JTK: Jurnal Tadris Kimiya 10, 1 (June 2025): 35-44
Website: http://journal.uinsgd.ac.id/index.php/tadris-kimiya/index
ISSN 2527-9637 **(online) ISSN** 2527-6816 **(print)**

Fostering Critical Thinking through Socio-Scientific Issue-Based Problem-Based Learning in Stoichiometry Instruction

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Received: April 2025; Accepted: May 2025; Published: June 2025

Abstract

Understanding stoichiometry remains a significant challenge for many secondary school students, primarily due to traditional instructional approaches that emphasize memorization rather than analytical reasoning. To address this issue, this study examines the effectiveness of a socio-scientific issue (SSI)-based problem-based learning (PBL) model in fostering students' critical thinking skills in stoichiometry instruction. The research employed a quasi-experimental design with a non-randomized pretest–posttest control group structure. Participants consisted of two grade X classes from SMAN 1 Sipirok, with one class assigned as the experimental group receiving SSI-based PBL instruction and the other as the control group receiving conventional teaching. Data were collected through essay tests designed around Ennis's twelve critical thinking indicators. The results of an independent samples *t*-test indicated a statistically significant difference in posttest scores between the two groups ($p = 0.027$, $p < 0.05$), demonstrating that the experimental group outperformed the control group in critical thinking. These findings suggest that integrating socio-scientific issues into problem-based learning can effectively enhance students' reasoning, engagement, and conceptual understanding in chemistry education. The study contributes to the ongoing discourse on innovative pedagogies by highlighting the pedagogical potential of SSI-based PBL for cultivating higher-order thinking skills in science classrooms.

Keywords: critical thinking PBL-SSI, stoichiometry

DOI: https://doi.org/10.15575/jtk.v10i1.43992

1. Introduction

In the 21st century, the development of science, technology, and information has been very rapid. This progress not only provides easy access to information globally but also creates new challenges in the form of ethical and moral issues, as well as global issues such as data privacy, artificial intelligence, and social inequality. These problems have the potential to threaten human dignity and survival if not addressed wisely (Sendika et al., 2024). To overcome this problem, it is necessary to pay attention to the quality of students who are ready to be educated in modern life, and have an awareness of the development of science and technology related to the ethical dimension (Zo'bi, 2014). Efforts to continuously improve educational processes and products must be given more attention, because it is believed that through education, it can maximize the potential of students as prospective human resources, skilled and have a critical, creative, logical, innovative attitude, and be able to face and solve problems (Prabawanto, 2017).

In the current era of globalization, people are required to have active critical thinking skills to compare evidence, evaluate competing needs, and make rational decisions. This ability is key in dealing with complex international issues such as climate change and environmental pollution. The integration of critical thinking in education helps prepare learners to face complex global challenges. This emphasizes the importance of developing critical thinking skills as an integral part of the modern education curriculum (Wibowo, 2024).

Thinking skills instruction is becoming more and more important in schools, particularly in light of the globalization era, which demands that people be flexible and effective. Education is placing more and more emphasis on teaching thinking skills, particularly in light of the globalization period, which demands that people be adaptable and productive (Bashith & Amin, 2017).

Teaching critical thinking skills not only helps students understand the subject matter but also encourages them to develop in-depth analytical skills and improve their overall thought process. Students who are trained to think critically tend to be better able to find relevant information, apply scientific knowledge, evaluate facts, and build logical and informed arguments. Research (Waruwu et al.,2024) shows that the implementation of the Merdeka Curriculum can improve students' critical thinking skills through a more flexible and student-centred learning approach.

This statement is supported by the United Nations Educational, Scientific and Cultural Organization (UNESCO), which stipulates that one of the important skills that students must have in the 21st century is the ability to think critically. Based on research in various fields, including social sciences and science, it is known that many graduates from various countries still lack critical thinking skills, so they have difficulty competing at the global level (Sani, 2014).

Teachers can observe students who actively ask questions, seek information from various sources, complete tasks, solve problems, and discipline and evaluate themselves. Critical thinking skills are essential for students in this process. However, according to data from the Program for International Student Assessment (PISA), Indonesian students still need to improve their critical thinking skills to reach global standards (Paristiowati et al., 2022)

In schools, chemistry lessons have not been oriented towards habituation and improvement of higher-level thinking skills (critical thinking), but still focus on low-level cognitive learning outcomes (Kurniahtunnisa et al., 2016). This is because learning is often teacher-centred and students tend not to be actively involved in knowledge exploration. Learning that has been done so far is too broad and there are too many things to be taught. Providing teaching materials is just a knowledge transfer activity, where the teacher only conveys knowledge to students and does not care whether students understand the knowledge given or not (Hilda, 2015).

