Jambura Journal of Educational Chemistry
Volume 8 Issue 2, August 2026
p-ISSN: 2655-7606, e-ISSN: 2656-6427
Journal Homepage: http://ejurnal.ung.ac.id/index.php/jjec

The Effect of Flipped Classroom Assisted by Edpuzzle and PhhET Simulation on Students' Critical Thinking Skills in Electrochemistry

Fitriyanti Ahmad[1]*, Masrid Pikoli[1], Erni Mohamad[1], Mangara Sihaloho[1], Thayban Thayban[1], Erga Kurniawati[1], La Alio[1]

[1]*Universitas Negeri Gorontalo, Gorontalo 96554, Indonesia*

Article Info

Article history:
Received: 12-05-2026
Revised: 07-06-2026
Accepted: 08-06-2026
Available online: 01-08-2026

Keywords:
Flipped Classroom; Edpuzzle; PhET, Critical Thinking; Electrochemistry

***Corresponding author:**
fitriahmad3112@gmail.com

Abstract

Students' critical thinking skills, particularly in electrochemistry, remain low because instruction tends to be teacher-centered and makes insufficient use of interactive technology. In addition, studies investigating the use of the flipped classroom approach assisted by Edpuzzle and PhET simulations in electrochemistry learning remain scarce. Therefore, this research was conducted to examine the impact of applying a flipped classroom model integrated with Edpuzzle and PhET simulations on students' critical thinking skills. The study used a quasi-experimental method with a non-equivalent control group design. The research sample consisted of 12th-grade students at SMA Negeri 2 Limboto, selected through purposive sampling. The research instrument consisted of a 10-item essay test that was valid and reliable, with a Cronbach's Alpha value of 0.814. The results showed that the average critical thinking ability of students in the experimental class increased from 29.17 to 74.26, with an N-Gain value of 0.63, classified as moderate. The Wilcoxon Signed-Rank test showed a significant difference between the pretest and posttest in both classes ($p < 0.05$), while the Mann–Whitney U test showed no significant difference in the pretest ($p = 0.060 > 0.05$), but a significant difference in the posttest ($p < 0.05$). Thus, the flipped classroom model supported by Edpuzzle and PhET simulations can serve as an alternative learning approach to enhance students' critical thinking skills in electrochemistry.

How to Cite: Ahmad, F., Pikoli, M., Mohamad, E., Sihaloho, M., Thayban, T., Kurniawati, E., & Alio, L. (2026). The Effect of Flipped Classroom Assisted by Edpuzzle and PhhET Simulation on Students' Critical Thinking Skills in Electrochemistry. *Jambura J. Educ. Chem., 8*(2), 205-213. https://doi.org/10.37905/jjec.v8i2.38902

1. INTRODUCTION

Electrochemistry is a fundamental topic in chemistry that involves the transfer of electrons through redox reactions occurring in conductive media. Its basic principles are closely related to oxidation-reduction reactions and electrolyte solutions (Kurniasari et al., 2019). The subject of chemistry is full of formulas, symbols, reactions, and concepts that students often find difficult. Chemistry involves calculations, information that needs to be memorized, and laws that link one concept to another, all of which must be understood thoroughly and accurately.(Hidayat & Dj, 2022).

Despite its importance, electrochemistry is widely recognized as a conceptually challenging topic due to its abstract nature and the need for both conceptual understanding and extensive practice. Students often experience difficulties in identifying elements in the periodic system and determining oxidation numbers, which are essential in electrochemical processes (Husrina, 2021). This issue becomes more complicated when students are required to apply redox principles to explain the electrochemical processes occurring in voltaic cells and electrolysis cells.

Research conducted by (Rahayu et al., 2023) revealed that students still struggle to connect macroscopic observations, symbolic equations, and submicroscopic representations in the concept of the voltaic cell. As a result, students often have difficulty

https://doi.org/10.37905/jjec.v8i2.38902

visualizing the processes of electron transfer and ionic interactions that occur in electrochemical systems, leading to misconceptions and fragmented conceptual understanding. Futhermore (Sakina et al., 2025), note that the submicroscopic features of voltaic cell materials are often not adequately depicted and lack a clear connection to macroscopic or symbolic representations, thereby limiting students' opportunities to develop a comprehensive understanding of electrochemical phenomena.

