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Original Research Article

The 5E Instructional Model and High School Students' Problem-Solving Competence in Redox Reactions: A Quasi-Experimental Study in Vietnam

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Abstract: This study examined the use of the 5E instructional model in teaching redox reactions and its association with high school students' problem-solving competence (PSC). A quasi-experimental design was employed involving an experimental group (n = 48) and a control group (n = 50) at a Vietnamese high school. Data were collected through achievement tests, a PSC rubric, classroom observations, and student self-assessment questionnaires. The results showed that the experimental group obtained higher post-test scores and demonstrated a more favorable score distribution compared to the control group. However, the experimental group also exhibited higher baseline performance in the pre-test, indicating that the groups were not fully equivalent at the outset. The calculated effect size (Cohen's d = 0.89) suggests a substantial between-group difference in post-test performance, although this should be interpreted cautiously due to baseline differences. In addition, the experimental group showed higher scores across key dimensions of PSC, including analysis, planning, implementation, evaluation, and reflection, as well as a higher overall PSC composite score. A significant positive correlation was found between teacher evaluations and student self-assessments ($r = 0.71$, $p < 0.001$). Overall, the findings indicate that the 5E instructional model was associated with more favorable learning outcomes in this context, but no causal inference can be made.

Keywords: 5E Instructional Model, Problem-Solving Competence, Redox Reactions, Chemistry Education, Inquiry-Based Learning, Quasi-Experimental Study.

1. INTRODUCTION

In recent years, competence-based education has become a central focus of educational reform worldwide, emphasizing the development of students' ability to apply knowledge in real-world contexts. Among these competencies, problem-solving competence (PSC) is considered a key component of scientific literacy, enabling learners to analyze complex situations, generate solutions, and evaluate outcomes effectively (OECD, 2019).

In chemistry education, developing PSC is particularly important due to the abstract and multi-representational nature of chemical knowledge. Students are required to integrate macroscopic observations, symbolic representations, and submicroscopic processes, which often leads to misconceptions and learning difficulties (Taber, 2013). Traditional teaching approaches that emphasize rote memorization and procedural problem-solving are insufficient to support meaningful understanding and competence development.

The 5E instructional model (Engage, Explore, Explain, Elaborate, Evaluate), developed by Bybee *et al.*, (2006), has been widely recognized as an effective framework for inquiry-based and student-centered learning. Grounded in constructivist theory (Piaget, 1970; Vygotsky, 1978), the model promotes active engagement, conceptual change, and the development of higher-order thinking skills. Previous studies have reported that the 5E model is associated with improvements in students' academic achievement and problem-solving ability in science education (Duran & Duran, 2004; Prince, 2004).

Recent research continues to support the relevance of the 5E instructional model in science education. A systematic review and meta-analysis by

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Polanin *et al*., (2024) reported positive overall effects of 5E-based and related instructional models on students' learning outcomes in STEM contexts, although the magnitude of these effects varied across studies depending on instructional conditions and research design. In the context of chemistry education, quasi-experimental evidence has also indicated that 5E-based instruction can enhance students' cognitive processes and attitudes toward learning chemistry (Sotáková and Ganajová, 2023).

At the same time, redox reactions remain a conceptually challenging topic for high school students. Learners often experience difficulties in coordinating symbolic representations with submicroscopic explanations and in understanding electron transfer processes, leading to persistent misconceptions (Hadinugrahaningsih *et al*., 2022). These characteristics make redox reactions a particularly suitable context for examining the potential of inquiry-based and student-centered instructional approaches such as the 5E model.

Despite the growing body of research supporting the use of the 5E instructional model, empirical evidence on its application in teaching redox reactions at the high school level remains limited, particularly in the Vietnamese context. In addition, much of the existing literature has focused primarily on academic achievement, while fewer studies have examined problem-solving competence (PSC) in topic-specific chemistry instruction. Given the increasing emphasis on competence-based education and the cognitive demands associated with redox concepts, further context-specific investigation is needed.