Many students believe that science lessons are just engineering, and there is no discussion. This is in contrast to other subjects such as history, social sciences and religious education. Over the past few years, interest in science education, especially in chemistry and physics, has declined (Ottander & Ekborg, 2012). According to Rahmawati & Taylor, one of the main challenges in chemistry education is to design learning approaches that connect conceptual understanding with real-life contexts to enhance student engagement and comprehension (Rahmawati et al., 2021).

Some of the shortcomings of the direct instruction method, such as difficulties in understanding students, result in a teacher not knowing how the student understands the lesson, making the direct instruction method very ineffective to use because some students need a variety of approaches and methods (Khoirun Nisah Lubis et al., 2024). However, the results of field studies in one of the public schools in South Tapanuli Regency, North Sumatra, in learning chemistry are still dominated by teachers using the direct instruction model. Teacher-focused learning causes students to develop less critical thinking and communication skills, because they only receive information provided without the opportunity to play an active role in the learning process.

The results of observations through pre-research show that students only receive lessons from teachers without any involvement with students, so that students are less active in finding concepts about the material being studied. Student learning outcomes are still dominated by the ability to remember and understand, without much opportunity to develop higher abilities such as applying, analyzing, evaluating, or creating. This condition shows that students have not been able to fully apply the learning material to a higher level of thinking. In other words, the learning process at school has not optimally directed students to develop critical and creative thinking skills through application, analysis, synthesis, evaluation, and creation based on concepts and principles that have been learned.

Students have difficulty in understanding abstract chemical concepts, especially in the topic of stoichiometry. The focus of learning that only emphasizes the aspects of remembering (C1) and understanding (C2) is caused by the teaching model applied by the teacher in delivering the material. Therefore, it is important to apply a student-centered learning model. The solution that researchers suggest is the use of the Problem-Based Learning (PBL) model to encourage the improvement of abilities at all cognitive levels on the Taxonomy of Bloom. PBL is a learning model that presents a variety of authentic and meaningful problematic situations to students, which can serve as a springboard for investigation and inquiry.

Problem-Based Learning (PBL) is an innovative learning model that encourages students to be actively involved in the learning process. PBL involves students in problem-solving through the stages of the scientific method so that they not only acquire knowledge relevant to the problem but also develop the ability to solve problems. (Rerung et al., 2021). PBL is very effective if it is based on socio-scientific issues that are directly related to students' daily lives, especially stoichiometry material. These social issues can also train students to argue, make decisions related to social issues, and develop their moral aspects (Behera, 2023). SSI is a representation of issues or problems in social life that are conceptually closely related to science with relative or uncertain answers.

Research by Aisya, Wibowo, and Aminatun (2017) shows that Socio-scientific Issues (SSI)-based learning strategies have a positive effect on students' reflective judgment abilities on ecosystem materials. In this study, the SSI approach assists students in developing critical thinking skills and a deeper understanding of concepts through discussion and analysis of scientific issues relevant to daily life.

With the application of the PBL model, students' abilities significantly improved in communication skills in the experimental class with a high category (Prima & Kaniawati, 2011). Therefore, this study was conducted to determine the effect of applying the SSI-based PBL model to develop student's critical thinking skills.

2. Research Method

This type of research is quantitative research using the quasi-experimental method. The research design used is a non-randomized-group pretest posttest design. In this design, a group of research subjects from a certain population is used and then grouped non-randomly into two groups. Which is the experimental group and the control group (Rangkuti, 2016). The pretest and posttest research design can be seen in Table 1.

Table 1. Pretest-Posttest Research Design

Class	Pre-Test	Treatment	Post-Test
Control	T_1	Not given treatment	T_2
Experiment	T_1	Given treatment	T_2

The population of this study was class X science students at public high schools in South Tapanuli Regency, North Sumatra. While sampling in this study uses a purposive sampling technique, which is done by taking subjects based on certain objectives. The samples in this study were two classes, which are class X MIA 1 as the control class and X MIA 2 as the experimental class.

In this study, the treatment was implemented through five PBL-SSI stage, which are orienting students to social science problems, organising students in learning, guiding independent and group investigations, developing and presenting work, analysing and evaluating the problem-solving process. In detail, the syntax or learning stages of the problem-based learning model based on socio-scientific issues in this study can be seen in Figure 1.

