IJCER
p-ISSN 2549-9947 | e-ISSN 2614-1426
doi: 10.20885/ijcer.vol9.iss2.art9
p-ISSN 2549-9947
e-ISSN 2614-1426

The Effect of PjBL-Based QODE Model on Critical Thinking and Learning Achievement of Buffer Solution Topic

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Received: August 19, 2025; Accepted: September 24, 2025; Published: October 25, 2025

ABSTRACT: Chemical misconceptions often occur when students need to understand the initial concept. This misconception has an impact on students' ability to understand the material and results in a decrease in students' learning achievement. Students' concept understanding can significantly improve by applying practical learning approaches, models, and strategies. This study aims to determine how applying the QODE learning model based on PjBL improves grade XI students' learning achievement and critical thinking skills on Buffer Solution topic. This type of research is a quasi-experiment with a nonequivalent control group pretest–posttest design. This study's subjects were control class for cooperative learning group investigation learning model and experimental class for PjBL-based QODE learning model at SMA Negeri 1 Sleman. Two intact classes (n = 36 per group) completed a two-tier multiple-choice critical-thinking test and an achievement test before and after a 3-session intervention. The research data were analyzed using the Wilcoxon and the N-gain tests. The Wilcoxon test result shows that both learning models used in experimental and control groups influence student learning achievement and critical thinking with the value of Sig. <0.05. N-Gain test shows that the experimental group experienced an increase of 0.74 for critical thinking skills and 0.78 for student learning achievement which in high category, while the control group experienced an increase of 0.38 for critical thinking skills and 0.73 for student learning achievement which in low and high category. These findings indicate that the QODE learning model based on PjBL contributes to improving students' critical thinking.
Keywords: QODE, PjBL, critical thinking, learning achievement, buffer solution

INTRODUCTION

The Merdeka Curriculum (*Kurikulum Merdeka*) or new paradigm curriculum is a form of renewal of the education system in Indonesia in the 21st century. Within the Merdeka Curriculum, Project-Based Learning (PjBL) and collaborative learning are emphasized to develop student profiles through authentic learning experiences [1]. This policy creates opportunities for students to engage deeply and critically with science, enabling them to resolve misconceptions through guided inquiry [2]. In addition, the independent learning process provides several meanings, including freedom of thought, innovation, learning independently, and creativity [3]. According to the Ministry of Education of the Republic of Indonesia, the characteristics of an independent curriculum are focusing on essential material, character and soft skills development, and flexibility for an educator [4]. Apart from students, the role of educators is no less important in realizing independent learning by innovating teaching and learning activities in the classroom.

A learning model is a strategic, research-informed design that organises teacher–student activities and the supporting systems of instruction, including assessment methods [5]. Such models guide teachers in planning steps and resources, help deliver content efficiently, and support students in developing ideas, skills, information, and ways of thinking toward learning goals [6]. The choice of approaches, models, and strategies significantly affects student achievement [7]. The emphasis on Project-Based Learning and collaborative learning in the Merdeka Curriculum is strengthened by deep

learning strategies that encourage inquiry-based exploration, reflective thinking, and concept integration that are essential components for building deep and meaningful understanding in science learning. Additionally, effective learning model is selected by adjusting to students' level of development and learning principles (such as motivation, interest, feedback/reinforcement, student activeness, and learning speed) [8]. Choosing an inappropriate learning model can result in a learning process that is not optimal [9]. It can cause boredom and a lack of understanding of the material and create a monotonous learning process [10].

However, most educators in Indonesia still use the lecture method learning model. The lecture method has been implemented since ancient times, is considered easier to implement, and does not require much equipment [11]. The lecture method is called the activity of conveying information with words. The main activity of students in the lecture method is to listen carefully and record the important points the educator conveys [12]. According to Sulandari [13], the lecture method has advantages, namely encouraging students to focus and be serious, making it easier for educators to control the class, making it easier for educators to convey material widely, can be followed by a large number of students, and builds a close emotional relationship between students and educators. However, the lecture method also has disadvantages, namely forming students to be passive, boring learning, learning by force, difficulty in understanding the material for students with visual learning styles, and lack of control over evaluation because there is no clear achievement point [13]. This is in sharp contrast to the objectives of the Merdeka Curriculum, which prioritizes student-centered learning with the hope of fostering a high level of independent learning awareness.