Therefore, this study examined the use of the 5E instructional model in teaching redox reactions to Grade 10 students in Vietnam. Specifically, the study aimed to: (1) design and implement 5E-based instructional activities for the topic of redox reactions; (2) compare students' achievement and problem-solving competence between those taught through the 5E model and those receiving conventional instruction; and (3) provide preliminary evidence on the potential value of the 5E instructional model for competence-based chemistry teaching in Vietnamese high schools.

2. METHODOLOGY

2.1 Research Design

This study employed a quasi-experimental pre-test–post-test design involving an experimental group (EG) and a control group (CG). The EG was taught using the 5E instructional model, whereas the CG received conventional teacher-centered instruction. Because intact classes were used, random assignment of students to groups was not feasible. Therefore, the study was designed to compare post-intervention performance patterns between the two groups while taking baseline differences into account. Both groups completed a pre-test before the intervention and a post-test after the instructional period.

2.2 Participants and Context

The participants were 98 Grade 10 students from Yen My High School, Hung Yen Province, Vietnam. Of these, 48 students were assigned to the experimental group and 50 students to the control group. The study was conducted in a natural school setting using two intact classes selected from the same grade level. Both groups followed the same chemistry curriculum and studied the same topic, namely redox reactions, during the intervention period.

The selection of classes was based on administrative feasibility within the school context rather than random assignment. To reduce contextual variation, both groups were taught within the same school term and under comparable classroom conditions. The same teacher taught both groups to ensure consistency in content coverage and instructional time.

Ethical considerations were taken into account. Permission to conduct the study was obtained from the school administration, and students participated voluntarily. All data were anonymized to ensure confidentiality.

2.3 Instructional Procedure

The intervention focused on the topic of redox reactions in Grade 10 chemistry. Both groups studied the same content during the same instructional period; however, the pedagogical approach differed between the two groups.

The intervention lasted for 8 lessons (approximately 4 weeks), which is consistent with the standard curriculum allocation for this topic in Vietnamese high schools.

In the experimental group, instruction was organized according to the five phases of the 5E instructional model: Engage, Explore, Explain, Elaborate, and Evaluate. Learning activities were designed to promote active participation, conceptual discussion, and problem-solving practice related to oxidation–reduction concepts.

In the Engage phase, students were introduced to motivating questions or chemical situations related to redox processes. In the Explore phase, they worked individually or in groups to examine examples, identify patterns, and discuss initial ideas. In the Explain phase, students clarified their reasoning with teacher guidance and connected their observations to formal chemical concepts. In the Elaborate phase, they applied their understanding to new exercises and problem-solving tasks. Finally, in the Evaluate phase, students completed formative or summative tasks to demonstrate their understanding and problem-solving performance.

In contrast, the control group received conventional instruction emphasizing teacher explanation, textbook-based examples, and individual practice. The lesson content, total instructional time, and assessment points were kept as comparable as possible across the two groups.

2.4 Instruments

Multiple instruments were used to collect data, including achievement tests, a problem-solving competence (PSC) rubric, classroom observation notes, and student self-assessment questionnaires.

The achievement tests consisted of a pre-test and a post-test designed to assess students' understanding of redox reactions and their ability to solve related chemistry problems. Each test included 20 items and was scored on a 10-point scale. The pre-test was administered before the intervention to examine baseline performance, while the post-test was administered after the instructional period to compare learning outcomes between the two groups.

The PSC rubric was developed to assess students' problem-solving performance in chemistry tasks. It consisted of ten criteria organized into five dimensions: analysis, planning, implementation, evaluation, and reflection. Each criterion was scored on a 4-point scale (1 = low, 4 = high). Because each dimension contained two criteria, mean scores were calculated for each dimension and reported on the same 1-4 scale. For comparative analysis, an overall PSC composite score was computed by summing the five dimension mean scores. Therefore, the overall PSC composite ranged from 5 to 20 rather than representing the raw total score of all ten criteria. Higher scores indicated stronger overall problem-solving competence.