From a pedagogical perspective, these various difficulties indicate limitations in students' critical thinking skills. Such skills are essential in chemistry learning since they help students examine problems systematically, evaluate arguments, interpret data, and draw logical conclusions (Maulida & Sri, 2024). Critical thinking is defined as a process of reflective and logical reasoning that guides individuals in determining what to believe and how to act (Ennis, 1996). In learning electrochemistry, students are expected to do more than simply memorize facts. They must analyze the relationships among observable phenomena, symbolic representations, and submicroscopic processes involving electron transfer. Furthermore, students need to identify relevant information, assess the validity of evidence, formulate logical conclusions, and select appropriate approaches to explain and solve electrochemical problems. (Widia & Nasrullah, 2025). This is supported by findi ngs showing that conventional learning results in relatively low critical thinking outcomes, with an average score of 52.80% (Wardani et al., 2024).

To address this issue, a learning approach is needed that encourages students to actively construct knowledge and develop higher-order thinking skills. One promising method is the flipped classroom model, which shifts the process of acquiring foundational knowledge to before class and uses class time for discussion, problem-solving, and critical analysis (Chen & Hung, 2025). Through this learning model, students are encouraged to participate more actively in building their own understanding and enhancing higher-order thinking abilites (Zhou, 2023).

Research findings have demonstrated that the flipped classroom approach is capable of producing substantial improvements in students' critical thinking abilities (Paristiowati et al., 2022). The effectiveness of the flipped classroom model can be enhanced by incorporating digital learning technologies. In the pre-class phase, Edpuzzle supports active learning by embedding questions and formative assessments into instructional videos, allowing students to grasp the fundamentals of electrochemistry while assessing their understanding before class begins (Mardhiyana et al., 2022).

In the classroom learning process, PhET simulations help students visualize electrochemical processes that are difficult to grasp and connect events at the submicroscopic level with observable phenomena. Through these activities, students are trained to observe, evaluate, and describe electrochemical processes based on available data, thereby fostering their understanding of concepts and developing their analytical thinking skills (Drastisianti et al., 2024). The use of interactive simulations allows students to observe phenomena that are difficult to explain in words, thereby enhancing their analytical, interpretive, and scientific reasoning skills. Through interactive and collaborative learning, the flipped classroom model helps improve students' critical thinking skills. Students play an active role in discussions, reflecting on their understanding, and making rational decisions. (Patiño-Masó et al., 2025)

Although previous studies have examined the flipped classroom model or the use of Edpuzzle and PhET separately, research integrating these three components simultaneously in electrochemistry learning remains limited. Most studies have focused on other topics, such as salt hydrolysis (Paristiowati et al., 2022). and electrolyte solutions (Damanik & Harta, 2023) thereby leaving a gap in understanding of how their integration influnces students' critical thinking abilities.

Therefore, research on the integration of the flipped classroom, Edpuzzle, and PhET in electrochemistry instruction is important not only because this combination has rarely been studied, but also because this integrated approach has the potential to address the specific cognitive demands of understanding electrochemical phenomena while developing students' critical thinking skills. Based on the above discussion, this study aims to examine the effect of implementing a flipped classroom model integrated with Edpuzzle and PhET simulations on students' critical thinking skills in electrochemistry instruction.

https://doi.org/10.37905/jjec.v8i2.38902

2. METHOD

2.1 Research Design and Participants

This study employs a quantitative approach using a quasi-experimental design in the form of a non-equivalent control group pretest-posttest design. The study aims to examine the effect of implementing a flipped classroom model supported by Edpuzzle and PhET simulations on students' critical thinking skills in electrochemistry.

The research was conducted at Limboto State High School No. 2 in Gorontalo, Indonesia, during the first semester of the 2025–2026 academic year. The research was carried out between September and December 2025, while the electrochemistry lessons were conducted over three sessions, with two 45-minute sessions in each session.

The participants consisted 52 twelfth-grade science students who were selected through purposive sampling based on similar academic achievement, class characteristics, and the chemistry teacher's recommendations. Class XII M1 (27 students) was designated as the experimental group, while Class XII M4 (25 students) served as the control group.

