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Interventions into students' academic performance at HOTS levels in redox reactions using problem-based learning and peer-tutoring strategies

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Abstract: The impact of problem-based learning and peer-tutoring strategies on the higher-order thinking performance of grade ten students in redox reactions in Kogi State, Nigeria, was explored using a quasi-experimental design of pretest-posttest unequal group setting. The population comprised 795 grade 10 students from 33 co-educational schools, out of which 146 students (males = 69, females = 77) emerged as the sample. Data were collected using the Higher Order chemistry Performance Test (HOCPT) with a reliability coefficient of 0.83. Mean, SD, bar charts, and ANCOVA were deployed for analysis. Both problem-based learning and peer-tutoring strategies considerably enhanced students' academic performance at higher-order thinking levels in redox reactions. Gender was not a determining factor in the effectiveness of these strategies, and a considerable interaction effect was not observed between strategies and gender. These findings suggest that problem-based learning and peer tutoring are effective in improving students' HOTS performance in chemistry, regardless of gender. Organization of training workshops to help chemistry teachers with the skills needed to implement activity-based instructional strategies effectively was recommended.

Keywords: HOTS, performance, peer-tutoring strategy, redox reactions

Abstrak: Dampak pembelajaran berbasis masalah dan strategi bimbingan sebaya terhadap kinerja berpikir tingkat tinggi siswa kelas sepuluh dalam reaksi redoks di Negara Bagian Kogi, Nigeria, dieksplorasi menggunakan desain kuasi-eksperimental dari pengaturan kelompok yang tidak sama dengan tes awal dan tes akhir. Populasi terdiri dari 795 siswa kelas 10 dari 33 sekolah pendidikan bersama, yang mana 146 siswa (laki-laki = 69, perempuan = 77) muncul sebagai sampel. Data dikumpulkan menggunakan Tes Kinerja Kimia Tingkat Tinggi (HOCPT) dengan koefisien reliabilitas 0,83. Rata-rata, standar deviasi, diagram batang, dan ANCOVA digunakan untuk analisis. Baik strategi pembelajaran berbasis masalah maupun bimbingan sebaya secara signifikan meningkatkan kinerja akademik siswa pada tingkat berpikir tingkat tinggi dalam reaksi redoks. Jenis kelamin bukanlah faktor penentu dalam efektivitas strategi ini, dan efek interaksi yang cukup besar tidak diamati antara strategi dan jenis kelamin. Temuan ini menunjukkan bahwa pembelajaran berbasis masalah dan bimbingan sebaya efektif dalam meningkatkan kinerja HOTS siswa dalam mata pelajaran Kimia, tanpa memandang jenis kelamin. Penyelenggaraan lokakarya pelatihan untuk membantu guru Kimia dengan keterampilan yang dibutuhkan untuk menerapkan strategi pengajaran berbasis aktivitas secara efektif direkomendasikan.

Kata kunci: HOTS, kinerja, strategi bimbingan sebaya, reaksi redoks

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INTRODUCTION

Chemistry is highly influential in the development of any nation from scientific-technological perspectives (Agogo & Onda, 2014). It holds a unique position in driving global advancements in science and technology (Shamduddin et al., 2017). Through the exploration of the natural world, chemistry has considerably contributed to fulfilling fundamental human needs, including food, clothing, housing, medicine, transportation, fertilizers, and insecticides (Opara & Waswa, 2013). From the aforementioned definitions, it is obvious that chemistry is a very essential science core subject for scientific and technological growth and for building entrepreneurial skills, which drive national growth via job creation. Due to the recognized importance of chemistry in both individual and national development, it has been designated as a prerequisite subject for entry into the education system in Nigerian, which gives a broad spectrum of natural and applied science courses, including biochemistry, chemical engineering, laboratory technology, medicine, pharmacy, pharmacognosy, toxicology, agricultural science, geology, and environmental science (Bugaje, 2013).

The numerous contributions made by chemistry notwithstanding, the study of the subject in schools is bedeviled with poor performance at higher-order thinking levels. Over the years, there has been a weakening students' performance in chemistry in public examinations conducted nationwide by the West African Examinations Council (WAEC) and the National Examinations Council (NECO) (Uchegbu et al., 2017; Nja et al., 2020; Nwankwo & Okigbo, 2021; Ojengwa et al., 2024). Students see chemistry as abstract and challenging, which is ascribed to their low performance in the subject (Kyado et al., 2021). This was further suggested by Kyado et al. (2021), and Uchegbu et al. (2016) identified that learners perceive certain chemistry concepts—such as chemical kinetics, thermodynamics, quantitative analysis, ionization, alkanols, hydrophobic interactions, redox reactions, hydrocarbons, stoichiometry, neutralization, quantum numbers, enantiomers, gas laws, enthalpy, mole concepts, atomicity, and nuclear chemistry—as particularly challenging. Also, several studies have implicated difficulties students face in learning chemistry: redox reactions, understanding of oxidation and reduction half reactions, salt bridges in electrolysis (Adu-Gyamfi et al., 2015; Bong & Lee, 2016; Walanda et al., 2017).