One way to improve the quality of learning is using the QODE model. The implementation of the QODE learning model (Questioning, Organising, Doing, and Evaluating) has 4 stages. Questioning activates prior knowledge and surfaces misconceptions, generating productive cognitive conflict; Organising engages teams in planning procedures, variables, and criteria, fostering metacognitive control; Doing links predictions to observations through hands-on investigation with immediate feedback; and Evaluating consolidates understanding through reflection and Claim–Evidence–Reasoning presentations. Studies in science classrooms report stepwise gains across QODE cycles [14, 15]. In addition, previous research by Rizkia, regarding the effectiveness of the QODE Learning Model and Discovery Learning in junior high school students in science content shows that the t-test value of QODE > Discovery Learning is 2.138 > 2.128, so it can be concluded that the QODE learning model is more effective than Discovery Learning in improving critical thinking in science lessons [16]. Although previous studies have demonstrated the effectiveness of PjBL in general science education at the junior high school level, the application of PjBL to complex science topics at the senior high school level remains under-explored. This study aims to fill this gap by evaluating the impact of the QODE learning model based on PjBL on students' critical thinking skills and achievement in mastering the concept of buffer solutions. Because The QODE learning model is an effective learning model used in science learning [17].

The PjBL learning model is designed for a complex event, so students must understand, investigate processes, and develop project formation as a learning method [18]. This learning model has great potential for students' thinking processes, especially critical thinking skills [19]. This project-based learning can provide opportunities for students to create a product based on problems found in everyday life [20]. The advantages of PjBL are that it can improve problem-solving, increase motivation, improve collaboration skills, and manage references [21]. Based on research conducted by Sastrika [22], the PjBL learning model can improve students' critical thinking skills and concept understanding with a comparison of conventional learning models. In addition, research conducted by Zahro [23] showed that the PjBL model could influence students' critical thinking skills by 44.89%. For buffer solutions, this pairing fits well: QODE provides the thinking steps (conflict, planning, practice, reflection), and PjBL provides a real context and team work. Together, they are expected to raise critical thinking and achievement more than lecture-based teaching.

Lecture-only instruction is ill-suited to chemistry, which depends on process-oriented reasoning and connected concepts. Passive learning, which only makes students recipients of information, causes them to lose their initiative and motivation to learn [24]. This reduces students' awareness of the need to learn independently, which also has an impact on their comprehension and critical thinking skills. Therefore, process-oriented learning that engages prediction, observation, and explanation is needed to deepen student`s understanding. Selection of inappropriate methods can result in misconceptions due to a lack of understanding of students. Chemical misconceptions often occur when chemistry has interrelated concepts, so if the initial concept is wrong, it will affect the ability of students to master the

material [25], including buffer solution topic that requires a strong understanding of the concept. The concepts in buffer topic are complex, so many students have difficulty understanding the process [26]. According to research conducted by Purnama, et al., the difficulties include 56.85% struggling with pH/pOH, 93.10% with the effect of small acid/base additions, and 13.7% with identifying buffer systems. These problems are not solved by memorising formulas; students need evidence-based reasoning and other critical-thinking practices [27]. Additionally, the results of research conducted by Miranda & Ginting, the percentage of misunderstanding is 41%, conceptual misunderstanding is 32%, and conceptual understanding is 27%. The misunderstandings that occurred were categorized as moderate. The profile of misunderstandings for each sub-topic of buffer solutions is as follows: definition and properties of buffer solutions 37.6%, components of buffer solutions 42.5%, calculation of the pH value of buffer solutions 44%, and the role of buffer solutions for living things 40.6%. The sub-material with the highest level of misunderstanding was the calculation of the pH value of buffer solutions (44%). The sub-material with the lowest level of misunderstanding was the definition and properties of buffer solutions (37.6%) [28].

Based on that statement, a strategy is needed to improve student's critical thinking and learning achievement through an appropriate learning model. One of the learning models that can be used to improve learning achievement and critical thinking skills is the PjBL-based QODE learning model. The QODE learning model has been used to teach junior high school students and improve student learning outcomes. However, it has not been widely used to improve student learning achievement and critical thinking skills in high school students, even though the learning model has aspects likely to improve critical thinking and student learning achievement. Therefore, researchers are interested in researching the effect of the PjBL-based QODE learning model on improving learning achievement and critical thinking skills of grade XI, even semester students, on Buffer solution topic.