The sample for this study was selected using purposive sampling, taking into account similar academic characteristics, a nearly equal number of students, and recommendations from chemistry teachers. To ensure that the students' initial abilities were comparable, an analysis was conducted on their pretest scores for critical thinking skills. The results of homogeneity test indicated that the variances of the two groups were homogeneous ($p = 0.235 > 0.05$). These findings indicate that the initial conditions of the two classes were relatively comparable before the treatment was applied.

The experimental group received instruction through the flipped classroom method combined with Edpuzzle and PhET simulations. In the pre-class phase, students learned about electrochemistry independently by watching interactive videos supported by Edpuzzle. Afterward, during in-class instruction, students engaged in discussions, problem-solving, and concept exploration using PhET simulations. Meanwhile, the control group followed traditional instruction focused on teacher-led explanations and in-class discussions.

a. Research Instrumen

The instruments included a teaching module and student worksheets (LKPD) designed based on the flipped classroom model, consisting of three phases: pre-class (Edpuzzle videos), in-class (discussion and PhET simulations), and post-class (reflection and evaluation).

To measure tudents' critical thinking abilities, the researchers a 10-item essay assessment designed according critical thinking indicators proposed by Robert H. Ennis, including elementary clarification, basic support, inference, advanced clarification, and strategies and tactics. Students' answers are graded using an analytical grading system with a scale of 0 to 4 for each question. A score of 0 is given for irrelevant or blank answers, while a score of 4 is given for answers that are comprehensive, scientifically accurate, and based on logical arguments. Therefore, the highest possible total score on this exam is 40. The total score earned by each student is then converted to a percentage using the following formula:

$$\text{Score} = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times 100 \qquad (1)$$

b. Instrumen Validity and Reliability

Before being used in the study, all instruments first underwent a content validation process through expert assessment involving two chemistry education lecturers and one chemistry teacher. The results of this validation showed that the teaching module, worksheets, and critical thinking test achieved validity percentages of 89.3%, 88.6%, and 83.3%, respectively. These findings indicate that all instruments met the validity criteria and can be used in the study.

The validity of the essay test instrument will be empirically tested using Pearson's product-moment correlation. The analysis results indicate that all test items meet the validity criteria, with correlation coefficients ranging from 0.375 to 0.826. Reliability was assessed using Cronbach's Alpha, yielding a value of 0.814, indicating a very high level of internal consistency. Thus, the instrument is considered reliable for evaluating students' critical thinking skills.

c. Data Analysis

The data obtained from this study were analyzed using descriptive and inferential statistical methods. The descriptive analysis aimed to demonstrate the students' critical thinking skills and the extent of improvement in learning outcomes following the instructional process. The effectiveness of the instructional method was

https://doi.org/10.37905/jjec.v8i2.38902

evaluated using the Normalized Gain (N-Gain) score, calculated using the following formula:

$$g=\frac{S_{post} - S_{pre}}{S_{max} - S_{pre}} \quad (2)$$

Where:

g = normalized gain score
S_{post} = posttest score
S_{pre} = pretest score
S_{max} = maximum possible score

The N-Gain values were interpreted as high ($g > 0.70$), medium ($0.30 \leq g < 0.70$), and low ($g < 0.30$).

Before testing the hypothesis, the data will be tested for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene's test at a significance level of 0.05. The results of the normality test indicate that the data do not follow a normal distribution ($p > 0.05$).

Because the assumption of normality was not met, data analysis was conducted using nonparametric statistical methods. The Wilcoxon Signed-Rank test was used to assess differences between pretest and posttest scores within each group. Meanwhile, the Mann–Whitney U test was used to evaluate the comparison of critical thinking skills between the treatment group and the control group. A comparison of pretest scores was conducted to ensure that the initial abilities of both groups were equivalent before the intervention was administered, while the comparison of posttest scores aimed to measure the impact of implementing the flipped classroom model supported by Edpuzzle and PhET simulations on students' critical thinking skills in electrochemistry learning.

3. RESULT AND DISCUSSION

3.1. Result

The present research investigated enhancements in learners' critical thinking abilities within electrochemistry education by employing a flipped classroom framework augmented with Edpuzzle and PhET simulations. The present research investigated enhancements in learners' critical thinking abilities within electrochemistry education by employing a flipped classroom framework augmented with Edpuzzle and PhET simulations.