Adu-Gyamfi et al. (2015) highlighted that students' learning challenges in balancing redox reactions often arise when introducing H^+, OH^-, and H_2O. Bong and Lee (2016) aligned these challenges with the absence of foundational knowledge in electrochemistry, language barriers, and reliance on mindless learning. Lawal et al. (2017) observed that most teachers predominantly use lecture-based strategies to teach redox reactions rather than active learning approaches. Ahmad (2019) criticized this method as ineffective, noting its inability to enhance students' academic performance. Isa et al. (2020) also noted that the lecture technique neglects to include activity-based learning, which is crucial for the application of information to real-world issues. Iftiah et al. (2023) contended that teacher-centered teaching fails to promote skill development, objectivity, or critical thinking in learners. In addition, Fernandez et al. (2013) noted that students often resort to memorizing chemistry facts merely to pass examinations, hindering meaningful learning. Weak mastery of fundamental concepts has been identified as a major obstacle in chemistry education (Burrows & Moorings, 2015; Luxford & Bretz, 2014). Ghani et al. (2017) emphasized that improving students' understanding of basic concepts is crucial for growing higher-order thinking skills (HOTS). Therefore, focus on beginning knowledge is essential for enhancement of students' cognitive abilities and overall learning aftermath in chemistry.

The term HOTS has been widely used in the literature of cognition. Sulaiman et al. (2017) stated HOTS as the capacity to use skills, knowledge, and values in reflection, reasoning, decision-making, problem-solving, and promoting innovation and creativity. Rosli and Maarof (2017) describe HOTS as the ability to use information, skills, and values in decision-making, problem-solving, deep thinking, and innovation. According to Cao (2018), and Pambudi et al. (2022), HOTS involves critical thinking, reflective thinking, meta-cognition, and creative thinking. Likewise, Kusumastuti et al. (2019) describe HOTS as the ability to think broadly, generate new ideas, and apply both new and prior knowledge to solve problems in dynamic situations. HOTS is associated with Bloom's taxonomy. The revised Bloom's taxonomy has six levels. The authors further disclose that creating is the peak of the cognitive realm. Bloom's taxonomy is an educational scaffold that organises teaching and learning outcomes. It helps group questions into higher-order thinking skills (HOTS) categories like analysis, evaluation, and creation (Bowker & Fazioli, 2016). To realize this need, it becomes a must that students should be guided in developing Higher-Order Thinking Skills (HOTS) through various aspects, including critical thinking, creativity, problem-solving, and high-level decision-making, which can be nurtured throughout the learning process (Pramesti et al., 2019). This development should take place both in the classroom and in the laboratory, where students can engage in hands-on, inquiry-based (Yonata & Nasrudin, 2018), and in assessment activities (Razmawaty & Othman, 2017).

HOTS are a crucial component of educational goals, equipping students to navigate real-life challenges (Khoiriyah & Husamah, 2018). The inclusion of HOTS-based questions in examinations encourages deeper thinking, enhances learning motivation by incorporating stimuli from the surrounding environment, and ultimately improves students' academic performance (Ghani et al., 2017). Furthermore, HOTS questions help students become more competitive at both national and international levels (Fanani, 2018). Research by Kusuma et al. (2017) and Ramadhan et al. (2019) indicates that HOTS assessment instruments effectively train and evaluate students' thinking skills. The primary objective is to foster critical thinking and problem-solving abilities by engaging students in inquiry-based learning, where they actively explore relevant questions rather than passively receiving information (John et al., 2017). However, HOTS cannot be taught directly; instead, students must develop these skills through structured learning activities that support their cognitive growth (Retnawati et al., 2018).

According to Udu (2018), selecting appropriate HOTS training activities reflects effective teaching techniques and enhances learning outcomes. To foster students' critical and deep thinking, as well as performance skills—key components of HOTS—teachers should employ diverse instructional strategies. These strategies, which emphasize learner-centered and activity-oriented approaches, encourage shared responsibilities between students and instructors. Among them are peer tutoring and problem-based learning (PBL). Additionally, studies by Baransano et al. (2017), Shadrec et al. (2018), and Werimon et al. (2017) have shown that active learning methods, such as cooperative learning, peer teaching, and problem-solving instruction, considerably improve chemistry students' achievement.

PBL is a student-centered instructional approach where both teachers and students take active roles in the learning process (Nwankwo et al., 2024). In a PBL classroom, the teacher primarily acts as a coach and facilitator, guiding students' learning and comprehension while students develop new ideas and concepts by building upon their existing knowledge (Murti et al., 2024; Omaga et al., 2017; Silahooy et al., 2019; Zhang et al., 2015; Zhen-jie et al., 2017). PBL is a strategy that cultivates deep thinking and problem-solving skills (Aidoo et al., 2016) by tasking students with common daily life huddles that they must analyze and resolve (Zannah et al., 2022). The effectiveness of PBL has been stressed by many educationists and studies have explored PBL from various perspectives, with its theoretical foundation rooted in Vygotsky's constructivism (Boye & Agyei, 2023). This theory emphasizes social interface and collaboration, positioning PBL as an instructional strategy that fosters active learning (Doolittle et al., 2023). Rather than merely delivering content, teachers in a PBL setting serve as facilitators, guiding learners and encouraging them to gather knowledge independently, rather than strictly adhering to a traditional curriculum (Fitria et al., 2022).

