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Think-Pair-Square: A Collaborative Approach to Enhancing Critical Thinking Skills in Chemical Equilibrium

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Abstract

Low levels of critical thinking skills among students on the topic of chemical equilibrium pose a significant challenge in chemistry education. This topic demands strong analytical, evaluative, and problem-solving abilities. This study aimed to investigate the effectiveness of the Think-Pair-Square (TPSq) learning model in enhancing students' critical thinking skills. A pre-experimental one-group pretest–posttest design was employed, involving 59 students from two classes selected through cluster random sampling. Data were collected using a critical thinking skills test administered before and after the intervention, and analyzed using N-Gain and effect size. The results indicated a significant improvement in students' critical thinking skills, with an average N-Gain of 0.48 (moderate category) and an effect size of 2.75 (very high category). These findings suggest that TPSq is an effective collaborative learning strategy for developing critical thinking skills in chemical equilibrium and can serve as an alternative instructional method that promotes student interaction and discussion.

Keywords: chemical equilibrium; collaborative learning; critical thinking; think-pair-square

Abstrak

Keterampilan berpikir kritis yang rendah di antara siswa dalam topik kesetimbangan kimia menimbulkan tantangan yang signifikan dalam pembelajaran kimia. Topik ini membutuhkan kemampuan analitis, evaluatif, dan pemecahan masalah yang kuat. Penelitian ini bertujuan untuk menyelidiki efektivitas model pembelajaran Think Pair Square (TPSq) dalam meningkatkan keterampilan berpikir kritis siswa. Desain pra-eksperimental satu kelompok pretes-postes digunakan dengan 59 siswa dari dua kelas, dipilih melalui cluster random sampling. Data dikumpulkan menggunakan tes keterampilan berpikir kritis yang diberikan sebelum dan sesudah intervensi, dan dianalisis menggunakan N-Gain dan Effect Size . Hasilnya menunjukkan peningkatan yang signifikan dalam keterampilan berpikir kritis siswa, dengan rata-rata N-Gain 0,48 (kategori sedang) dan Effect Size 2,75 (kategori sangat tinggi). Temuan ini menunjukkan bahwa TPSq merupakan strategi pembelajaran kolaboratif yang efektif untuk mengembangkan keterampilan berpikir kritis dalam topik kesetimbangan kimia dan dapat berfungsi sebagai metode pengajaran alternatif yang mendorong interaksi dan diskusi siswa.

Keywords: berpikir kritis; kesetimbangan kimia; pembelajaran kolaboratif; think-pair-square

Introduction

Critical thinking is one of the essential 21st-century skills that must be developed through the learning process. The topic of chemical equilibrium requires students to analyze, evaluate, and solve complex problems (Takowa et al., 2025). However, research shows that students' critical thinking skills in this area remain low, thereby hindering effective learning (Affandy et al., 2019). According to Affandy et al. (2019), this low ability is caused by students' difficulty in focusing on the core of a problem, their limited use of relevant concepts, and weak reasoning and clarity in answering questions. These issues indicate that students often reproduce answers without a deep understanding.

Critical thinking is an essential skill for students to master in order to comprehend learning concepts in depth and solve problems analytically (Ennis, 2011; Nurdiana et al., 2024). In chemistry learning, particularly in the topic of chemical equilibrium, critical thinking skills are crucial, as the material is abstract and complex (Lie, 2004). Students' difficulties in developing these skills are also influenced by misconceptions arising from their inability to integrate the triplet representations: macroscopic, submicroscopic, and symbolic. This limitation makes it challenging for them to predict equilibrium shifts and provide scientific justification for these changes (Permatasari et al., 2022; Rahmi, 2020).

The Think-Pair-Square (TPSq) learning model is a cooperative approach that integrates three stages: individual thinking (Think), paired discussion (Pair), and small-group discussion (Square). This model aims to enhance critical thinking skills through processes of individual reflection, collaboration, and intensive discussion, thereby deepening students' understanding of the material (Antika et al., 2019; Zahira et al., 2023). The approach provides opportunities for students to sharpen their critical thinking skills by actively engaging in discussion and idea exchange. This study was conducted to examine the effectiveness of the TPSq model in teaching chemical equilibrium at SMA Negeri 13 Samarinda, as an effort to address the understanding gap and improve student learning outcomes through the development of systematic and structured critical thinking skills.

Method

Research methodology encompasses the steps involved in acquiring scientific knowledge or expertise and becoming a scientific approach to obtaining data for specific purposes and utilities. This study employed the Research and Development (R&D) method. Research and development represent the methodology used to enhance a product to improve one of the rights developed by researchers.