RESEARCH METHODS

Research Type and Design

This type of research is quasi-experimental research. Quasi-experimental research is where researchers control as many variables as possible from the occurring conditions [29]. This type of research does not use the randomization of control or experimental groups [30]. The design used in this study was a nonequivalent control group pretest–posttest. The research design compared the control group and the experimental group. Both groups took a pre-test to determine the initial condition of a group and to see the difference between the control and experimental groups [31]. The design of the nonequivalent control group pretest–posttest can be seen in Table 1.

TABLE 1. Nonequivalent control grup pretest–posttest design

Group	Pretest	Treatment	Posttest
Control	O1	X1	O2
Experiment	O1	X2	O2

Description:
O1: Pre-test (Two Tier Multiple Choice Question and Questionnaire)
O2: Post-test (Two Tier Multiple Choice Question and Questionnaire)
X1: Treatment using Cooperative Learning Group Investigation learning model
X2: Treatment using PjBL-based QODE learning model

Research Subject

This research was conducted at SMA Negeri 1 Sleman. The population in this study was students of class XI of Science in the 2022/2023 school year. Sampling in this study used purposive sampling. Both classes were selected based on the similarity of their previous scores, and both classes were taught by the same teacher so that they had the same learning experiences and styles. The first class is XI Science 1, with as many as 36 students in the control group. The second class is XI Science 2, with as many as 36 students in the experimental group.

Research Instrument

The critical thinking skills assessment instrument was given twice during the pre-test and post-test to see the difference in results before and after treatment using a two-tier multiple choice instrument. The test questions prepared were 12 multiple-choice questions and 12 reasons. Using a multiple choice instrument, the instrument for assessing students' learning achievement was given twice, namely during

the pre-test and post-test, to see the difference in results before and after treatment. The test questions used totalled 12 multiple-choice questions. The research instrument has been tested for validation and reliability by students who have received buffer solution topic, as many as 30 students. Before used, the instrument was tested on 35 12th grade students at SMA Negeri 1 Sleman because these students had already learned about buffer solutions in 11th grade. The validity of the instrument was tested using a R-table test with a df (degree of freedom) value of N-2 = 35-2 = 33, where N is the number of students who completed the 20 initial questions before the validity and reliability tests, so the R-table used was 0.344. If the R-count was greater than 0.344, the question was declared valid. Furthermore, the reliability test was conducted by looking at the Cronbach's Alpha value. If the Cronbach's Alpha value is > 0.60, the instrument is declared reliable.

Data Analysis Technique

The normality test was conducted using the Kolmogorov-Smirnov analysis and the homogeneity test using Levene Test. The hypothesis in this study was tested using a non-parametric static test, namely the Wilcoxon Test. All tests were conducted using the statistical analysis. The effectiveness of the learning model used in this study can be seen by calculating the N-Gain value. The data analysis technique used is descriptive. This analysis is used to see how the effectiveness of the learning model is based on the level of usefulness and its implementation. The N-Gain value was obtained through statistical analysis. The criteria of the N-Gain value can be seen in Table 2. Then, see the effectiveness interpretation category based on the N-Gain value in Table 3.

TABLE 2. N-Gain Score Criteria

N-Gain Score	Criteria	N-Gain Score
Gain > 0.7	High	Gain > 0.7
0.7 >= gain >= 0.3	Middle	0.7 >= gain >= 0.3
Gain <= 0.3	Low	Gain <= 0.3

TABLE 3. N-Gain Effectiveness Interpretation Category

Presentase (%)	Interpreation
< 40	Not Effective
40-55	Less Effective
56-75	Moderately Effective
<75	Effective

RESULT AND DISCUSSION

The focus of this study was to determine the effect of the PjBL-based QODE learning model on improving learning achievement and critical thinking skills of class XI students on buffer solution topic. The results of this study are in the form of test score data of experimental group students before and after being given to follow the learning of buffer solution topic with the PjBL-based QODE learning model. The test instrument given to students consists of indicators of critical thinking and student learning achievement.