Studies of Jimoh and Fatokun (2020); Chileya and Shumba (2020); Onyi et al. (2022) demonstrated a statistically significant difference in accomplishment mean scores in chemistry, favouring the experimental group subjected to Problem-Based Learning (PBL). The results indicated that PBL is an effective pedagogical method for improving learners' critical thinking and problem-solving abilities. Likewise, PBL fosters advanced cognitive abilities, including creativity and critical analysis (Afikah et al., 2022; Apipah & Novaliyosi, 2023; Iwan et al., 2020; Khanam & Awan, 2022; Sartika et al., 2023). Additionally, a study conducted by Ayyildiz and Tarhan (2017) averred that learners taught through problem-based instruction outperform those taught using traditional methods. However, Kulo and Cestone (2023) argue that the evidence supporting PBL's superiority remains inconclusive. Regarding gender differences, Joy (2014), and Jimoh and Fatokun (2020) found no considerable differences in achievement between chemistry students taught using PBL based on gender. Contrarily, Raimi and Sodamade (2018) reported that PBL benefits female students more at the cognitive level, though not at the affective level. Further, Onyi et al. (2022) found that PBL had a considerable influence on student achievement, favoring male students

Peer tutoring or peer-assisted learning or peer mentoring as named interchangeably, is an effective and cost-efficient technique that offers students academic and personal help from their peers (Jibrin et al., 2016). Rooted in both behaviorist and constructivist learning theories (Botty & Shahrill, 2014), peer tutoring is an active teaching approach that promotes student inclusion and collaborative learning (Cockerill et al., 2018). Okechukwu et al. (2019) describe peer tutoring as an instructional method in which students receive guidance from trained peers under a teacher's supervision. Similarly, Igbo (2015) defines it as a process where a proficient student helps another student under the teacher's oversight. This technique involves pairing a higher-performing student with a lower-performing one to reinforce critical academic or behavioral concepts. Peer tutoring benefits both tutors and tutees by enhancing subject comprehension while fostering essential communication and teamwork skills (Adamu & Kusa, 2018).

Peer tutoring is noted for making a positive impact on students' academic endeavours. Wael (2014) advocated its use to enhance overall student performance. Beyond academics, the strategy encourages student inclusion (Malone et al., 2019) and boosts classroom climate (Jean-Francois, 2017). This strategy encourages both academic and social interactions, promoting active learning and participation (Fung et al., 2018). Peer tutoring not only enhances students' academic performance but also strengthens their reporting skills and mutual relationships (Tran, 2014). Additionally, it builds confidence in introverted students, enabling shy learners to play part actively in the learning operation (Bombardelli, 2016). this approach, tutees receive direct instruction from a peer, while tutors reinforce their knowledge by explaining concepts and answering questions. Given the shared discourse between students, tutees often feel more comfortable asking questions and gaining a deeper understanding of the content (Ayvazo & Aljadeff-Abergel, 2019). Empirically, studies conducted by Azeez et al. (2022), Ogunleye and Bamidele (2014), and Samuel and Sambo (2019) reported significant differences in the average achievement scores of students learning chemistry using peer tutoring learning techniques, with the experimental group showing greater improvement. Jibrin et al. (2016) observed that the implementation of a peer-tutoring technique in the classroom facilitates active student engagement in the learning process, promotes idea exchange, alleviates anxiety, and enhances academic achievement, irrespective of gender. On the contrary, a study conducted by Ovie (2022) revealed that there was a considerable sex influence on students' chemistry achievement when exposed to peer instructional strategy.

Research on gender differences in academic achievement, particularly in science subjects like chemistry, has yielded mixed findings. Joseph et al. (2015) and Ushie and Edinyang (2018) suggest that gender considerably influences students' academic achievements, making it a crucial factor in educational discourse. With gender equity gaining attention in Nigeria, the concept is often understood as a cultural construct defining the roles of males and females in society (Filgona & Sababa, 2017). While some scholars argue that differences in strengths and weaknesses exist between the sexes (Olagbaju, 2014), others see gender-related disparities in academic performance as a complex and often contradictory issue (Ezenwafor & Obidile, 2016). Some studies, such as those by Ebenuwa-Okoh (2016), Kareem (2015), and Olasehinde and Olatoye (2014), found no considerable difference in chemistry achievement between students' genders. However, Azibaolanari et al. (2016) reported a notable difference in achievement between genders. Additionally, Nnenna and Adukwu (2018), Odagboyi (2015), and Dania (2014) found that male students tended to outperform their female counterparts in chemistry. These contradictory results underscore the necessity of further study to comprehend the fundamental factors contributing to gender disparities in academic performance in chemistry. These inconclusive results on gender call for further investigation to find out if chemistry-based learning and peer-tutoring strategies may enhance students' academic performance at the HOTS level regardless of gender.

