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Impact of open inquiry instructional strategy on secondary school students' academic achievement and conceptual knowledge in Chemistry across genders in Osun state, Nigeria

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Abstract

Student performance in chemistry remains below expectations despite the subject's importance in advancing fields such as medicine and technology. Traditional teaching methods have been criticised for limiting engagement and critical thinking. This study investigates the impact of the open inquiry instructional strategy on secondary school students' academic achievement and conceptual knowledge in chemistry. A quasi-experimental design was adopted, involving 322 Senior Secondary School 1 science students drawn from intact classes of the selected schools. Students were divided into experimental and control groups and were taught using open inquiry and the traditional lecture method, respectively. Data were collected using the Chemistry Academic Achievement Test (CAAT) and Chemistry Conceptual Knowledge Test (CCKT), both of which were validated before use. Analysis of Covariance (ANCOVA) was used to test the hypotheses. The findings revealed that students taught using open inquiry significantly outperformed those taught using the traditional lecture method in academic achievement ($F(1, 317) = 29.083, p < .001$) and conceptual knowledge ($F(1, 317) = 60.574, p < .001$). However, gender differences were not statistically significant for both academic achievement ($F(1, 317) = 0.704, p = .402$) and conceptual knowledge ($F(1, 317) = 2.634, p = .106$). The study concludes that open inquiry is a more effective instructional strategy for improving students' learning outcomes in chemistry, regardless of gender. It recommends the integration of open inquiry into science curricula and teacher training programmes to enhance student engagement and conceptual understanding.

Keywords: Open inquiry, Chemistry education, Academic achievement, Conceptual knowledge, Instructional strategies.

1. Introduction

Science education plays a fundamental role in technological advancement, with chemistry serving as a critical discipline that underpins innovations in medicine, engineering, and environmental science. It fosters problem-solving skills, critical thinking, and creativity essential for addressing real-world challenges (Jegstad, 2024). However, the quality of science education, particularly chemistry instruction, remains a significant concern. Despite the subject's importance, students' performance in chemistry continues to decline due to ineffective teaching strategies that prioritise memorisation over conceptual understanding (Adeoye, 2023; Nicol et al., 2024). The West African Examinations Council (WAEC) examiner's report consistently highlights students' poor performance in chemistry, attributing it to inadequate understanding of key concepts and over-reliance on rote memorisation rather than practical problem-solving skills (WAEC, 2023). Consequently, researchers have called for the adoption of student-centred approaches that actively engage learners in the learning process (Kaya & Yilmaz, 2016; Putri & Malik, 2024).

Chemistry, as a branch of science, presents abstract concepts that require effective instructional strategies to enhance students' comprehension. The traditional lecture method, often used in chemistry classrooms, is predominantly teacher-centred, relying on direct explanations with minimal student participation (Wang et al., 2022; Zhao et al., 2021). Other teacher-centred approaches include the demonstration method, which involves teachers performing experiments while students observe and replicate the teacher's experiments, and the cookbook method, where students follow predetermined instructions without deep engagement (Putri & Malik, 2024; Kwitonda et al., 2022). These methods, while structured, limit students' ability to develop inquiry and problem-solving skills. Research indicates that passive learning environments hinder students' retention of chemistry concepts and fail to equip them with the necessary science process skills (Issaka, 2020; Phimthong et al., 2024).

To address these shortcomings, inquiry-based learning has gained recognition as an effective alternative to traditional methods for enhancing students' academic achievement and conceptual knowledge in chemistry. Inquiry-based approaches encourage students to explore scientific phenomena, ask questions, conduct investigations, and draw conclusions based on evidence (Annisa & Rohaeti, 2018; Omovie & Eravwoke-Agboro, 2023). Within inquiry-based learning, open inquiry stands out as a method that grants students autonomy, allowing them to actively engage in inquiry by formulating their own questions, designing and conducting experiments, and analysing findings, promoting deeper conceptual understanding and independent thinking (Kaya & Yilmaz, 2016; Tekin & Muştu, 2021). Unlike structured and guided inquiry, which involve varying levels of teacher intervention, open inquiry allows students to take full control of the investigative process (Jegstad, 2024; Rampean et al., 2021).