This study employed a pre-experimental one-group pretest–posttest design involving 59 students as research participants, selected through cluster random sampling (Almubarak & Rahmat, 2021). The critical thinking skills test was based on five key indicators: simple explanation, building basic skills, inference, further explanation, and strategies and tactics (Putri & Jamaan, 2023).

The research was conducted in two meetings. The first meeting included a pretest to measure students' initial abilities. The preparatory stage began with classroom observations to collect essential information regarding student characteristics, chemistry lesson schedules, teachers' instructional methods, and available facilities and infrastructure. The researcher then determined the research sample and prepared the teaching module used during the learning process. In addition, research instruments, including pretest and posttest questions, question grids, and assessment rubrics, were developed to measure students' critical thinking skills. Finally, a detailed research schedule was established to ensure all activities proceeded according to plan.

During the implementation stage, the research was carried out according to the predetermined schedule. The researcher administered the pretest to the experimental class using questions designed to assess

students' critical thinking skills. After the pretest, the learning process on chemical equilibrium was conducted using the TPSq learning model in the experimental class. Throughout the learning activities, assessments of students' critical thinking skills were carried out. At the second meeting, the posttest was administered using a different set of questions to measure the improvement in students' critical thinking skills. The teacher also distributed student worksheets to guide students during the learning process. After the Square stage, students presented the results of their discussions and participated in a group question-and-answer session.

The data processing stage began with statistical analysis of the collected data to determine the effect of the TPSq model on students' critical thinking skills. The analysis results were then used to develop a comprehensive discussion that connected the research findings with relevant theories and previous studies. Finally, conclusions were drawn based on the analytical results to summarize the overall research process.

The data were analyzed by calculating the mean values of the pretest and posttest, the N-Gain value to determine the relative improvement in critical thinking skills, and the effect size to measure the magnitude of the effect of the TPSq learning treatment. The data analysis included a normality test, a Wilcoxon test, and the calculation of N-Gain and effect size to determine the improvement and effect of the learning intervention (Khairunnisa et al., 2022).

$$\text{N} - \text{Gain} = \frac{\text{S}_{\text{posttest}} - \text{S}_{\text{pretest}}}{\text{Skor Ideal (100)} - \text{S}_{\text{pretest}}}$$

The calculation results were adjusted based on Firda et al. (2022), with the N-Gain score categories presented in Table 1.

Table 1.
N-Gain Score Categories

N-Gain Score	Criteria
0.70 ≤ n ≤ 1.00	High
0.30 ≤ n < 0.70	Medium
0.00 ≤ n < 0.30	Low

Table 1 shows the N-Gain analysis categories for measuring the extent of improvement in student understanding after receiving instruction. According to Khairunnisa et al. (2022), the effect size is a statistical measure that indicates the extent to which one variable affects another or demonstrates how effectively a variable affects another variable. The effect size in this study was calculated to determine the magnitude of the effect produced by applying the TPSq learning model on students' critical thinking skills, particularly in solving problems related to chemical equilibrium. The effect size (d) was calculated using the following formula.

$$d = \frac{(M_2 - M_1)}{\sqrt{\frac{SD\ 1^2 + SD\ 2^2}{2}}}$$

Description:
d = effect size
Mean 1 = average pretest score
Mean 2 = average posttest score
SD 1 = pretest standard deviation
SD 2 = posttest standard deviation

The obtained results were then categorized according to Table 2.

Table 2.
Effect Size Categories

Effect Size	Interpretation
0 < d < 0.2	Small
0.2 ≤ d ≤ 0.5	Medium
0.5 < d ≤ 0.8	High
d > 0.8	Very High

Thabhe reliability test was used to assess the consistency of all items within the instrument. This test aimed to determine whether the results remained consistent when repeated measurements were conducted (Mustaqlilah et al., 2023). One common type of reliability test is the test-retest method, which involves administering the same instrument to the same respondents at two different times. In this method, reliability is determined by correlating the results of the first measurement with those of the second measurement (Forester et al., 2024). The reliability value was calculated using the Pearson Product-Moment correlation formula as follows (Forester et al., 2024).

$$Rxy = \frac{n\sum XY - (\sum X)(\sum Y)}{\sqrt{\{n\sum X^2 - (\sum X)^2\}\{n\sum Y^2 - (\sum Y)^2\}}}$$

Description:

Rxy = correlation coefficient between item score (X) and total score (Y)

n = number of respondents

X = first test score (pretest)

Y = second test score (posttest)

X^2 = square of item score X

Y^2 = square of item score Y

XY = product of X and Y

The level of significance was determined using the following criteria (Forester et al., 2024).

- If r-value > r-table, the correlation is considered significant.
- If r-value < r-table, the correlation is considered insignificant.