The Federal Republic of Nigeria (FME, 2013) highlights the importance of employing learner-centered and activity-based teaching strategies, ensuring that educational activities prioritize the learner for optimal self-development and fulfillment. In an attempt to achieve this by chemistry teachers, several Despite the use of instructional strategies like lectures, discussions, and demonstrations in teaching chemistry, students' academic achievement in the Senior School Certificate Examination (SSCE), particularly in WAEC and NECO, has remained unimpressive in recent years (Isa et al., 2020; Nwankwo & Okigbo, 2021). The consequences of poor performance of students at higher-order thinking levels in chemistry could impede the chance of students pursuing careers in pharmacy, medicine, and engineering which will in turn hinder the socio-economic development of Nigeria.

This continuous poor tendency in the performance of students who study chemistry is so alarming that the strategies being employed in teaching/ learning processes seem to be ineffective. These instructional strategies emphasize the passive acquisition of knowledge of chemistry, thereby resulting in poor academic performance. Under these circumstances, learning appears not to be for conceptual understanding but rather memorisation and recollection of facts based on the cognitive level of growth. This emerging concern has necessitated research on strategies in which students play an active, collaborative, and interactive role with each other to construct student knowledge, especially in HOTS.

METHOD

We conducted this quasi-experimental study in Ankpa, Kogi State, using a pretest-posttest unequal group design. The target population comprised 734 Senior Secondary School II chemistry students from 33 schools in the Ankpa Education Zone. Using a purposive sampling technique, we selected 146 students (77 females and 69 males) from three intact schools. The schools were randomly assigned to the two groups (experimental and control), ensuring each had an equal and independent chance of inclusion. Selection criteria included government-approved co-educational schools with a conducive learning environment, functional chemistry laboratories, WAEC and NECO accreditation for at least ten years, and qualified chemistry teachers holding a first degree with at least five years of teaching experience.

A single instrument, the Higher Order Chemistry Performance Test (HOCPT), was developed to measure students' achievement and knowledge gained during the experimentation. The HOCPT consisted of 25 multiple-choice questions, each with four options, drawn from past WAEC and UTME questions on redox reactions and key chemistry concepts. To ensure validity, the instrument underwent face and content validation by three experts. Based on their feedback, necessary corrections and modifications were made before conducting a trial test. The K-R21 yielded a reliability coefficient of 0.83 for the HOCPT, indicating that the instrument was sufficiently reliable for the study.

The subject teachers in the chosen schools underwent training as research assistants on the use of problem-based learning and peer-tutoring strategies using validated lesson packages on the redox reactions concept of chemistry developed by the researcher. Treatment was assigned to two experimental groups (Problem-based learning strategy and Peer-tutoring strategy) and one control group (Lecture method). Each group was taught Redox reactions. This topic was broken into five (5) teaching lessons. Each lesson was taught within two (2) periods of 40 minutes each per week. The treatment was conducted over five weeks. Following the intervention, the Higher Order chemistry Performance Test (HOCPT), which was initially used as a pre-test, was reshuffled and administered as a post-test to assess the impact of the treatment. The entire research process was completed within seven weeks. Efforts were made to control and minimize the influence of extraneous variables during data collection. The data obtained were analysed using mean, SD, and a bar chart. Additionally, ANCOVA was employed.

RESULTS AND DISCUSSION

Problem-based learning, peer-tutoring strategies and students' performance at HOTS level

Results in Table 1 reveal that the mean performance scores of students taught redox reactions using PBL strategy are 8.95 and 62.66 in Pre-HOCPT and Post-HOCPT with standard deviations of 6.42 and 11.47 respectively. Students taught redox reactions using peer-tutoring strategy had Pre-HOCPT and Post-HOCPT mean performance scores of 8.21

and 61.33 with corresponding standard deviations of 6.29 and 10.88 respectively and students taught redox reactions using the lecture method had Pre-HOCPT and Post-HOCPT mean performance scores of 8.38 and 35.65 with corresponding SD of 6.62 and 7.49 respectively. The table also shows that students taught redox reactions using a PBL strategy had a mean gain of 53.71; students taught using a peer-tutoring strategy had a mean gain of 53.12 while their counterparts taught using lecture methods had a mean gain of 27.27. This alerts that the PBL strategy, the peer-tutoring strategy and lecture method improved students' academic performance at higher-order thinking levels but the problem-based learning and peer-tutoring strategies are superior. The summary of the Pre-HOCPT and Post-HOCPT mean scores of students taught using PBL strategy, peer-tutoring strategy and lecture method in redox reactions is represented in Figure 1.