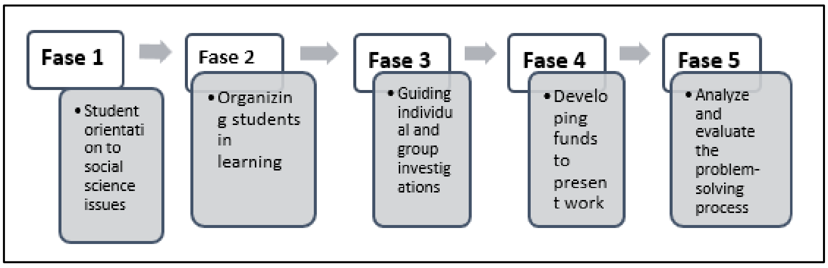

Figure 1. Stage of the Problem-Based Learning Model

The data collection technique used a critical thinking ability test on reaction equation material and mole calculation. The research subjects consisted of two classes which are experimental class (X MIA-2) and control class (X MIA-1), each consisting of 35 students. The tests were given in the form of a pretest and a posttest. Data were analyzed quantitatively using an independent sample *t*-test, which began with normality and homogeneity tests, assisted by SPSS software version 24.

3. Result and Discussion

Data from the pretest and posttest scores of high school students in the control class and experimental class can be seen in Figure 2.

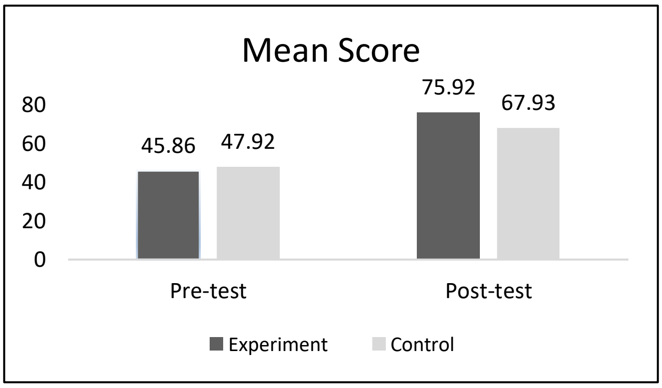

Figure 2. The Average Results of Students' Pretest and Posttest

Figure 2 shows that, prior to receiving treatment, there was no significant difference in the average pretest scores for critical thinking skills between the experimental and control classes. After treatment, the average posttest score for critical thinking skills was higher in the experimental class than in the control class. The experimental class had a higher average value of 75.92 than the control class.

We analyzed the pretest and posttest data using normality test and *t*-test to determine the effect of the treatment on students' critical thinking skills. The normality test result can be seen in Table 2.

Table 2. Normality Test Results

Class	Kolmogorov-Smirnov		
	N	Significance	α
Pretest experiment	35	0.51	0.05
Posttest experiment	35	0.57	0.05
Pretest control	35	0.33	0.05
Posttest control	35	0.20	0.05

A normality test was conducted to determine whether the pretest and posttest data were normally distributed. The results showed that the significance values for the pretest and posttest data in the experimental class, as well as the pretest data in the control class, were all greater than 0.05. Therefore, the data were considered to be normally distributed and met the requirements for parametric testing. Subsequently, to determine the difference in students' critical thinking skills between the experimental and control classes, an independent sample *t*-test was used. The results of this test can be seen in Table 3.

Table 3. Independent Sample *t*-Test Results

Data Test	Level of Significance (α)	Sig. (2-tailed)	Conclusion
Pretest	0.05	0.335	Sig. (2-tailed) > α H_0 accepted, there is no difference in the average pretest score of critical thinking skills
Posttest	0.05	0.027	Sig. (2-tailed) < α H_0 is rejected, there is a difference in the average posttest score of critical thinking skills

Based on the results of the independent sample *t*-test, the pretest value at α = 0.05 obtained a significant value (2-tailed) of 0.335. The significant value (2-tailed) is greater than 0.05, so H_0 is accepted. That is, there is no significant difference in the average pretest score of critical thinking skills between the control class and the experimental class. So that the sample is suitable for research.

Based on Table 3 the results of the posttest independent sample *t*-test with a significance level value (α = 0.05) obtained a significant value (2-tailed) of 0.027. The significant value (2-tailed) obtained is smaller than 0.05, so H_0 is rejected and H1 is accepted. This shows that there is a significant difference in the average posttest scores of critical thinking skills of the control class and experimental class students.

In the experimental class, the ability to think critically on the pretest and posttest scores increases from each critical thinking indicator. The results of each indicator of critical thinking ability can be seen in Figure 3.