Results and Discussion

This study aims to determine the effectiveness of the Think Pair Share learning model on students' critical thinking in chemical equilibrium material. To determine the effectiveness of the Think Pair Share learning model, a pretest and posttest were conducted in the experimental and control classes, as presented in Table 3.

Table 3.
Average Pretest and Posttest Scores

Class	Written Test	Student Score	Category
XI-1	Pretest	25.38	Low
	Posttest	62.11	High
XI-2	Pretest	25.15	Low
	Posttest	60.15	High

Table 3 shows that the average pretest scores of Class XI-1 and Class XI-2 were 25.38 and 25.15, respectively, while the posttest scores increased to 62.11 and 60.15.

In Table 4, after obtaining the average pretest and posttest scores, the analysis continued with the calculation of N-Gain to measure the relative increase in student understanding, using the N-Gain formula -Gain = (posttest - pretest) / (maximum score - pretest), which was categorized as high (>0.7), moderate (0.3-0.7), or low (<0.3). Next, the Effect Size was calculated using the formula Cohen's d = (posttest average - pretest average) / combined standard deviation, to evaluate the strength of the learning intervention's influence on these changes.

Table 4
Data Analysis Results

Class	N-Gain	Effect Size
XI-1 & XI-2	0.480	2.754
Criteria	Medium	Very High

Table 4 The Kolmogorov–Smirnov and Shapiro–Wilk normality tests showed that the data were not normally distributed; therefore, the Wilcoxon test was applied to assess the difference between the pretest and posttest scores. The Wilcoxon test

results were significant (p = 0.000), confirming an increase in students' critical thinking skills. The average N-Gain value of 0.48 falls within the medium category, while the effect size of 2.75 indicates a very high learning effect, demonstrating the significant effect of the TPSq model in improving critical thinking skills. Figure 1 clearly shows the development of student activity in each class from meetings 1 and 2 regarding the implementation of learning as showed in Figure 1.

Figure 1.
Student Learning Activity Data

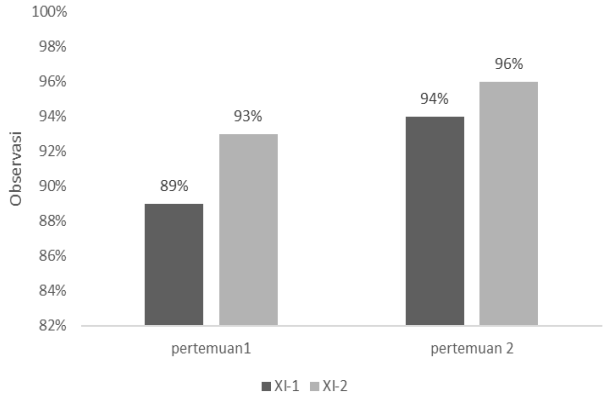
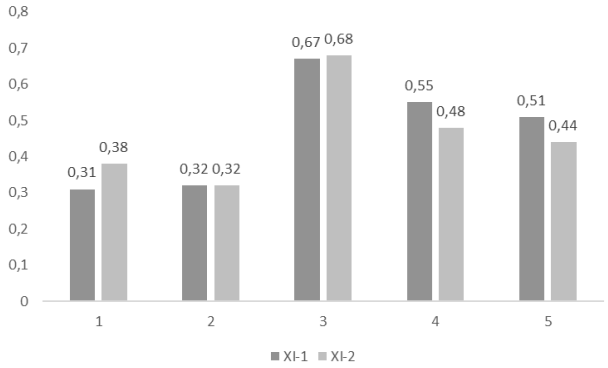


Figure 1 clearly shows that the TPSq learning model has a significant effect on the learning process of students, starting from 89% for class XI-1 and 93% for class XI-2. After the same treatment was applied in the second meeting, it was evident that the teacher successfully implemented the TPSq model with an implementation rate of 100%, while student activity reached 94–96%, indicating a high level of active participation. Comparison of N-Gain for five indicators (1 to 5), where indicator 1 has the lowest value and indicator 3 has the highest value as showed in Figure 2.

Figure 2.
N-Gain of Critical Thinking Skills



Notes:
1 = Providing a Simple Explanation
2 = Building Basic Skills
3 = Drawing Conclusions
4 = Providing Further Explanation
5 = Organizing Strategy and Tactics

Indicator 1, which likely represents the basic concept of misconceptions about chemical equilibrium, such as the understanding of dynamic equilibrium, showed the smallest increase in understanding after the Think Pair Square learning intervention. The TPSq learning model proved effective in enhancing students' critical thinking skills in chemical equilibrium topics. The implementation of this model allowed students to participate actively through the stages of independent thinking (Think), pair discussions (Pair), and small group discussions (Square). This aligns with constructivist theory, which emphasizes the importance of social interaction and collaboration in constructing new knowledge (Martinis et al., 2008; Paul et al., 2014). Thus, TPSq not only enables students to understand concepts individually but also deepens comprehension through discussion and sharing perspectives with peers. The TPSq model enhances critical thinking skills through its three-tiered stages: 1) The Think stage encourages individual reflection to grasp the material; 2) The Pair stage invites students to discuss and strengthen arguments collaboratively; and 3) The Square stage merges two pairs to build collective understanding and draw conclusions (Zahira et al., 2023).