Table 1. PBL strategy, peer-tutoring strategy, lecture method and students' mean performance score at HOTS levels in redox reactions

Treatment Groups	N	Pre-HOCPT		Post-HOCPT		Mean Gain
		Mean	SD	Mean	SD	
Problem-based learning	42	8.95	6.42	62.66	11.47	53.71
Peer-tutoring strategy	57	8.21	6.29	61.33	10.88	53.12
Lecture method	47	8.38	6.62	35.65	7.49	27.27

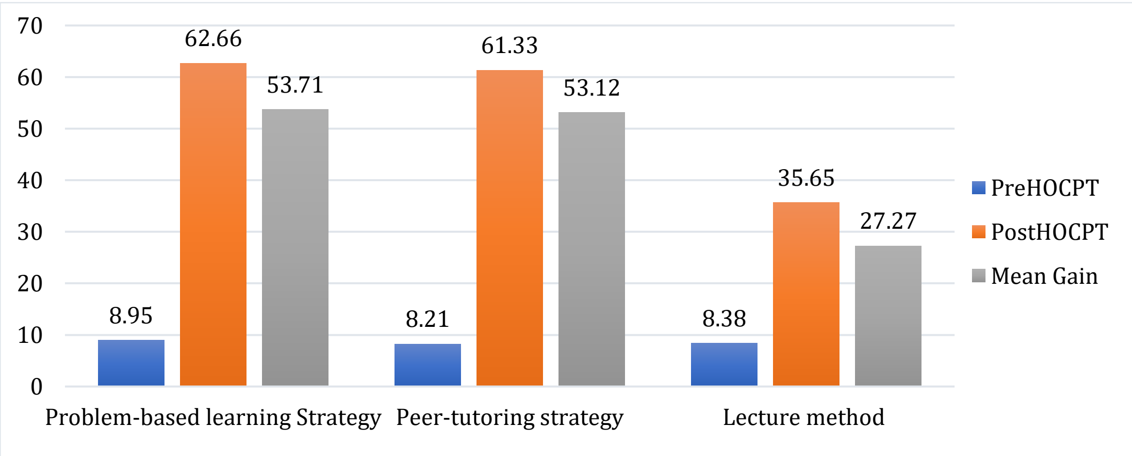

Fig. 1. Pre-HOCPT, Post-HOCPT and mean gain in effect of PBL strategy, peer-tutoring and lecture method on students' HOTS levels in redox reactions

It can be seen in Table 2 that the calculated F-value is 228.119 with a degree of freedom of 2,142 and a p-value of 0.000< 0.05. Since the significance of 0.00 is less than the P-value of 0.05. This indicates a considerable difference in the mean performance scores at higher-order thinking levels among students taught chemistry concepts using the PBL strategy, the intervention strategy, and the lecture method. Based on the evidence from data analysis, this favour the PBL and intervention strategies group with mean gains of 53.71 and 53.12, respectively, compared to the 27.27 mean gain of the lecture method. The treatment was responsible for 0.763 (76.3%) of the change observed in the academic performance of the students after the HOCPT, as indicated by the partial Eta squared estimate.

Table 2. Test of difference in mean performance at higher order thinking levels of students taught redox reactions using PBL strategy, peer-tutoring strategy and lecture method

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	30059.315[a]	3	10019.772	217.393	0.000	0.821
Intercept	91298.282	1	91298.282	1980.849	0.000	0.933
PreHOCPT	8073.704	1	8073.704	175.171	0.000	0.552
Strategies	21028.210	2	10514.105	228.119	0.000	0.763
Error	6544.850	142	46.090			
Total	453744.000	146				
Corrected Total	36604.164	145				

a. R Squared = 0.821 (Adjusted R Squared = 0.817)

Table 3 presents the pairwise comparisons of teaching strategies in chemistry and their effects on students' mean performance scores at higher-order thinking levels. The results indicate no considerable difference between PBL and the intervention strategies (P = 0.986 > 0.05). However, a considerable difference was observed between PBL and the lecture method (P = 0.000 < 0.05), as well as between intervention and the lecture method (P = 0.000 < 0.05). Consequently, confirming that there is a considerable difference in mean performance scores at higher-order thinking levels among students taught redox reactions using PBL, the intervention strategy, and lecture methods.

Table 3. Pairwise comparisons of performance scores at higher order thinking levels of students taught redox reaction using PBL and peer-tutoring strategy

(I) Strategies used in teaching Chemistry	(J) Strategies used in teaching Chemistry	Mean Difference (I-J)	Std. Error	Sig.
PBL	Peer-tutoring strategy	0.423	1.382	0.986
	Lecture method	25.943*	1.444	0.000
Lecture method	Peer-tutoring strategy	-25.520*	1.338	0.000

Performance at HOTS levels of male and female students taught chemistry using the PBL strategy

Table 4 displays the mean performance score at higher-order thinking levels of male and female students taught redox reactions using a PBL strategy. Results in Table 4 reveal that the mean performance score of male students taught redox reactions using PBL strategy is 8.66 and 62.50 in Pre-HOCPT and Post-HOCPT with standard deviations of 6.94 and 10.47 respectively while their female counterparts had Pre-HOCPT and Post HOCPT mean performance score of 9.33 and 62.88 with corresponding standard deviations of 5.82 and 13.00 respectively. Although the mean performance of the score at higher order thinking levels of both genders taught redox reactions using the PBL strategy is almost at par. The summary of the Pre-HOCPT, Post-HOCPT and mean gain in performance score at higher order thinking levels of both genders taught redox reactions using PBL is shown in Figure 2.

