeting, students improve their ability to link critical thinking with more complex chemistry concepts. Students can relate their understanding of problems to deeper chemical theories, depicting a more comprehensive understanding of the chemistry context being studied. Thus, PBL can provide a platform for students to develop and enhance their critical thinking skills over time. This development reflects the positive outcomes of a problem-solving and concept application-focused learning approach, from problem formulation to analysis, making conclusions, and linking them to chemistry concepts.

Using real and complex problems, often involving open-ended questions in PBL, encourages students to think about various solutions and evaluate various information independently or in groups. Solving real problems requires deep and strategic critical thinking, naturally reinforced in the PBL environment. This causes PBL syntax to be more capable of providing a strong framework for developing students' critical thinking skills. Additionally, the use of virtual lab media (Crocodile Chemistry) also contributes positively to PBL. This is because students, in exploring concept discoveries, find the existence of virtual media very helpful in providing a more comprehensive and in-depth understanding of concepts.

These results align with the research conducted by Rahmawati et al. (2019), where the problem-based learning model is better at improving students' critical thinking skills than the guided inquiry model in colloid material chemistry learning. Puspita et al. (2018) also stated that there are differences in students' critical thinking skills using the guided inquiry and PBL models in biology learning, with PBL enhancing students' critical thinking skills more than the guided inquiry model. Furthermore, it is also consistent with the research conducted by Diani et al. (2016) and Harpina (2018), where the problem-based learning (PBL) model has a better influence than the guided inquiry learning model on students' critical thinking skills.

CONCLUSIONS

The research results indicate a significant difference in the average critical thinking ability scores of Grade XI students at SMA Negeri 1 Bluto who learn using Problem-Based Learning (PBL), Guided Inquiry, and conventional models assisted by virtual lab media. The PBL and Guided Inquiry learning models assisted by virtual lab media enhance students' critical thinking skills more effectively than the conventional learning model. However, the PBL learning model is

more effective than the Guided Inquiry learning model. This can be seen from several aspects of students' skills in learning activities, such as formulating problems, posing analytical questions, drawing conclusions, and conducting analysis to discover learning concepts.

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