Table 1. A comparative of pretest, posttest, and N-gain scores

Group	Pretest	Posttest	N-Gain	Category
Experimental	29.17	74.26	0.63	Moderate
Control	22.20	29.40	0.09	Low

As Presented in Table 1 participants in the experimental group showed considerable gains in critical thinking skills, reflected by an N-Gain value of 0.63 (moderate level). By comparison, the control group achieved only marginal improvement, with an N-Gain of 0.09, categorized as low. This indicates that the flipped classroom model supported by Edpuzzle and PhET simulations contributed more effectively to enhancing students' critical thinking skills compared to conventional instruction.

To gain a more detailed understanding of progress in every aspect of critical thinking abilities, Figure 1 presents the N-Gain for each respective indicator.

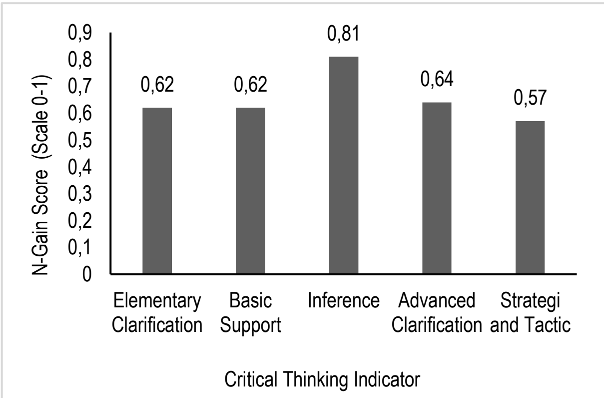

Figure 1. Students' N-Gain scores each critical thinking indicator.

Before testing the hypotheses, the data were first tested for normality to determine the appropriate statistical analysis method. The results of the normality test using the Shapiro–Wilk test are presented in Table 2.

Table 2. Summary of normality test result

Data	Normality Test	Statistic	p-Value	Interpretacion
Pretest-posttest of Experimental Class	Kolmogrov-Smirnov	0.197	< 0.001	Not Normally Disributed
	Shapiro-Wilk	0.905	< 0.001	Not Normally Disributed
Posttest of Control and Experimental Class	Kolmogrov-Smirnov	0.173	< 0.001	Not Normally Disributed
	Shapiro-Wilk	0.922	0.002	Not Normally Disributed

https://doi.org/10.37905/jjec.v8i2.38902

As shown in Table 2, all p-values are below 0.05, indicating that the data distribution is not normal. Therefore, nonparametric statistical analysis methods were applied in this study. The Wilcoxon Signed-Rank test was used to compare pretest and posttest scores within each group, while the Mann–Whitney U test was used to assess critical thinking skills between the experimental and control groups.

In order to assess the statistical significance of gains within each group, the Wilcoxon Signed Rank Test was applied. Findings from this analysis are detailed in Table 3.

Table 3. Outcomes of the Wilcoxon signed-rank test analysis

Group	Z Value	P-Value	Interpretacion
Experimental	-4.545	0.000	Significant
Control	-3.085	0.002	Significant

As indicated in Table 2, the Wilcoxon Signed Rank Test confirmed highly significant variations in pretest versus posttest scores for both groups ($p < 0.05$), signifying marked progress in students' critical thinking competencies post-instruction across the board.

Additionally, the Mann–Whitney U Test was utilized to evaluate differences between the experimental and control groups, with outcomes detailed in Table 4.

Table 4. Findings from the Mann-Whitney u test on pretest scores

Test Statistic	Value
Mann-Whitney U	235.000
Z	-1.884
Asymp. Sig. (2-tailed)	0.060

Based on Table 4, the significance value was 0.060 ($p > 0.05$), indicating that there was no significant difference in the initial critical thinking skills between the experimental and control groups. These findings indicate that the two groups possessed relatively comparable baseline proficiencies prior to the implementation of the experimental intervention.