Table 4. Performance scores of male and female students using PBL strategy

Treatment Group	Gender	N	Pre-HOCPT Mean	Pre-HOCPT SD	Post-HOCPT Mean	Post-HOCPT SD	Mean Gain	Mean Difference
PBL	Male	24	8.66	6.94	62.50	10.47	53.84	0.29
	Female	18	9.33	5.82	62.88	13.00	53.55	

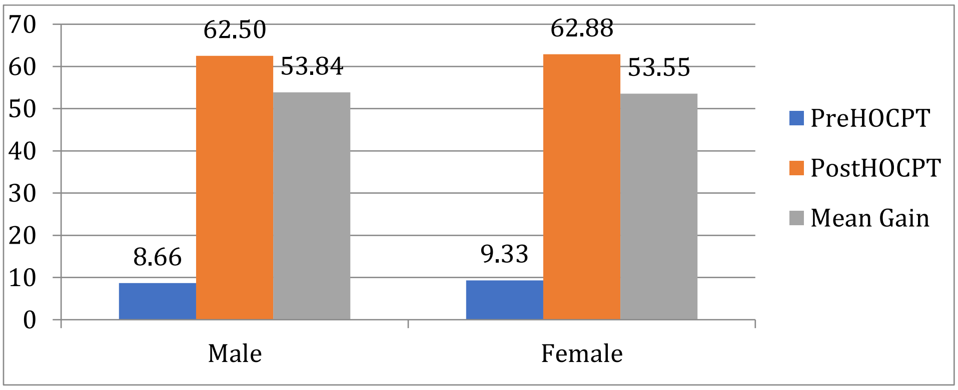

Fig. 2. Pre-HOCT, post-HOCT and mean gain in performance score at HOTS levels of male and female students taught redox reactions using PBL strategy

It is on display in Table 5 that the obtained F-value is 0.059, with degrees of freedom of 1 and 39, and a p-value of 0.810, which is higher than the significance level of 0.05. Since the test significance (0.810) exceeds 0.05. This indicates that there is no considerable difference in the mean performance scores at higher-order thinking levels between male and female students taught chemistry using a problem-based learning strategy. Furthermore, the partial Eta squared value of 0.001 suggests that gender accounts for only 0.1% of the variance in students' mean performance scores at higher-order thinking levels in the PBL strategy class.

Table 5. ANCOVA of mean performance at HOTS levels of students taught redox reactions via PBL by gender

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	3336.243[a]	2	1668.122	31.564	0.000	0.618
Intercept	34593.882	1	34593.882	654.586	0.000	0.944
PreHOCPT	3334.688	1	3334.688	63.099	0.000	0.618
Gender	3.090	1	3.090	0.058	0.810	0.001
Error	2061.090	39	52.848			
Total	170336.000	42				
Corrected Total	5397.333	41				

a. R Squared = 0.618 (Adjusted R Squared = 0.599)

Performance at HOTS levels of students taught chemistry through the peer-tutoring strategy by gender

Table 6 shows the mean performance score at higher-order thinking levels of students taught redox reactions via a peer-tutoring strategy by gender. Results reveal that the mean performance score of male students taught redox reactions using peer-tutoring learning strategy is 7.33 and 58.88 in Pre-HOCPT and Post-HOCPT with standard deviations of 6.01 and 9.36 respectively, while their female counterparts had Pre-HOCPT and Post HOCPT mean performance score of 8.61 and 62.05 with corresponding SD of 6.45 and 11.96 respectively. Although the mean performance of the score at higher order thinking levels of both genders taught redox reactions using the peer-tutoring strategy is almost on par. The summary of the Pre-HOCPT, Post-HOCPT, and mean gain in performance score at higher order thinking levels of students taught redox reactions via peer-tutoring strategy by gender is as shown in Figure 3.

Table 6. Performance scores of students' taught redox reactions via peer-tutoring strategy by gender

Treatment Group	Gender	N	Pre-HOCPT Mean	Pre-HOCPT SD	Post-HOCPT Mean	Post-HOCPT SD	Mean Gain	Mean Difference
Peer-tutoring Strategy	Male	18	7.33	6.01	58.88	9.36	51.55	1.89
	Female	39	8.61	6.45	62.05	1.96	53.44	

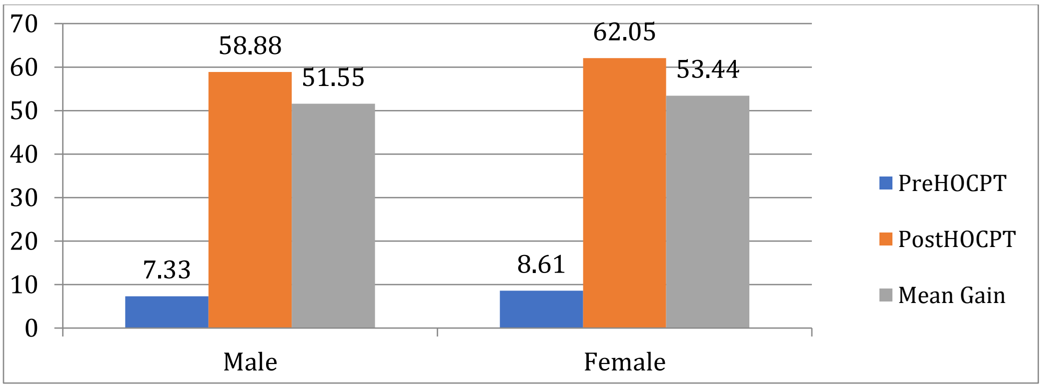

Fig. 3. Higher order thinking levels of students taught chemistry via peer-tutoring strategy by gender