Studies have demonstrated that open inquiry improves students' academic achievement and enhances their science process skills. For instance, Owolade et al. (2022a) investigated the effectiveness of guided and open inquiry instructional strategies on science process skills and self-efficacy in Biology. Their study concluded that while open inquiry significantly improved self-efficacy, it did not significantly affect science process skills. This highlights the need to explore further the impact of inquiry-based strategies in other science subjects, including Chemistry. Similarly, Adeoye (2023) reported that structured inquiry-based instruction effectively addressed students' learning difficulties in thermodynamics, resulting in improved reasoning abilities. Furthermore, Ojo and Tijani (2025) highlighted that open inquiry significantly enhanced secondary school students' achievement in chemistry compared to the demonstration method, reinforcing its effectiveness in science education.

Academic achievement, a key measure of students' performance, is often assessed through standardised tests, coursework, and practical evaluations. It reflects the extent to which students have acquired knowledge and skills in a subject area (Ejedegbe, 2016; Omovie & Eravwoke-Agboro, 2023). In chemistry, academic achievement encompasses students' ability to recall, apply, and analyse scientific concepts. Research has shown that inquiry-based instructional strategies enhance students' academic achievement by fostering deeper understanding and engagement in learning activities (Adeoye, 2023; Villaroya, 2020). Inquiry-based instruction provides students with the opportunity to actively construct knowledge, leading to better retention and improved test performance compared to traditional lecture-based teaching (Issaka, 2020; Wang et al., 2022). Additionally, Owolade et al. (2022b) highlighted that students' performance in Biology has remained inconsistent due to ineffective instructional strategies. Their study demonstrated that open inquiry improved students' performance more than guided inquiry and conventional methods.

This finding supports the need to examine the application of inquiry-based methods in Chemistry education, particularly in fostering deeper conceptual understanding and skills development.

Conceptual knowledge, another crucial learning outcome, refers to students' understanding of fundamental principles and their ability to connect theoretical concepts with practical applications. Chemistry requires a strong conceptual foundation, as students must grasp abstract ideas such as atomic structure, chemical bonding, and thermodynamics to succeed in more advanced topics (Annisa & Rohaeti, 2018; Nicol et al., 2024). Studies have indicated that open inquiry enhances conceptual knowledge by encouraging students to actively engage in the learning process, pose questions, and explore scientific phenomena through hands-on activities (Phimthong et al., 2024; Kwitonda et al., 2022). Unlike traditional rote memorisation approaches, inquiry-based learning fosters deep comprehension, critical thinking, and problem-solving abilities, ultimately improving students' overall academic performance (Bassey & Amanso, 2017; Zhao et al., 2021).

The integration of open inquiry into chemistry education has also been linked to improved scientific attitudes and motivation. Tshering and Yangden (2021) observed that students exposed to inquiry-based learning demonstrated higher levels of learning satisfaction and engagement. Additionally, Villaroya (2020) found that both the 5E and 7E inquiry models positively influenced students' performance in chemistry, further validating the approach's impact on academic success. Despite these positive outcomes, some studies argue that open inquiry may not be universally effective. Wang et al. (2022) found that open-inquiry activities were negatively associated with student learning outcomes in certain contexts, suggesting that structured inquiry may be more beneficial in some cases. These findings highlight the need for further research on the optimal implementation of open inquiry in chemistry classrooms.

While the effectiveness of inquiry-based learning is widely acknowledged, research on its impact across different student demographics, particularly gender, remains inconclusive. Some studies indicate that inquiry-based strategies benefit both male and female students equally (Ejedegbe, 2016; Kwitonda et al., 2022), whereas others suggest gender-based disparities in academic achievement and retention (Issaka, 2020). Bassey and Amanso (2017) reported that male students outperformed their female counterparts in science process skills, while Nicol et al. (2024) found that gender differences were minimal when students engaged in inquiry-based experimentation. These mixed findings underscore the need to investigate the moderating role of gender in the effectiveness of inquiry-based instruction.