Classroom observations were conducted during the intervention to document student participation, interaction patterns, and classroom responses to instructional activities. In addition, student self-assessment questionnaires were administered to gather learners' perceptions of their own problem-solving processes and engagement in learning activities. The questionnaire included 10 items using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree).

2.5 Validity and Reliability of Instruments

The content validity of the instruments was established through expert review prior to the main study. Three experts in chemistry education examined the alignment of the test items and rubric criteria with the learning objectives of the redox reactions unit and the intended dimensions of problem-solving competence. Based on their feedback, revisions were made to improve the clarity, relevance, and wording of several items.

A pilot study was conducted with 20 students before the main intervention to examine the clarity and usability of the instruments. Based on the pilot results, ambiguous wording was revised and several items were refined to improve comprehension and scoring consistency.

The internal consistency of the PSC rubric was evaluated using Cronbach's alpha, which yielded a coefficient of $\alpha = 0.87$, indicating good reliability. To enhance the robustness of the PSC assessment, rubric-based teacher ratings were also compared with students' self-assessment scores in the post-intervention analysis. This comparison provided additional evidence supporting the consistency of the PSC measurement.

2.6 Data Analysis

The collected data were analyzed using both descriptive and inferential statistical methods. Descriptive statistics, including mean (M) and standard deviation (SD), were used to summarize students' performance in the pre-test and post-test for both the experimental group (EG) and the control group (CG). In addition, frequency distributions and cumulative percentages were used to examine overall performance patterns across score ranges.

To examine initial group equivalence, an independent samples t-test was conducted on pre-test scores. The result indicated a statistically significant difference between the two groups at baseline, $t(96) = 4.52$, $p < .001$, with a large effect size ($d = 0.91$).

To examine between-group differences in post-test performance, an independent-samples t-test was conducted. Cohen's d was calculated to estimate the magnitude of the between-group difference.

Because the groups were not randomly assigned and baseline differences were detected, the post-test results were interpreted cautiously. Where possible, adjusted analyses such as analysis of covariance (ANCOVA), with post-test score as the dependent variable, group as the fixed factor, and pre-test score as the covariate, are recommended to control for initial differences. In the present study, emphasis was placed on comparative performance patterns rather than causal inference. This approach is consistent with recommended practices for analyzing quasi-experimental data with non-equivalent groups.

All statistical analyses were conducted at a significance level of $\alpha = .05$.

3. RESULTS AND DISCUSSION

3.1 Pre-test Results

The pre-test results (Table 1, Figure 1) reveal that the experimental group (EG) demonstrated higher initial performance than the control group (CG). The cumulative distribution curves indicate that a greater proportion of students in the EG achieved higher score ranges (7–10), whereas the CG was more concentrated in the mid-score range.

Table 1: Distribution of pre-test scores for control group (CG) and experimental group (EG)

Score (xi)	CG (Frequency)	EG (Frequency)	CG (%)	EG (%)	CG Cumulative (%)	EG Cumulative (%)
0	0	0	0.00	0.00	0.00	0.00
1	0	0	0.00	0.00	0.00	0.00
2	0	0	0.00	0.00	0.00	0.00
3	1	0	2.00	0.00	2.00	0.00
4	3	1	6.00	2.08	8.00	2.08
5	11	3	22.00	6.25	30.00	8.33
6	8	4	16.00	8.33	46.00	16.67
7	12	4	24.00	8.33	70.00	25.00
8	8	16	16.00	33.33	86.00	58.33
9	5	12	10.00	25.00	96.00	83.33
10	2	8	4.00	16.67	100.00	100.00
Total	**50**	**48**	**100.00**	**100.00**		