Table 5. Results of the Mann-Whitney u test posttest scores

Test Statistic	Value
Mann-Whitney U	7.500
Z	-6.051
Asymp. Sig. (2-tailed)	< 0.001

As evidenced by Table 5, the p-value stood at <0.001 ($p < 0.05$), underscoring a meaningful distinction in critical thinking performance between the experimental and control cohorts post-treatment. With equivalent starting abilities in both groups, such variance is attributable to the application of the flipped classroom approach supported by Edpuzzle and PhET Interactive Simulations.

Consequently, for a more precise evaluation, the examination centered on N-Gain outcomes, which revealed greater enhancement in the experimental group compared to the control group.

3.2. Discussion

The study results show that the use of the flipped classroom model, supplemented by Edpuzzle and PhET simulations, successfully improved students' critical thinking skills. This is evident from the N-Gain score of the experimental group, which reached 0.63 (moderate category), higher than that of the control group, which only reached 0.09 (low category). These findings suggest that the flipped classroom approach enhances students' active participation through independent learning activities before class and collaborative activities during instruction, thereby supporting the development of students' critical thinking skills.

Based on Figure 1, variations in the improvement of critical thinking skills are evident across each indicator. The inference indicator showed the highest improvement with an N-Gain value of 0.81 (high category), while strategies and tactics recorded the lowest improvement with an N-Gain value of 0.57 (moderate category). On the other hand, the basic clarification (0.62), basic support (0.62), and advanced clarification (0.64) indicators also fall into the moderate category. These results indicate that students are better able to draw conclusions from available information than to systematically design problem-solving strategies.

This pattern of improvement is closely linked to the learning stages in the flipped classroom model. During the pre-class stage, students study the material through instructional videos using Edpuzzle, which helps build initial understanding of electrochemical concepts. This contributes to an improvement in elementary clarification skills that is, the ability to identify and explain basic concepts. This finding is supported by Eka (2024), who states that the ability to provide simple explanations reflects students' understanding of basic concepts.

During the in-class phase, students engaged in discussions, completed worksheets, and explored concepts using PhET simulations. This phase contributed significantly to improvements in the "basic support" and "advanced clarification" indicators, as students were encouraged to analyze information, evaluate evidence, and construct logical explanations. The use of PhET simulations helps visualize abstract electrochemical processes, thereby facilitating the understanding and analysis of concepts. These findings align with Jufriansah et al. (2022), who state that interactive simulations can enhance conceptual understanding. Additionally, Septiany (2024) states that critical thinking refers to an individual's capacity to analyze and assess information grounded on relevant evidence.

Improvements in the basic support and advanced clarification indicators are likely influenced by the complementary use of Edpuzzle and PhET simulations. Edpuzzle helps students build preliminary understanding before instruction, while PhET allows students to visualize abstract electrochemical concepts. These results align with the research by (Rahmawati et al., 2022), which indicates that PhET simulations can help students understand chemical concepts by linking macroscopic, submicroscopic, and symbolic representations. In this study, the visualization of electron transfer processes and electrochemical reactions using PhET contributed to strengthening students' conceptual understanding, enabling them to provide explanations and reasoning grounded in relevant concepts.

The highest N-Gain score achieved in the inference indicator indicates that the post-class phase significantly contributes to improving students' conclusion-drawing skills. At this stage, students are encouraged to reflect on the learning outcomes, accomplish additional tasks, and construct conclusions based on the analysis they have conducted. Through this organized learning process, students are better able to connect information and formulate conclusions in a logical and systematic manner. These findings align with those of Nanda (2021) and Ma (2023), who state that the flipped classroom approach can enhance students' ability to draw conclusions through active engagement.

The more significant improvement in the inference indicator compared to the strategy and tactics indicators is likely due to differences in the level of cognitive complexity between these two indicators. During the learning process, students often practice understanding information and drawing conclusions based on evidence obtained through discussions, worksheets, and simulations, thereby developing their inference skills more effectively. On the other hand, the strategy and tactics indicators require more complex metacognitive skills, such as planning solution steps, monitoring the thinking process, and evaluating available solution options. According to (Rivas et al., 2022), these metacognitive processes are part of more complex critical thinking and require continuous practice to develop effectively.