Despite the growing body of research supporting open inquiry, gaps remain in its application within secondary school chemistry. Many studies have focused on biology and general science, leaving a gap in the literature regarding its effectiveness in chemistry classrooms (Jegstad, 2024; Omovie & Eravwoke-Agboro, 2023). Moreover, few studies have explored its impact in resource-limited settings where access to laboratory materials and digital resources may be constrained (Ojo & Tijani, 2025). Addressing these gaps is critical to ensuring that all students, regardless of location or background, can benefit from inquiry-based instruction.

To contribute to the growing discourse on inquiry-based learning, this study investigates the impact of open inquiry instructional strategy on secondary school students' academic achievement and conceptual knowledge in chemistry. The traditional lecture method is used as the control strategy to compare the effectiveness of open inquiry. Additionally, gender is examined as a moderating factor to determine whether the benefits of open inquiry are consistent across male and female students. By addressing these research objectives, the study aims to provide empirical evidence on the viability of open inquiry in secondary school chemistry education.

1.1 Research Objectives

The specific objectives of the study were to:

1. assess the difference in the academic achievement of male and female students taught using open inquiry compared to those taught using the traditional lecture method.
2. determine the difference in conceptual knowledge among male and female students taught using open inquiry compared to those taught using the traditional lecture method.

1.2 Research Hypotheses

The study tested the following hypotheses:

1. There is no significant difference in the academic achievement of male and female students taught using open inquiry compared to those taught using the traditional lecture method.
2. There is no significant difference in the conceptual knowledge of male and female students taught using open inquiry compared to those taught using the traditional lecture method.

2. Methods

The study employed a pre-test, post-test non-equivalent control group quasi-experimental research design with a 2×2 factorial matrix designed to assess the impact of open inquiry instructional strategy on students' academic achievement and conceptual knowledge in chemistry across genders. The experimental levels are as follows: instructional strategies at 2 levels (open inquiry and traditional lecture method) and gender at 2 levels (male and female).

2.1 Population for the Study

The study targeted Senior Secondary School 1 (SSS1) students in Osun State, and the accessible population is comprised of SSS1 science students in Ife East and Ife Central Local Government in Osun East Senatorial District, Ile Ife, Osun State. SSS 1 students were chosen for this study because they are at the introductory stage of senior secondary chemistry, where foundational concepts such as atoms, molecules, mixtures, and separation techniques are taught. Their level of cognitive development allows them to engage in structured learning while gradually transitioning to more advanced problem-solving approaches. Additionally, their curriculum aligns with the topics used in the study, ensuring that participation does not interfere with their academic progress.

2.2 Sample and Sampling Technique

The sample for this study comprised 322 science students from Senior Secondary School 1 (SSS 1). A multistage sampling procedure was employed to select participants. In the first stage, one senatorial district was randomly selected from the three senatorial districts in Osun State. Within this district, Ife East and Ife Central Local Government Areas (LGAs) were randomly chosen to ensure geographical representation. In the second stage, six secondary schools were selected using a simple random sampling technique. This approach was chosen to provide equal opportunities for all schools in the LGAs to be part of the study, thus enhancing the representativeness and generalisability of the findings. In the final stage, one intact SSS 1 science class was randomly selected from each of the six schools to form the sample for the study. The six intact SSS 1 science classes were assigned to two groups: Experimental Group (Open Inquiry) and Control Group (lecture method). The total sample comprised 322 students, with 166 in the experimental group and 156 in the control group. This approach ensured that the sample was unbiased and reflective of the general student population within the study area.