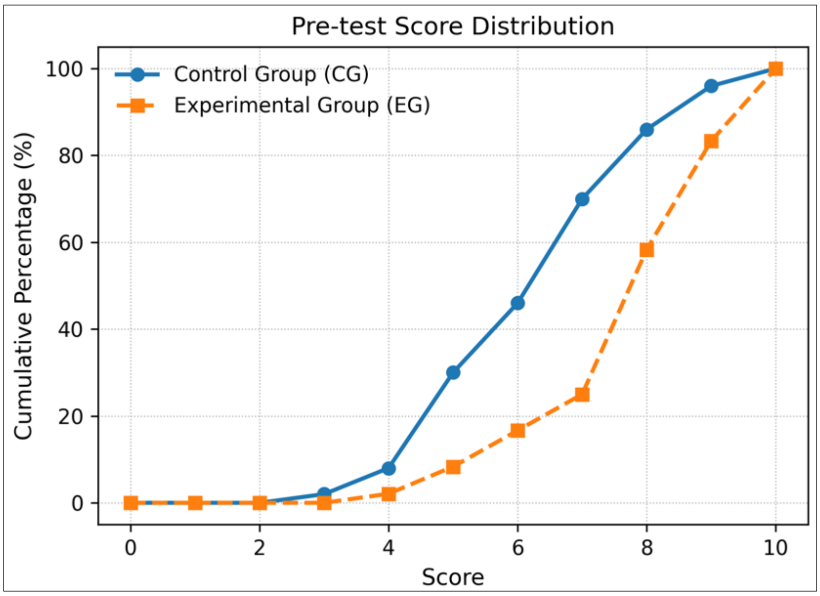

Figure 1: Cumulative percentage distribution of pre-test scores

These results indicate that the two groups were not equivalent at baseline, with the experimental group demonstrating higher initial performance. While such variation is not uncommon in quasi-experimental studies involving intact classes, it represents a potential source of bias when interpreting post-intervention outcomes. Therefore, subsequent analyses focus on between-group differences in post-test performance, score distributions, and effect size, rather than definitive causal inference.

3.2 Post-Test Results

As shown in Table 2 and Figure 2, the experimental group (EG) obtained a higher mean post-test score than the control group (CG). However, the EG also showed higher baseline performance in the pre-test, indicating that the two groups were not fully equivalent at the beginning of the study. The effect size (Cohen's d = 0.89) suggests a substantial between-group difference in post-test performance; however, because the groups were non-equivalent at baseline, this result should be interpreted as an association rather than definitive causal evidence.

Table 2: Comparison of pre-test and post-test scores for control group (CG) and experimental group (EG)

Group	N	Pre-test M (SD)	Post-test M (SD)
CG	50	6.62 (1.65)	6.44 (1.72)
EG	48	8.06 (1.50)	7.92 (1.58)
Note. Pre-test comparison: $t(96) = 4.52$, $p < .001$, $d = 0.91$. Post-test comparison: $t(96) = 4.43$, $p < .001$, $d = 0.89$.			

The effect size (Cohen's d = 0.89) suggests a substantial between-group difference in post-test performance. However, because the groups were non-equivalent at baseline, this difference should be interpreted as an association rather than definitive causal evidence.

The mean post-test score of the EG (M ≈ 7.92) exceeded that of the CG (M ≈ 6.44), as illustrated in Figure 2. This indicates that students in the experimental group maintained a higher overall performance level at the end of the instructional period. However, because the experimental group also demonstrated higher baseline performance, the post-test difference should not be interpreted as definitive evidence of improvement attributable solely to the intervention. A more cautious interpretation is that the 5E instructional model was associated with a more favorable post-test performance pattern, as reflected in both the higher mean score and the greater concentration of students in the upper score ranges. These findings suggest a possible contribution of the intervention to student performance, but they do not by themselves establish clear causal improvement.