Table 7. ANCOVA of mean performance at HOTS levels of students taught via peer-tutoring strategy by gender

Source	Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4732.86	2	2366.43	54.986	0.000	0.671
Intercept	48674.17	1	48674.17	1130.993	0.000	0.954
PreHOCPT	4609.70	1	4609.70	107.111	0.000	0.665
Gender	20.85	1	20.85	0.484	0.489	0
Error	2323.98	54	43.04			
Total	219520.00	57				
Corrected Total	7056.842	56				

a. R Squared = .671 (Adjusted R Squared = .658)

$F(1, 54) = 0.484$, $p = 0.489 > .05$, displayed on Table 7 is not considerable. The test significance (0.489) exceeds 0.05, so the hypothesis stands. This indicates that the mean performance scores at higher-order thinking levels due to gender when taught chemistry via a peer-tutoring strategy were statistically significant. Furthermore, the partial Eta squared value of 0.009 suggests that gender accounts for only 0.9% of the variance in students' mean performance scores at higher-order thinking levels in the peer-tutoring strategy class.

Interaction of strategies and gender on students' HOTS levels in Redox Reaction

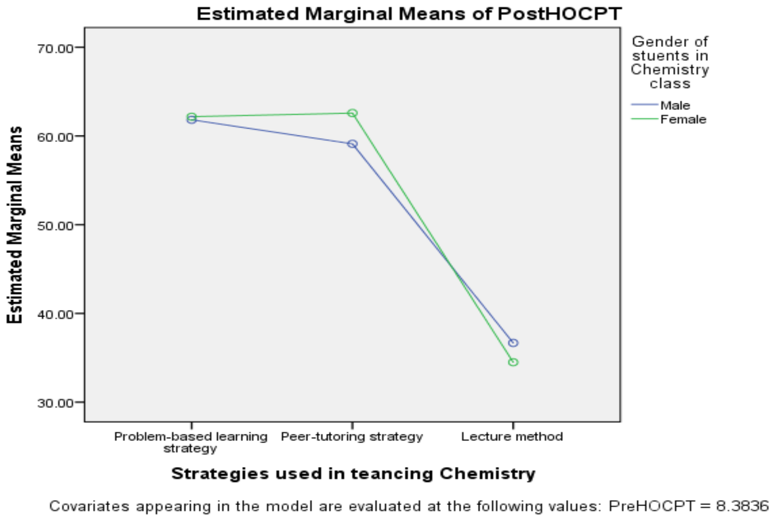

Fig. 4. Interaction of strategies and gender on students' HOTS levels in redox reactions

Figure 4 illustrates the interaction effects of instructional strategies and gender on students' mean performance scores at HOT levels in redox reactions. The plot reveals that the performance trajectories of both sexes intersect in the regions corresponding to the peer-tutoring and lecture method. Additionally, a similar intersection is observed within the problem-based learning strategy. These interaction patterns suggest that instructional strategies and gender collectively influence students' mean performance scores at HOT levels in redox reactions.

Table 8. Interaction of strategies of instruction and gender on students' mean performance score at HOT levels

Source	Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	30250.614[a]	6	5041.769	110.301	0.000	0.826
Intercept	84615.829	1	84615.829	1851.186	0.000	0.930
PreHOCPT	8034.755	1	8034.755	175.781	0.000	0.558
Strategies	18159.438	2	9079.719	198.642	0.000	0.741
Gender	9.442	1	9.442	0.207	0.650	0.001
Strategies* Gender	173.885	2	86.943	1.902	0.153	0.027
Error	6353.550	139	45.709			
Total	453744.000	146				
Corrected Total	36604.164	145				

a. R Squared = 0.826 (Adjusted R Squared = 0.819)

Table 8 presents the results of the ANCOVA test, indicating a calculated F-value of 1.902 at a p-value of 0.153, higher than 0.05. Since the significance level (0.153) exceeds the threshold of 0.05. This suggests that there is no considerable interaction effect between teaching strategies and gender on secondary school students' mean performance scores at

HOT levels in redox reactions. The partial Eta squared value of 0.027 indicates that only 2.7% of the variation in students' performance scores can be attributed to the interaction between instructional strategies and gender.

Findings revealed that the PBL and peer-tutoring strategies enhanced students' performance at higher-order thinking levels of redox reactions compared to the lecture method. This is evidenced by pairwise comparisons of the strategies of instructions and their effects on the mean performance scores. The finding concurs with Raimi and Sodamade (2018), Jimoh and Fatokun (2020), and Chileya and Shumba (2020); in their investigations of the impact of PBL on the academic performance of chemistry learners, demonstrated a statistically significant difference in the mean attainment scores, which favoured the experimental group. This finding aligns with the study by Khanam and Awan (2022), which demonstrated that students in the PBL method class outperformed their peers in HOTS in science.