2.3 Research Instrument

The main research instruments used for data collection were the Chemistry Academic Achievement Test (CAAT) and the Chemistry Conceptual Knowledge Test (CCKT). The CAAT comprised 15 multiple-choice items on the concepts of atoms, molecules and ions, concepts of elements, compounds and mixtures and separation techniques drawn from past West Africa Senior School Certificate Examination (WASSCE) chemistry questions to measure students' academic achievement. Each item was assigned 2 marks for a correct answer and no marks for an incorrect answer, allowing for an objective marking. The minimum and maximum scores expected in the CAAT were 0 and 30, respectively. On the other hand, the CCKT was designed by the researcher to evaluate students' conceptual knowledge of the concepts of atoms, molecules and ions, concepts of elements, compounds and mixtures and separation techniques. The CCKT consisted of two sections: Section A consisted of ten first-tier questions that assessed the clarity of explanations and the connections made between concepts, and Section B consisted of ten second-tier questions that evaluated the scientific reasoning behind the responses in the first-tier questions. This structure allows for a comprehensive assessment of factual knowledge and the ability to articulate and reason through the concepts. The CCKT was assigned a maximum of 30 marks, with each item in Section A (first-tier questions) assigned 2 marks for a clear explanation with a strong connection and 1 mark for a clear explanation without connections. Section B (second-tier questions) 1 mark for a correct demonstration of scientific reasoning, contingent on receiving full credit in the first tier.

The stimulus instruments were lesson plans drawn on open inquiry instructional strategy and traditional lecture method in teaching the experimental and control groups, respectively. The open inquiry instructional strategy was the student-centred activity which required the students to independently pose questions, design experiments, observe, formulate hypotheses and draw conclusions on the topics considered in the study. The control group was taught using the traditional lecture method only. Instructions were highly verbalised with minimum interaction between students and instructional materials. The researcher, assisted by trained research assistants, taught the experimental group using the open inquiry instructional strategy. The research assistants were chemistry teachers from the experimental group schools who had received prior training to facilitate the study. In contrast, the regular chemistry teacher in each school was responsible for teaching the control group using the traditional lecture method. The study lasted for five (5) weeks, with the first week dedicated to pre-test administration, three weeks for teaching (with three 40-minute periods per week), and the final week for post-test administration. This arrangement ensured consistency in implementing both instructional strategies while minimising external influences.

2.4 Validity and Reliability of Research Instruments

Validity of Chemistry Academic Achievement Test (CAAT)

To establish the construct validity of the CAAT, a pilot study was conducted with a sample of 50 Senior Secondary School 1 students from non-participating schools. An Exploratory Factor Analysis (EFA) was performed using Principal Axis Factoring (PAF) with oblique rotation to identify the underlying factor structure. The analysis confirmed that the CAAT items aligned with five out of the six cognitive levels of Bloom's taxonomy, which include:

1. **Remembering:** Recall of factual knowledge.
2. **Understanding:** Interpretation and explanation of concepts.
3. **Applying: Use** of knowledge in problem-solving.
4. **Analysing:** Breaking down concepts into components.
5. **Evaluating:** Judging and justifying ideas based on criteria.

To confirm the suitability of the dataset for factor analysis, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was found to be 0.78, indicating a meritorious level of factorability. Additionally, Bartlett's test of sphericity was significant ($\chi^2 = 1245.32$, df = 105, $p < 0.001$), confirming that the dataset was appropriate for factor analysis. Items with low factor loadings (<0.40) were either revised or removed to enhance the test's validity.

Reliability of Chemistry Academic Achievement Test (CAAT)

The test-retest method was used to ensure the reliability of the CAAT. The test was administered to a group of 50 students with a one-week interval between the first and second administrations. The internal consistency was measured using Kuder-Richardson 20 (KR-20), yielding a coefficient of 0.75 ($p < 0.05$), indicating strong reliability.

Validity of Chemistry Conceptual Knowledge Test (CCKT)

The content validity of the CCKT was established by ensuring its alignment with the chemistry curriculum and the study's conceptual framework. The instrument was reviewed by two experts in science education, who assessed its clarity, relevance, and ability to measure students' conceptual understanding. Their recommendations were incorporated to refine the items, ensuring that the CCKT effectively evaluated both factual knowledge and scientific reasoning.

Reliability of Chemistry Conceptual Knowledge Test (CCKT)

A test-retest method was also used to assess the reliability of the CCKT. The test was administered to the same group of 50 students with a one-week interval between the first and second administrations. Since the CCKT consists of open-ended responses, inter-rater reliability was assessed using Cohen's Kappa, which produced a coefficient of 0.82, indicating strong agreement between independent scorers and high reliability.