The minimal improvement in strategy and tactics indicators can be attributed to the complexity of electrochemistry material, which requires students to connect macroscopic, symbolic, and submicroscopic representations. Sukmawati (2020) notes that difficulties in understanding electrochemistry are often caused by the fact that processes such as electron movement and electrolysis reactions cannot be observed directly. Consequently, although students can understand concepts and draw conclusions, they still struggle to select the appropriate strategies to solve problems. Furthermore, strategic and tactical skills encompass metacognitive abilities, such as planning, monitoring, and evaluation, which require consistent practice. Therefore, the results, which remain in the moderate category, indicate the need for more challenging problem-solving activities during the learning process.

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indicate the need for more challenging problem-solving activities during the learning process.

Inferential statistical analysis further supports these findings. The results of the Wilcoxon Signed-Rank test presented in Table 2 show a significant difference between the pretest and posttest scores in both groups, indicating that the learning process contributed to an improvement in students' critical thinking skills.

Subsequently, the Mann–Whitney U test outcomes detailed in Tables 3 and 4 facilitated a comparison of critical thinking abilities among learners in the experimental and control groups, both prior to and following the intervention. These findings offer further substantiation for the efficacy of the flipped classroom approach, augmented by Edpuzzle and PhET Interactive Simulations, in advancing students' critical thinking competencies relative to traditional teaching methods.

Based on the Mann–Whitney U test analysis of the pretest data in Table 3, the significance value was found to be $p = 0.060$ ($p > 0.05$), indicating that there was no statistically significant difference in the initial critical thinking abilities of the experimental and control groups. These findings imply that both groups possessed relatively equivalent baseline competencies before the intervention was implemented.

Moreover, the Mann–Whitney U test analysis of the posttest data in table 4 produced a significance value of $p < 0.001$ ($p < 0.05$), which indicates a significant difference in students' critical thinking abilities between the two groups after the intervention. Considering that the groups had similar baseline abilities prior to treatment, the observed difference may be associated with the application of the flipped classroom model assisted by Edpuzzle and PhET simulations.

Although there has been progress in critical thinking skills, the findings of this study must be interpreted with caution. This improvement cannot be entirely attributed to the use of the flipped classroom supported by Edpuzzle and PhET, as other factors—such as the Hawthorne effect and the novelty effect—may also influence student motivation, participation, and engagement during the learning process. Therefore, future research is recommended to assess student learning motivation and implement interventions over a longer period to reduce the likelihood of bias and obtain more accurate results.

4. CONCLUSION

The results of this study indicate that the use of a flipped classroom model supported by Edpuzzle and PhET simulations is associated with improved critical thinking skills among students in electrochemistry. In this study, students in the experimental group achieved a higher N-Gain score (0.63; moderate category) compared to students in the control group (0.09; low category). These findings suggest that this learning approach has the potential to provide students with more opportunities to engage in learning activities that are analytical, reflective, and evidence-based.

Improvements in critical thinking skills were not uniform across all indicators. The inference indicator showed the highest improvement (N-Gain = 0.81), indicating that students have become more proficient in drawing conclusions from available evidence and information. Conversely, the strategies and tactics indicator showed the lowest improvement (N-Gain = 0.57), indicating that students still struggle with planning, monitoring, and evaluating strategies for problem-solving. This pattern may be related to the nature of electrochemistry material, which requires students to connect macroscopic, symbolic, and submicroscopic representations while applying metacognitive strategies in the problem-solving process.

The findings of this study should be analyzed with an awareness of its limitations. In addition to the use of a quasi-experimental design and the limited number of participants from a single school, several practical challenges also arose during the study. Some students faced difficulties accessing learning materials via Edpuzzle outside of class due to variations in internet availability and the devices they used. Furthermore, some students required time to adapt to the demands of learning within the flipped classroom method. Therefore, it is recommended that future research focus on the development and evaluation of learning strategies specifically designed to enhance students' strategic and metacognitive problem-solving skills—particularly regarding the strategies and tactics involved in critical thinking—through more sustained and complex problem-based learning activities.

5. ACKNOWLEDGEMENTS

The researcher would like to express sincere appreciation to State Senior High School 2 Limboto for granting permission and providing support throughout the implementation of this study. Appreciation is also extended to the school principal, the chemistry teacher, and all participating students whose involvement contributed to the smooth conduct of the research. In addition, the researcher acknowledges all parties who provided both direct and indirect assistance, which greatly contributed to the successful completion of this study.

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