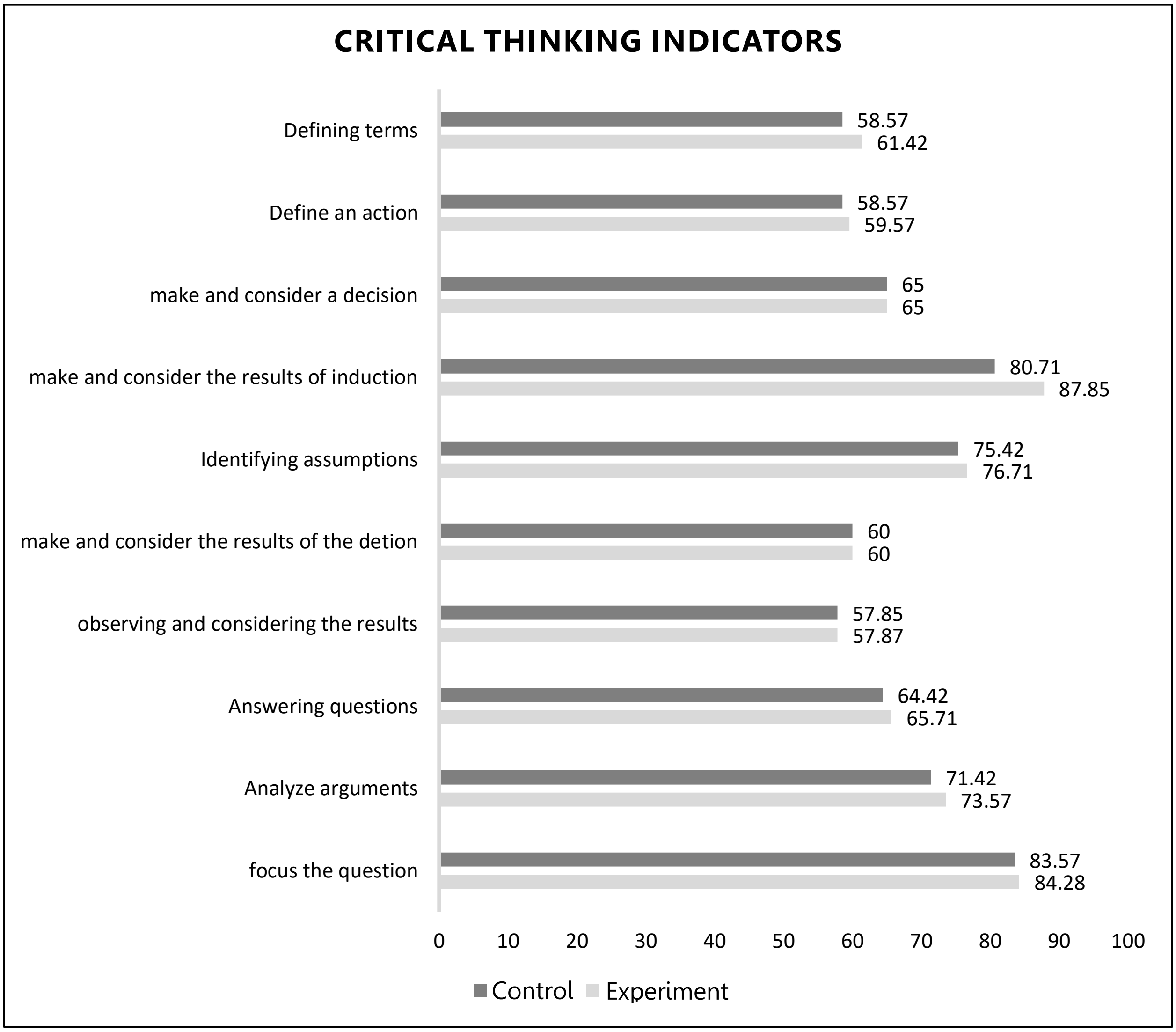

Figure 3. Percentage of Achievement of Critical Thinking Ability Indicators Posttest Data

Figure 3 shows that, compared to the control class, each indicator of critical thinking ability in the experimental class obtained a higher percentage. When identifying assumptions, students need to reason about the event presented in the problem in order to construct arguments and draw appropriate conclusions. Students must form assumptions about the outcome of each option so they can determine the correct answer. Students in the experimental class obtained a higher percentage than those in the control class. This is because students in the experimental class were able to identify the correct answer and provide the right reasoning. While the control class students were able to select the correct answer, but their reasoning was incomplete.