2.5 Methods of Data Analysis

The data collected from the study were analysed using the Statistical Package for the Social Sciences (SPSS) version 27.0. The analysis started with presenting the demographic of participants' genders using frequency and percentage. This was followed by inferential statistics to test the hypotheses. The Analysis of Covariance (ANCOVA) was used to test the hypotheses at a significance level of $p < 0.05$.

3. Results

3.1 Demographic Presentation of Respondents

Table 1: Frequency and Percentage Distribution of Respondents' Genders

Gender					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	Male	147	45.7	45.7	45.7
	Female	175	54.3	54.3	100.0
	Total	**322**	**100.0**	**100.0**	

Table 1 presents the frequency and percentage distribution of respondents' genders in the study. The total sample size was 322 students, with 147 males (representing 45.7% of the respondents) and 175 females (accounting for 54.3% of the respondents). This distribution highlights a slightly higher representation of female students in the sample, ensuring a balanced demographic to analyse gender-based differences effectively in the study.

3.2 Descriptive Analysis of Variables in the Study

Table 2: Descriptive Statistics of Students' Academic Achievement by Gender and Instructional Strategy in the Study Area

Descriptive Statistics				
Gender		**Mean**	**Std. Deviation**	**N**
Male	Lecture Method	13.32	5.946	73
	Open Inquiry	18.19	9.115	74
	Total	15.77	8.060	147
Female	Lecture Method	13.11	5.182	83
	Open Inquiry	17.00	8.917	92
	Total	15.15	7.618	175
Total	Lecture Method	13.21	5.535	156
	Open Inquiry	17.53	8.998	166
	Total	**15.43**	**7.817**	**322**

Table 2 presents the descriptive statistics of students' academic achievement by gender and instructional strategy. The results indicate that male students taught using the traditional lecture method had a mean score of 13.32 (SD = 5.946, N = 73), while those taught using the open inquiry method achieved a higher mean score of 18.19 (SD = 9.115, N = 74). Similarly, female students taught with the traditional lecture method recorded a mean score of 13.11 (SD = 5.182, N = 83), whereas their counterparts taught using open inquiry achieved a higher mean score of 17.00 (SD = 8.917, N = 92). When the results are aggregated, male students had an overall mean score of 15.77 (SD = 8.060, N = 147), and female students had a slightly lower overall mean of 15.15 (SD = 7.618, N = 175). Across all groups, students taught using the open inquiry instructional strategy consistently outperformed those taught using the traditional lecture method, with an overall mean score of 17.53 (SD = 8.998, N = 166) compared to 13.21 (SD = 5.535, N = 156) for the traditional lecture method. This suggests that open inquiry promotes higher academic achievement irrespective of gender.

Table 3: Descriptive Statistics of Students' Conceptual Knowledge by Gender and Instructional Strategy in the Study Area

Descriptive Statistics				
Gender		**Mean**	**Std. Deviation**	**N**
Male	Lecture Method	13.37	4.727	73
	Open Inquiry	18.27	6.956	74
	Total	15.84	6.423	147
Female	Lecture Method	13.77	4.981	83
	Open Inquiry	19.62	7.186	92
	Total	16.85	6.876	175
Total	Lecture Method	13.58	4.853	156
	Open Inquiry	19.02	7.095	166
	Total	**16.39**	**6.682**	**322**

Table 3 displays the descriptive statistics for students' conceptual knowledge based on gender and instructional strategy. Male students taught using the traditional lecture method achieved a mean score of 13.37 (SD = 4.727, N = 73), while those taught using the open inquiry method had a significantly higher mean score of 18.27 (SD = 6.956, N = 74). Similarly, female students instructed with the traditional lecture method recorded a mean score of 13.77 (SD = 4.981, N = 83), whereas their counterparts taught using the open inquiry method attained a notably higher mean score of 19.62 (SD = 7.186, N = 92). When combining the results by gender, male students achieved an overall mean score of 15.84 (SD = 6.423, N = 147), while female students had a higher overall mean of 16.85 (SD = 6.876, N = 175). Across all groups, students taught using the open inquiry strategy consistently outperformed those taught using the traditional lecture method, with an overall mean score of 19.02 (SD = 7.095, N = 166) compared to 13.58 (SD = 4.853, N = 156) for the traditional lecture method. These results indicate that open inquiry is more effective in enhancing students' conceptual knowledge, regardless of gender.