Table 3: Distribution of post-test scores for control group (CG) and experimental group (EG)

Score (xi)	CG (Frequency)	EG (Frequency)	CG (%)	EG (%)	CG Cumulative (%)	EG Cumulative (%)
0	0	0	0.00	0.00	0.00	0.00
1	0	0	0.00	0.00	0.00	0.00
2	0	0	0.00	0.00	0.00	0.00
3	2	0	4.00	0.00	4.00	0.00
4	4	2	8.00	4.17	12.00	4.17
5	10	2	20.00	4.17	32.00	8.33
6	10	5	20.00	10.42	52.00	18.75
7	11	6	22.00	12.50	74.00	31.25
8	6	15	12.00	31.25	86.00	62.50
9	5	10	10.00	20.83	96.00	83.33
10	2	8	4.00	16.67	100.00	100.00
Total	**50**	**48**	**100.00**	**100.00**		

The cumulative distribution curve for the EG shows a rightward shift relative to the CG (Figure 3), indicating that a larger proportion of EG students were concentrated in the upper score ranges, whereas the CG remained more concentrated in the middle score ranges.

Overall, these findings suggest that students in the experimental group maintained a higher performance level and exhibited a more favorable post-test score distribution. However, given the initial baseline differences, these results should be interpreted cautiously and not as conclusive evidence that the intervention alone caused the observed differences.

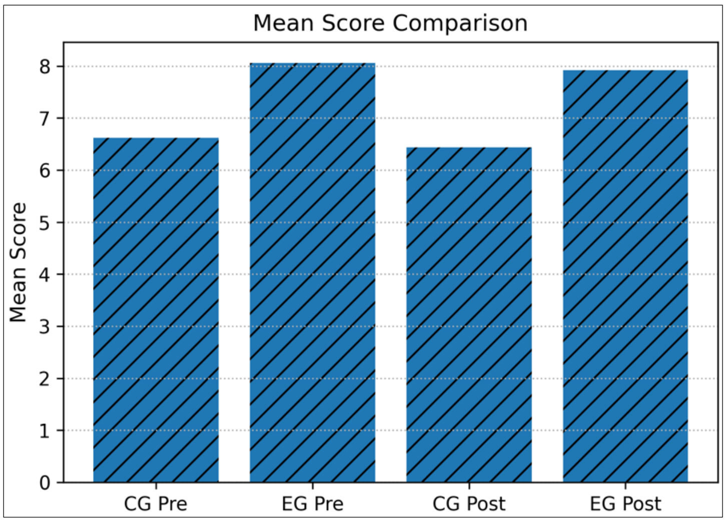

Figure 2: Mean comparison between control group (CG) and experimental group (EG) in pre-test and post-test

Figure 2 further illustrates that the EG maintained a higher mean score than the CG in both pre-test and post-test measures.

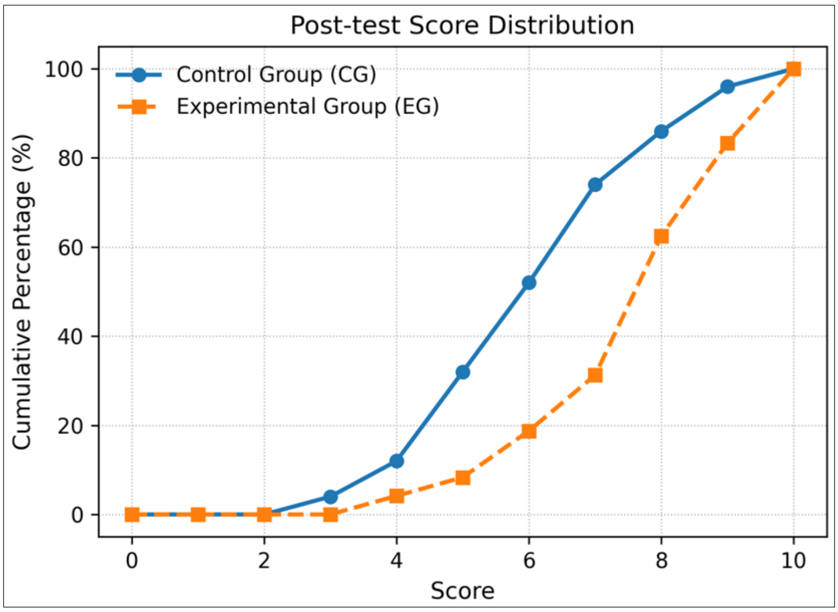

Figure 3: Cumulative percentage distribution of post-test scores for CG and EG

In addition to mean comparisons, the distribution of post-test scores provides further insight, confirming that the EG showed a greater concentration of students in the higher score ranges compared to the CG (Table 3; Figure 3).