This study measured students' learning achievement by comparing their initial test scores (pre-test) to their final test scores (post-test). The data were analyzed using descriptive analysis techniques, which are presented in Table 4.

TABLE 4. Descriptive Statistical Results of Learners' Learning Achievement

No	Descriptive Measures	Experiment Group	
		Pre-Test	Post Test
1	Average	27.89	84.31
2	Standard deviation	13.540	21.892
3	Maximum score	75	100
4	Minimum score	8	25
5	Variance	183.339	479.281

Based on the results of the descriptive statistics above, it can be seen that the average pre-test score of 27.89 is far below the Minimum Completeness Criteria (*Kriteria Ketuntasan Minimal*/KKM). This result shows the low learning achievement of students before being given buffer solution learning with the PjBL-based QODE learning model. Then, there was an increase in the post-test value to

84.31,above the Minimum Completeness Criteria (*Kriteria Ketuntasan Minimal*/KKM), explaining that there is an increase in students' learning achievement after being given material with PjBL-based QODE.

Statistics Test Results

Critical Thinking Ability

Testing the effectiveness of the PjBL-based QODE learning model on students' critical thinking skills begins with a prerequisite test. Data analysis prerequisite tests are normality and homogeneity tests. The results of the two tests will be used to determine whether the data analysis uses parametric or non-parametric statistical tests [32]. Normality tests can be done in several ways, such as by looking at sig. Kolmogorov-Smirnov for data with more than 30 respondents and looking at sig. Shapiro-Wilk for data of less than 30 respondents [33]. This study uses Kolmogorov-Smirnov analysis because the number of students is more than 30 respondents. The following are the results of the Kolmogorov-Smirnov normality test presented in Table 5.

TABLE 5. Normality Test Results of Critical Thinking Ability Data

Data	Statistic	Sig.	Description
Experiment Group	0.256	0.000	not normal
Control Group	0.191	0.003	not normal

According to Pratama [34], the Kolmogorov-Smirnov normality test decision-making is if the significance value is> 0.05, then the data is declared normally distributed, and if the significance value is <0.05, then the data is declared abnormally distributed. The data above shows that the significance value of the experimental and control groups is <0.05, so it can be concluded that the group data tested is not normally distributed.

Then, the homogeneity test is carried out; using the Levene Test [35]. This study used the Levene homogeneity test because, in the normality test, the research data was declared not normally distributed, while in the Levene homogeneity test, the data used did not have to be normally distributed [36]. The following are the results of the Levene's homogeneity test presented in Table 6.

TABLE 6. Homogeneity Test Results of Critical Thinking Ability Data

Levene Statistic	Sig.	Description
0.558	0.458	Homogen

According toSuryani [37], the basis for deciding on Levene's homogeneity test is if the significance value >0.05; then the data is declared homogeneous. If the significance value <0.05, then the data is declared inhomogeneous. The results of the calculation above show a significance value of 0.458 > 0.05, so the data is declared homogeneous. The conclusion for the data analysis requirements test in this study is that the data is not normal and homogeneous. So, the test can continue with the hypothesis test. Because the results of the statistical test of students' critical thinking skills are not normally distributed and homogeneous, the hypothesis test cannot use parametric tests but uses non-parametric tests. The non-parametric test used is the Wilcoxon signed ranks test because the data to be tested is paired between the pre-test and post-test. The results of hypothesis testing using the Wilcoxon signed ranks test are presented in Table 7.

TABLE 7. Wilcoxon Signed Ranks Test

	Experiment Group	Control Group
Z	-5.201	-4.997
Asymp. Sig. (2-tailed)	0.000	0.000

Based on the results above, it can be seen that the Asymp. Sig. (2-tailed) both the experimental group and control group are 0.000. The conclusion is if the value of Asymp. Sig. <0.05, then there is the effect of applying the QODE learning model based on PjBL on the critical thinking skills of students in the experimental group and the control group [38].

Student Learning Achievement

Testing the effectiveness of the PjBL-based QODE learning model on learning achievement begins with a prerequisite test, namely normality and homogeneity tests. This study used Kolmogorov-Smirnov analysis in the normality test because the number of students was more than 30 respondents. The following are the results of the Kolmogorov-Smirnov normality test presented in Table 8.