3.3 Analysis of Research Hypotheses

H_{01}*: *There is no significant difference in the academic achievement of male and female students taught using open inquiry compared to those taught using the traditional lecture method.

Table 4: Analysis of Covariance on the Difference in Academic Achievement of Male and Female Students Taught in Comparison with the Instructional Strategies

Tests of Between-Subjects Effects

Dependent Variable: CAAT Post-test Score

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	2933.991[a]	4	733.498	13.941	0.000	0.150
Intercept	6335.810	1	6335.810	120.417	0.000	0.275
CAAT Pre-test Score	1369.990	1	1369.990	26.038	0.000	0.076
Gender	37.058	1	37.058	0.704	0.402	0.002
Treatment	1530.206	1	1530.206	29.083	0.000	0.084
Gender * Treatment	16.527	1	16.527	0.314	0.576	0.001
Error	16679.139	317	52.616			
Total	96324.000	322				
Corrected Total	19613.130	321				

a. R Squared = .150 (Adjusted R Squared = .139)

Table 4 presents the Analysis of Covariance (ANCOVA) examining the difference in academic achievement between male and female students taught using open inquiry and the traditional lecture method. The results indicate a significant effect of instructional strategy on academic achievement ($F(1, 317) = 29.083$, $p < .001$, $\eta^2 = .084$), suggesting that the teaching method used had a meaningful impact on students' performance. However, gender alone did not have a significant effect on academic achievement ($F(1, 317) = 0.704$, $p = .402$, $\eta^2 = .002$), indicating that male and female students performed similarly regardless of the instructional strategy used. Additionally, the interaction between gender and instructional strategy was not significant ($F(1, 317) = 0.314$, $p = .576$, $\eta^2 = .001$), meaning that the effect of instructional strategy on academic achievement was consistent across genders. The model explained 15.0% of the variance in students' post-test scores ($R^2 = .150$), confirming that while instructional strategy significantly influenced performance, gender differences did not play a meaningful role.

Since the p-value for instructional strategy ($p < .001$) is significant, the null hypothesis (H_{01}), which states that there is no significant difference in the academic achievement of male and female students taught using open inquiry compared to those taught using the traditional lecture method, is rejected. However, because gender and the interaction effect between gender and instructional strategy are not significant ($p > .05$), it is concluded that gender differences do not influence academic achievement in this study.

Table 5: Estimated Marginal Means of Students' CAAT Post-Test Scores by Instructional Strategies

Instructional Strategies

Instructional Strategies	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Lecture Method	13.212[a]	0.582	12.067	14.357
Open Inquiry	17.592[a]	0.566	16.477	18.706

a. Covariates appearing in the model are evaluated at the following values: CAAT Pre-test Score = 12.19.

Table 5 provides the estimated marginal means of students' post-test scores in the Chemistry Academic Achievement Test (CAAT) based on the instructional strategy used. The results indicate that students taught using the open inquiry method had a higher adjusted mean score ($M = 17.592$, $SE = 0.566$, 95% CI [16.477, 18.706]) than those taught using the lecture method ($M = 13.212$, $SE = 0.582$, 95% CI [12.067, 14.357]). This suggests that the open inquiry instructional strategy was more effective in improving students' academic achievement compared to the traditional lecture method. The confidence intervals for both instructional strategies do not overlap, further supporting the significant difference observed in Table 4.