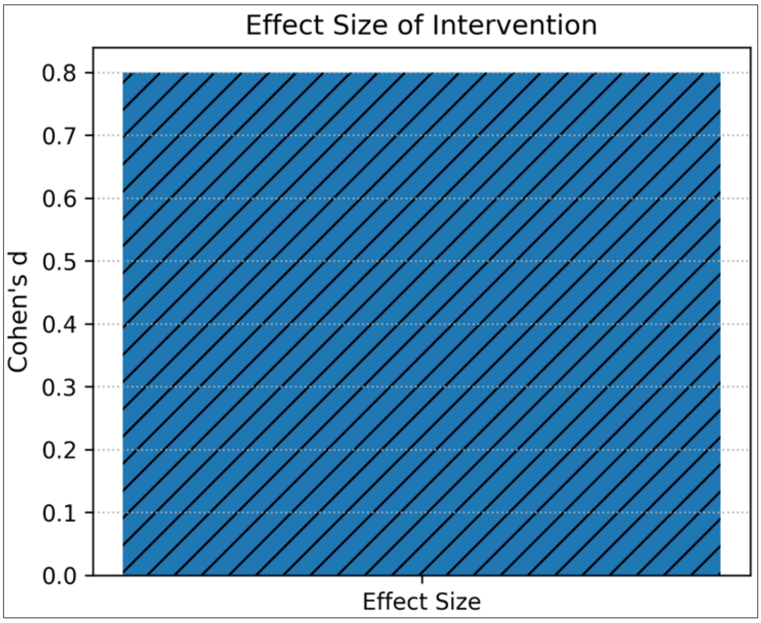

Figure 4: Effect size (Cohen's d) of the intervention

The effect size estimate (Figure 4) reflects the magnitude of the between-group difference in post-test performance. While Cohen's d = 0.89 indicates a substantial difference, this result should be interpreted in light of the non-equivalence of groups at baseline.

Importantly, although the EG demonstrated higher post-test performance, this group also showed higher baseline scores in the pre-test. Therefore, the observed differences should not be interpreted as definitive evidence of causal impact. Instead, the results suggest that the 5E instructional model may have been associated with more favorable performance patterns, particularly a greater concentration of students in the higher score ranges within the experimental group.

3.3 Problem-Solving Competence Results

The analysis of problem-solving competence (PSC) provides further evidence of differences between the experimental group (EG) and the control group (CG), using the PSC rubric described in Section 2.4. Table 4 summarizes students' mean scores across the five PSC dimensions as well as the overall PSC composite score, which was calculated as the sum of the five dimension mean scores.

Table 4: Comparison of problem-solving competence (PSC) dimension scores and overall PSC composite between control group (CG) and experimental group (EG)

Dimension	CG Mean (SD)	EG Mean (SD)	t	p	Cohen's d
Analysis	2.63 (0.56)	3.19 (0.51)	4.95	<0.001	1.04
Planning	2.58 (0.59)	3.14 (0.53)	4.62	<0.001	0.97
Implementation	2.72 (0.55)	3.06 (0.50)	3.18	0.002	0.65
Evaluation	2.51 (0.61)	3.11 (0.54)	5.21	<0.001	1.09
Reflection	2.44 (0.63)	3.09 (0.56)	5.34	<0.001	1.12
Overall PSC composite	12.88 (2.08)	15.59 (1.96)	6.27	<0.001	1.26

Students in the experimental group achieved higher mean scores across all PSC dimensions compared to those in the control group. The largest differences were observed in higher-order cognitive processes, including analysis, evaluation, and reflection, with large effect sizes (Cohen's $d > 1.00$).

The overall PSC composite score of the experimental group ($M = 15.59$, $SD = 1.96$) was substantially higher than that of the control group ($M = 12.88$, $SD = 2.08$), indicating a notable between-group difference in overall problem-solving competence.