Based on the research data, the significance value in the experimental group is 0.000 <0.05, and in the control group is 0.000 <0.05. Decision-making is that the data is declared normally distributed if the significance value is > 0.05. So, both data show that the data is not normally distributed in the experimental and control groups. Then, the homogeneity test was carried out using the Levene test. The following are the results of the Levene homogeneity test presented in Table 9.

TABLE 8. Normality Test Result of Student Learning Achievement Data

Data	Statistic	Sig.	Description
Experiment Group	0.294	0.000	not normal
Control Group	0.316	0.000	not normal

TABEL 9. Homogenity Test Results of Student Learning Achievement Data

Levene Statistic	Sig.	Description
0.098	0.755	homogen

Based on the research data above, the significance value is 0.755> 0.05. The decision-making requirement is that the data be declared homogeneous if the significance value is> 0.05. So, the questionnaire data in this study is homogeneous. Then, the next test is the hypothesis test. The results of students' learning achievement do not meet the requirements for parametric tests; namely, the data used are interval or ratio and normally distributed, while in the research results, the data are homogeneous but not normally distributed, so a non-parametric test is used. The non-parametric test used is the Wilcoxon signed ranks test because the data to be tested is paired between the pre-test and post-test. The results of hypothesis testing using the Wilcoxon signed ranks test are presented in Table 10.

TABLE 10. Wilcoxon Signed Ranks Test

	Experiment Group	Control Group
Z	-5.133	-4.711
Asymp. Sig. (2-tailed)	0.000	0.000

The results show that the significance value in the control group is 0.000 < 0.05, and in the experimental group is 0.000 < 0.05. The decision-making requirement is the significance value <0.05, then there is the effect of applying the QODE learning model based on PjBL on the critical thinking skills of students in the experimental group and the control group. Therefore, data processing was continued with the N-Gain test to describe the level of improvement in critical thinking skills and student learning achievement in each of the learning models that had been implemented.

Effectiveness of Learning Model Implementation

Critical Thinking Ability

The effectiveness of the learning model used to develop critical thinking skills can be seen from the calculation of the N-Gain value, which Is presented in Table 11.

TABLE 11. N-Gain Result of Critical Thinking Ability

Group	Pre-test Average	Post-test Average	Gain Score	Percentage
Experiment	20.63	79.74	0.74	74%
Control	25.26	78.38	0.38	38%

Based on the table, if seen in the experimental group, the N-Gain value is 0.74. Based on the N-Gain Score Criteria Table, the N-Gain value obtained is included in the good criteria. When viewed from the table of interpretation categories of gain effectiveness based on percentage, the acquisition of N-Gain of 74% is included in the Moderately Effective category. Meanwhile, the control group N-Gain value of 0.38 is included in the low category. Based on the N-Gain Score Criteria Table, the N-Gain value obtained is included in the medium criteria. When viewed from the table of interpretation categories of gain effectiveness based on percentage, the acquisition of N-Gain of 38% is included in the Ineffective category. Based on N-Gain result the PjBL-based QODE learning model is moderately effective in improving students' critical thinking skills. On the other hand, the N-Gain test for Group Investigation learning model not effective to improving students' critical thinking skills.

Student Learning Achievement

The effectiveness of the learning model's application to students' learning achievement can be seen from the calculation of the N-Gain value, which Is presented in Table 12.

TABLE 12. N-Gain Result of Student Learning Achievement

Group	Pre-test Average	Post-test Average	Gain Score	Percentage
Experiment	27.89	84.31	0.78	78%
Control	34.03	82.18	0.73	73%

Based on the table, if seen in the experimental group, the N-Gain value is 0.78. Based on the N-Gain Score Criteria Table, the N-Gain value obtained is included in the high criteria. When viewed from the category table of interpretation of the gain effectiveness based on percentage, the acquisition of N-Gain of 78% is included in the Effective category. Meanwhile, the control group N-Gain value is 0.73. Based on the N-Gain Score Criteria Table, the N-Gain value obtained is included in the medium criteria. When viewed from the category table of interpretation of the effectiveness of applied gain based on percentage, the acquisition of an N-Gain of 73% is included in the Moderately Effective category. Based on the N-Gain test the result, PjBL-based QODE learning model can be used effectively and for Group Investigation learning model can be used moderately effective to improve students' learning achievement.