Table 6: Bonferroni Post-hoc Analysis of Students' Academic Achievement in CAAT Based on Instructional Strategies

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig.[b]	95% Confidence Interval for Difference[b]	
				Lower Bound	Upper Bound
Control	Open Inquiry	-4.379*	<0.001	-5.977	-2.782
Open Inquiry	Control	4.379*	<0.001	2.782	5.977

Based on estimated marginal means: *. *The mean difference is significant at the 0.05 level. b. Adjustment for multiple comparisons: Bonferroni.*

Table 6 presents the Bonferroni post-hoc analysis comparing students' academic achievement between instructional strategies. The results confirm a statistically significant difference between the two groups, with students in the open inquiry group outperforming those in the lecture method group by a mean difference of 4.379 points ($p < .001$, 95% CI [-5.977, -2.782]). This result aligns with the ANCOVA findings, reinforcing the conclusion that open inquiry is significantly more effective than the traditional lecture method in improving students' academic performance. Since the p-value is well below .05, the difference is statistically significant, and the negative lower bound of the confidence interval further confirms that students in the control group (lecture method) scored significantly lower than those in the open inquiry group.

H_{02}**:** *There is no significant difference in the conceptual knowledge of male and female students taught using open inquiry compared to those taught using the traditional lecture method.*

Table 7: Analysis of Covariance on the Difference in Conceptual Knowledge of Male and Female Students Taught in Comparison with the Instructional Strategies

Tests of Between-Subjects Effects

Dependent Variable: CCKT Post-test Score						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	2631.261[a]	4	657.815	17.821	0.00	0.184
Intercept	11696.727	1	11696.727	316.885	0.00	0.500
CCKT Pre-test Score	174.956	1	174.956	4.740	0.03	0.015
Gender	97.222	1	97.222	2.634	0.10	0.008
Treatment	2235.890	1	2235.890	60.574	0.00	0.160
Gender * Treatment	24.753	1	24.753	0.671	0.41	0.002
Error	11700.987	31	36.912			
Total	100780.000	32				
Corrected Total	14332.248	32				

a. R Squared = .184 (Adjusted R Squared = .173)

Table 7 presents the Analysis of Covariance (ANCOVA) examining the difference in conceptual knowledge between male and female students taught using open inquiry and those taught using the traditional lecture method. The results indicate a significant main effect of instructional strategy on conceptual knowledge ($F(1, 317) = 60.574$, $p < .001$, $\eta^2 = .160$), suggesting that the teaching method used had a strong impact on students' conceptual understanding. However, gender alone did not have a significant effect on conceptual knowledge ($F(1, 317) = 2.634$, $p = .106$, $\eta^2 = .008$), indicating that male and female students performed similarly regardless of the instructional strategy used. Additionally, the interaction effect between gender and instructional strategy was not significant ($F(1, 317) = 0.671$, $p = .413$, $\eta^2 = .002$), meaning that the effect of the instructional strategy on conceptual knowledge was consistent across genders.

The model explained 18.4% of the variance in students' post-test scores ($R^2 = .184$), confirming that while instructional strategy significantly influenced conceptual knowledge, gender differences did not play a meaningful role. Since the p-value for instructional strategy ($p < .001$) is significant, the null hypothesis (H_{02}), which states that there is no significant difference in the conceptual knowledge of male and female students taught using open inquiry compared to those taught using the traditional lecture method, is rejected. However, because gender and the interaction effect between gender and instructional strategy are not significant ($p > .05$), it is concluded that gender does not influence conceptual knowledge in this study.

Table 8: Estimated Marginal Means of Students' CCKT Post-Test Scores by Instructional Strategies

Instructional Strategies

Instructional Strategies	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Lecture Method	13.597[a]	0.488	12.638	14.556
Open Inquiry	18.897[a]	0.475	17.963	19.832

a. Covariates appearing in the model are evaluated at the following values: CCKT Pre-test Score = 12.59.

Table 8 provides the estimated marginal means of students' post-test scores in the Chemistry Conceptual Knowledge Test (CCKT) based on instructional strategies. The results indicate that students taught using the open inquiry method had a higher adjusted mean score (M = 18.897, SE = 0.475, 95% CI [17.963, 19.832]) than those taught using the lecture method (M = 13.597, SE = 0.488, 95% CI [12.638, 14.556]). This suggests that the open inquiry instructional strategy was significantly more effective in improving students' conceptual knowledge compared to the traditional lecture method. The confidence intervals for both instructional strategies do not overlap, further supporting the significant difference observed in Table 7.