The findings of this study align with previous research by Ogunleye and Bamidele (2014), Samuel and Sambo (2019), and Tartenger et al. (2024), which revealed the superiority of peer-tutoring instruction in enhancing achievement in chemistry over the conventional strategy. Azeez et al. (2022) similarly proved that both jigsaw and peer-tutoring teaching methodologies significantly improve students' performance and interest in the periodic table of elements. Furthermore, Nasir et al. (2017) discovered that these integrated teaching practices enhanced HOTS in high achievers while also benefiting low achievers. This result is further corroborated by Daud et al. (2019), Liana et al. (2020), Takko et al. (2020), and Tangkui and Keong (2020), who reported considerable differences in mean HOTS between the experimental and conventional learn environments. PBL enhanced students' academic performance at HOT levels probably because there was collaboration in the class, involvement in critical thinking, and striving to solve problems among the students. The peer-tutoring on the other hand promotes active participation, encouraged an engaging learning environment compared to traditional lecture methods.

Furthermore, the study indicated that the mean scores at HOT levels between male and female students taught redox reactions via PBL strategy did not differ considerably. This indicates that problem-based learning is gender-inclusive, as it engages students in problem-solving processes regardless of gender. The strategy encourages students to analyze problems, conduct investigations, collaborate, and present solutions, permitting equal learning opportunities for both genders. This finding agrees with the studies of Joy (2014) and Jimoh and Fatokun (2020), who found that male and female chemistry students achieved equally when taught using PBL. However, it contrasts with the findings of Raimi and Sodamade (2018), which suggested a gender bias in favor of female students, particularly at the cognitive level. It also contradicts the study by Onyi et al. (2022), which reported males considerably outperforming female students.

Also, no noteworthy difference exists in the mean performance score at HOT levels between male and female students taught redox reactions via peer-tutoring. This signifies that the use of peer-tutoring is not gender sensitive concerning students' performance scores at higher order thinking levels in redox reactions. This finding may result from the peer-tutoring strategy, which fosters a supportive learning environment, structured higher-order thinking activities, positive reinforcement, active teacher oversight, frequent verbal interaction and feedback, and a supportive learning environment. Consequently, it facilitates student collaboration and enhances academic achievement, irrespective of gender. This discovery is consistent with the findings of Ajayi and Ogbeba (2017), who also discovered that the mean achievement scores of students do not differ statistically based on gender when stoichiometry is taught through hands-on activities. This suggests that the instructional strategies provide equal learning opportunities for both genders, reinforcing that active engagement in learning processes benefits all students, regardless of gender. In accordance with this, Azeez et al. (2022) found that the academic performance of students who were exposed to peer-tutoring instructional strategies was not significantly influenced by gender or interest. This further supports the notion that collaborative and interactive learning methods promote equitable academic performance among students. However, the finding disagrees with Tartenge et al. (2024) who found that sex influence had a considerable effect on students' chemistry achievement when exposed to peer instructional strategy.

Finally, the interaction effect of strategies and gender on performance score at HOT levels in redox reactions was not considerable. This might have come from the non-intersection of male and female in the peer-tutoring strategy. This discovery is supported by the evidence of Ajayi and Ogbeba (2017) and Okeke (2028), who demonstrated that the achievement scores of students in stoichiometry were not influenced by the interaction effect between methods and gender.

CONCLUSION

PBL and peer-tutoring strategies enhanced the academic performance of students at HOT levels in redox reactions. These findings proved that PBL and peer-tutoring strategies have the potential to support the enhancement of HOT levels in redox reactions. In addition, findings show that the gender of students does not matter in performance at HOT levels in redox reactions. This implies that none of the strategies was gender biased. The interaction effect of strategies of instruction and gender on the students' mean performance scores at higher thinking levels in redox reactions was negligible. This suggests that when both genders are afforded the opportunity to participate actively in the learning process, they are able to fully develop their capabilities and perform at an equitable level. However, because this study involved purposive sampling and treatment of such to examine the effects, the outcomes therefore can be generalized within the given population. This calls for further replications of the same study to enhance robust generalisations.

Arising from the conclusion, we hereby recommend that:

1. Since PBL and peer-tutoring strategies considerably enhanced the secondary school student's academic performance at HOT levels in chemistry concepts, stake holders in education should organize seminars for chemistry teachers on how to use these activity-based instructional strategies. Peer coaching can also be carried out once a teacher has mastered the integration of HOT levels in teaching.
2. Since becoming problem solvers and conscious-thinking global citizens, is necessary that chemistry teachers should lay emphasis on HOT levels along with lower-order thinking levels.
3. The stakeholders in education should advocate for the inclusion of problem-based learning and peer-tutoring strategies in the curriculum. This is to develop students'

academic performance and prepare the future generations in the elements of lifelong learning, problem, critical and analytical thinking.

4. Since problem-based learning and peer-tutoring are gender unbiased with regards to performance scores, chemistry teachers should adopt these strategies to promote interaction, active learning, creativity and critical thinking that could lead to enhanced academic achievement.

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