In addition, a statistically significant positive correlation was found between teacher evaluations and student self-assessments ($r = 0.71$, $p < 0.001$), suggesting a strong level of consistency between external and self-reported measures of problem-solving competence.

However, given the initial non-equivalence between groups at baseline, these differences should be interpreted cautiously and considered as indicative of association rather than definitive causal effects.

4. DISCUSSION

The findings of this study suggest that students taught through the 5E instructional model demonstrated more favorable post-test performance patterns than those receiving conventional instruction. Although the experimental group showed higher baseline performance, the post-test results indicate that this group maintained its relative advantage and exhibited a greater concentration of scores in the higher achievement ranges. These patterns may indicate a possible association between the 5E instructional model and student performance outcomes.

The effect size (Cohen's $d = 0.89$) further suggests a substantial between-group difference in post-test performance. However, because the experimental and control groups were not equivalent at baseline, this difference should not be interpreted as conclusive evidence that the intervention alone produced the observed outcome.

The PSC results provide additional support for this interpretation. The experimental group obtained higher scores across all reported PSC dimensions, particularly in analysis, evaluation, and reflection. These findings are consistent with constructivist learning theory, which emphasizes active engagement, inquiry, and reflection as key mechanisms for developing higher-order problem-solving competence.

At the same time, the PSC findings should also be interpreted cautiously. Although the higher PSC scores in the experimental group are noteworthy, the non-equivalence of groups at the beginning of the study limits strong causal interpretation. Therefore, the results are better understood as evidence of an association between 5E-based instruction and more favorable achievement and PSC patterns within this instructional context.

Future studies may apply more rigorous statistical controls, such as analysis of covariance (ANCOVA) using pre-test scores as covariates, to adjust for baseline differences and strengthen causal interpretation.

Nevertheless, the overall pattern of findings indicates that the 5E instructional model may provide a supportive framework for helping students engage more actively with conceptually demanding chemistry content such as redox reactions. Future research is recommended to employ more rigorous statistical controls, such as ANCOVA, or randomized designs to strengthen causal inference.

Due to the non-equivalence of groups at baseline, the findings of this study should be interpreted with caution. More rigorous statistical approaches, such as ANCOVA or gain score analysis, are recommended in future research to control for initial differences and provide stronger evidence for causal interpretation.

5. CONCLUSION

This study examined the use of the 5E instructional model in teaching redox reactions and its association with high school students' problem-solving competence (PSC). The findings indicate that students in the experimental group obtained higher post-test scores and showed more favorable performance on problem-solving tasks than those in the control group. In particular, the results highlight quantitative differences in higher-order cognitive processes, including analysis, planning, implementation, evaluation, and reflection.

These patterns suggest that the structured inquiry-based learning cycle embedded in the 5E model may be associated with productive problem-solving processes in chemistry education. Although the experimental group exhibited higher baseline performance, the observed post-intervention patterns, including the shift toward higher achievement ranges and the more favorable PSC profile of the experimental group, suggest that the 5E instructional model may have played a role in shaping student performance. However, this interpretation should be made cautiously because the groups were not fully equivalent at baseline.

From a pedagogical perspective, this study contributes to the growing body of research on competence-based education by demonstrating how structured instructional models can be implemented in secondary school contexts to support active engagement, deeper understanding, and higher-order thinking. However, several limitations should be acknowledged. The use of intact groups resulted in initial differences between the experimental and control groups, which may have influenced the outcomes. In addition, the study was conducted within a single school context and over a limited instructional period, which may restrict the generalizability of the findings.

Future research is recommended to employ more rigorous experimental designs, such as randomized controlled trials or statistical approaches like ANCOVA, to better control for baseline variation. Further studies should also explore the long-term impact of the 5E model and its potential integration with other instructional strategies to enhance creativity and divergent thinking.

In conclusion, while acknowledging its limitations, this study provides preliminary evidence that the 5E instructional model may be a promising approach for supporting problem-solving competence in chemistry education.

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