Based on the hypothesis analysis data up to the N-gain test above, students in the experimental group show a better increase in value than the control group. In addition, during the learning process, the researcher also observed students' attitudes and responses. Researchers conducted learning by applying the steps of the PjBL-based QODE learning model. So, it can be concluded that the PjBL-based QODE learning model can effectively improve students' critical thinking skills and learning outcomes on buffer solution topic.

According to research conducted by Usman [39] on combining two learning models, namely cooperative script and reciprocal teaching, this can encourage students to express their opinions, thoughts, and ideas in order to develop their creative thinking skills. Based on the result, integrate the QODE learning model with the PjBL learning model to implement learning using QODE based on PjBL can also increase on critical thinking and learning achievement because in this research integrate two different learning models aim to increasing their effectiveness.The syntax of the QODE learning model is questioning, organising, doing, and evaluating where in each syntax, the researcher provides direction in doing a project in the form of a video of the role of buffer solutions in everyday life in the fields of cosmetics, biochemistry, pharmacy, and the food industry. At the first meeting, the researcher started with questioning and organising syntax; the researcher gave directions to form groups and gave an overview related to the project assignment. At the end of the meeting, the researcher opened a discussion about the project assignment given.

Then, at the second meeting, still with the same syntax, namely questioning and organising, the researcher presents a video and a problem in a PowerPoint; the problem presented by the researcher raises students' curiosity about buffer solutions, so students ask questions and form discussions. Learners discuss the topics of buffer solution, including the definition of buffer solution, characteristics of buffer solution, properties of buffer solution, components of buffer solution (acid and base), working principle of buffer solution (acid and base), determining pH, and the role of buffer solution. The researcher acted as a facilitator who guided the discussion and recorded the students' activeness. In addition, the researcher also opened a discussion session and delivered the progress of the final project.

In the third meeting, researchers continued with the syntax of doing and evaluating; at this meeting, students made final project presentations along with discussions and evaluations related to the projects that had been done. Researchers gave project assignments with the theme of the role of buffer solutions in everyday life. The researcher directed learners to ask critically and actively in the presentation process. The researcher brought students to learn based on events or occurrences in everyday life (contextual approach) so that the concept of complex buffer solution topic could be imagined and certainly easier to understand. The contextual approach can also build students' knowledge by connecting the learning material, namely the buffer solution, with real life [40].

Furthermore, in determining the right instrument, researchers used pre-test and post-test questions with a two-tier multiple-choice model to measure critical thinking skills and multiple-choice questions to

measure students' learning achievement improvement. The two-tier multiple choice questions can help students to think at a high level where the design uses Bloom's Taxonomy cognitive domain at the application (C3), analysis (C4), evaluation (C5), and application (C6) levels [41]. The design of two-tier multiple-choice questions considers several indicators that can improve students' critical thinking skills, including identifying the issue/position, analysis, contradictory evidence, and personal bias or assumptions [42]. Multiple choice questions are commonly used to measure students' learning achievement improvement by comparing the pre-test and post-test scores. Multiple choice tests measure student learning outcomes after the teaching and learning process [43].

CONCLUSION

Critical thinking skills among experimental groups were higher than those in control groups. The Wilcoxon test shows that there is the effect of applying the QODE learning model based on PjBL on the critical thinking skills and learning achievement of students both in experiment and control group.The experimental group's N-gain value of critical thinking skills is categorized as high criteria of 0.74. Meanwhile, the control group is categorized as low criteria of 0.38. In addition, the learning achievement of experimental group students has the same level of criteria as the control group, where the N-Gain value of the experimental group is included in the high criteria of 0.78, as well as for the control group, which is included in the high criteria of 0.73. N-Gain result shows the PjBL-based QODE learning model is moderately effective in improving students' critical thinking skills. On the other hand, the N-Gain test for Group Investigation learning model not effective to improving students' critical thinking skills. In addition, PjBL-based QODE learning model can be used effectively and for Group Investigation learning model can be used moderately effective to improve students' learning achievement. This study recommends that the PjBL-based QODE learning model in experiment group is effective in improving students' critical thinking skills and equally effective in improving learning achievement on the topic of buffer solutions than Group Investigation learning model in control group.

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