Data analysis from the pretest and posttest revealed a significant improvement in students' critical thinking skills. The medium N-Gain value (0.48) and very high effect size (2.75) demonstrate that the TPSq model had a significant positive effect. This improvement indicates that learning strategies accommodating various learning styles and allowing for experimentation and gradual validation of understanding are highly effective (Amalia et al., 2019; Zahira et al., 2023). In practice, students were encouraged not merely to memorize material but to analyze, evaluate, and synthesize information critically according to the requirements of chemical equilibrium concepts.

Another factor contributing to the success of the TPSq model was the teacher's role as an active facilitator. Teachers systematically guided students' thought processes at each stage of TPSq by posing stimulating questions, leading discussions, and helping to overcome difficulties (Khairunnisa et al., 2022; MZ et al., 2021). This approach helped students grasp complex material more easily while fostering motivation and engagement. The interactive and collaborative classroom atmosphere allowed students to express opinions, ask questions, and engage in discussions comfortably, creating a learning environment conducive to the development of critical thinking skills.

In terms of the indicators of critical thinking skills measured, inference showed the most significant improvement. The N-Gain value of this indicator reached 0.67 to 0.68, categorized as medium and higher than other indicators (Putri et al., 2023; Kusuma et al., 2024). This indicates that the TPSq model encourages students not only to gather and comprehend information but also to process data and develop logical, valid arguments through discussion. In addition, the indicators of providing further explanation and organizing strategies and tactics also showed a notable increase, reflecting students' improved ability to explore the material and plan solutions systematically. Overall, the five indicators of critical thinking skills, particularly inference, showed significant improvement. This finding aligns with previous studies, which confirmed that TPSq provides an optimal environment for students to think critically and collaborate effectively (Amalia et al., 2019; Antika et al., 2019).

Conversely, the indicator with the lowest improvement was providing a simple explanation, with an N-Gain value ranging from 0.31 to 0.38. Although still in the moderate category, this value was relatively lower than other indicators (Antika et al., 2019; Almubarak et al., 2021). This may be due to students' continued difficulty in delivering concise, clear, and focused explanations of the core of the problem using simple language. This finding suggests that while students have begun to develop analytical and evaluative abilities, their mastery of basic communication skills in

presenting effective explanations still requires further enhancement.

Observation of the distribution of skill improvement across indicators indicates that the development of critical thinking does not occur uniformly. Naturally, skills that follow higher levels of thinking, from simplifying information to drawing conclusions and strategizing, require varied approaches and exercises. Hence, teachers can make targeted adjustments and provide additional practice in weaker aspects, such as verbal communication and the articulation of ideas, to ensure that all dimensions of critical thinking skills develop optimally.

However, the TPSq model also has certain limitations, such as relatively longer implementation time and the potential for decreased concentration if the class is not well managed. Some students may find it challenging to maintain focus during prolonged group discussions, making the teacher's role as a facilitator and atmosphere manager essential (Yamin, 2008). Nevertheless, the advantages of this model, in promoting active participation, collaboration, and the enhancement of critical thinking, make it a highly suitable learning strategy, particularly for subjects requiring deep understanding and higher-order thinking, such as chemical equilibrium. The active involvement of teachers and students is key to the success of this model in creating an interactive learning environment that enhances motivation and learning outcomes.

Overall, TPSq has proven effective as a collaborative learning model that empowers students to think critically in an active and structured manner. By emphasizing constructivist and interactive approaches, TPSq not only helps students achieve a deeper understanding of complex chemistry concepts but also equips them with essential critical thinking skills needed in 21st-century education and daily life (Martinis et al., 2008; Paul et al., 2014).

Conclusion

Based on the data analysis conducted, it can be concluded that the TPSq learning model was effective in improving students' critical thinking skills in the chemical equilibrium topic, with an N-Gain value in the moderate category (0.48) and an effect size in the very high category (2.75). The highest improvement was observed in the indicator of "drawing conclusions," with values of 0.67 and 0.68 (moderate category), while the lowest improvement was found in the indicator of "simple explanation," with values of 0.31 and 0.38 (moderate category).

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