This study aims to determine the effect of the application of Problem-Based Learning (PBL) based on Socio-Scientific Issues (SSI) on students' critical thinking skills in stoichiometry material. In addition, this study seeks to explore how the integration of SSI can enhance student engagement in chemistry learning by making it more relevant to real-world contexts. The use of SSI allows chemistry to be taught not merely as abstract formulas and reactions but as meaningful knowledge that relates directly to societal and environmental issues.

Critical thinking is one of the essential skills in the modern era, especially in the midst of rapid and complex information flow. It enables individuals to analyze information objectively, make decisions based on sound evidence, and solve problems effectively (Tanjung, 2019). In the context of education, critical thinking is an important foundation for students to develop the ability to reason, understand various perspectives, and face life's challenges with innovative solutions. An education that supports critical thinking not only helps students in academics but also in their social life (Fithriyah et al., 2016).

The Socio-Scientific Issue (SSI)-based Problem-Based Learning (PBL) approach offers a powerful method in chemical education by allowing students to examine chemistry concepts through real-life contexts. This approach fosters deeper understanding by linking theoretical knowledge with issues that matter in the students' daily lives such as pollution, food safety, or energy use thus making chemistry more meaningful and applicable. It encourages students to apply critical analysis, creativity, and reflection—key components of critical thinking. Through issue-based learning, students learn to consider diverse perspectives, formulate logical arguments, and make ethical and informed decisions. Research by Sulaiman indicates that the SSI-based PBL model significantly enhances students' critical thinking skills compared to conventional methods (Sulaiman & Azizah, 2020).

Learning activities in this study were carried out in two meetings using the SSI-based PBL model, which consists of five stages as outlined by Rizkita which are orienting students to socio-science problems, organizing students for learning, assisting students and group investigation, developing and presenting work and analyzing and evaluating the problem-solving process (Rizkita et al., 2016). These stages were implemented fully in each meeting to ensure that students not only understood the contextual problems but also connected them to the chemistry content being taught, particularly stoichiometry. The integration of SSI encourages students to go beyond rote learning by promoting inquiry and the practical application of chemical principles.

Based on the discussion related to the stages of the SSI-based PBL learning model, it can be concluded that students are active in learning activities because students can express opinions, cooperate in groups, provide ideas, suggestions and also criticism to the presenting group. This is in line with Utomo's research, saying that the learning process using the SSI-based PBL model makes teachers give freedom to think and look for the right answers or solutions in solving social issues or problems while still considering ethics, morals, and social, so that students think more critically in solving problems displayed in learning activities (Utomo et al., 2020).

Based on the results of the research that has been conducted, the application of the Problem-Based Learning (PBL) learning model based on Socio-scientific Issues (SSI) has proven to be effective in improving students' critical thinking skills in stoichiometric materials. This is shown by the increase in the average score as well as the percentage of achievement on each critical thinking indicator after treatment. Students become more active in identifying problems, analyzing information, and crafting logical arguments to solve problems related to contextual scientific issues. This finding is strengthened by Yulianti's research, which also shows that the socio-scientific issue-based learning approach in the PBL model can improve students' critical thinking skills (Yulianti, 2015).

This is because experimental class students have been trained to identify assumptions in SSI discourse to determine which choices are considered correct so that they can provide the right argument. Meanwhile, the control class using conventional methods is not accustomed to using discourse, so it lacks training skills in identifying assumptions and constructing arguments. According to El-Shaer & Gaber, students who use PBL in their learning process have a better ability to make inferences and assumptions than students who use traditional methods (Gaber & El-shaer, 2014). By using the SSI context, learning becomes more interactive, so that students can practice argumentation and decision-making skills related to issues in society (Ottander & Ekborg, 2012).

In addition, the application of the SSI context in the classroom learning process can develop students' critical thinking skills more effectively than the conventional learning model. This happens because students are more involved in the learning process and can understand the relationship between the concepts they have learned and the problems that exist in everyday life.

4. Conclusion

Learning (PBL) model integrated with Socio-Scientific Issues (SSI) had a significant effect on improving students' critical thinking skills in stoichiometry material. This was evidenced by the hypothesis test using the Independent Sample *t*-Test, which showed a significance value (sig. 2-tailed) of 0.027, lower than the significance level of $\alpha = 0.05$. Therefore, there is a statistically significant difference between the posttest scores of students' critical thinking skills in the experimental class and the control class. This means that the use of the PBL model based on SSI is effective in enhancing high school students' critical thinking abilities.

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