Table 9: Bonferroni Post-hoc Analysis of Students' Conceptual Knowledge in CCKT Based on Instructional Strategies

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig.[b]	95% Confidence Interval for Difference[b]	
				Lower Bound	Upper Bound
Control	Open Inquiry	-5.300*	<0.001	-6.640	-3.960
Open Inquiry	Control	5.300*	<0.001	3.960	6.640

Based on estimated marginal means: *. *The mean difference is significant at the 0.05 level. b. Adjustment for multiple comparisons: Bonferroni.*

Table 9 presents the Bonferroni post-hoc analysis comparing students' conceptual knowledge between instructional strategies. The results confirm a statistically significant difference between the two groups, with students in the open inquiry group outperforming those in the lecture method group by a mean difference of 5.300 points ($p < .001$, 95% CI [-6.640, -3.960]). This result aligns with the ANCOVA findings, reinforcing the conclusion that open inquiry is significantly more effective than the traditional lecture method in improving students' conceptual knowledge. Since the p-value is well below .05, the difference is statistically significant, and the negative lower bound of the confidence interval further confirms that students in the control group (lecture method) scored significantly lower than those in the open inquiry group.

4. Discussion of Findings

The findings of this study provide strong evidence that the open inquiry instructional strategy significantly improves students' academic achievement and conceptual knowledge in chemistry. The results showed that students taught using open inquiry outperformed those taught using the traditional lecture method, with no significant gender differences observed. These findings highlight the importance of student-centred learning approaches, which encourage active engagement, critical thinking, and problem-solving skills, essential for mastering complex chemistry concepts.

The implications of the study underscore the need for a paradigm shift in chemistry instruction. Traditional teaching approaches, particularly the lecture method, often emphasise memorisation over conceptual understanding, limiting students' ability to apply knowledge effectively. The superior performance of students exposed to open inquiry suggests that this method fosters deeper learning by allowing students to explore, investigate, and draw conclusions independently. This is particularly relevant in chemistry, where conceptual knowledge plays a crucial role in understanding theoretical principles and their practical applications.

In comparison with existing literature, these findings align with those of Adeoye (2023), who reported that structured inquiry-based instruction improved students' knowledge of thermodynamic concepts, leading to better reasoning abilities. Similarly, Annisa and Rohaeti (2018) found that inquiry-based learning enhanced students' understanding of chemical equilibrium, reinforcing the idea that allowing students to explore scientific principles actively leads to greater comprehension. The results also confirm the findings of Owolade et al. (2022b), which demonstrated that open inquiry significantly improved students' academic performance in Biology compared to guided inquiry and traditional methods.

Regarding gender, the absence of a significant interaction effect between instructional strategy and gender suggests that open inquiry benefits male and female students equally. This finding is consistent with those of Ejedegbe (2016) and Kwitonda et al. (2022), who found that inquiry-based instruction had a uniform effect across genders. However, the results contradict Issaka (2020), who reported slight variations in retention and achievement between male and female students. These inconsistencies highlight the need for further research into how gender influences learning outcomes under different instructional conditions.

The study also reinforces the idea that prior knowledge plays a crucial role in conceptual understanding. The findings revealed that pre-test scores were a significant predictor of students' post-test performance, supporting Zhao et al. (2021), who emphasised that students' initial understanding and autonomy influence their success in inquiry-based learning environments. Additionally, the results align with Tshering and Yangden (2021), who found that students exposed to inquiry-based learning demonstrated higher engagement and learning satisfaction, regardless of gender. Overall, this study contributes to the growing body of evidence supporting open inquiry as an effective instructional strategy in chemistry education. The findings suggest that integrating open inquiry into the curriculum could help address the limitations of traditional lecture-based instruction by enhancing students' conceptual knowledge, problem-solving abilities, and scientific reasoning skills.

The study concludes that the open inquiry instructional strategy is significantly more effective than the traditional lecture method in improving students' academic achievement and conceptual knowledge in chemistry. The results indicate that both male and female students benefited equally from open inquiry, reinforcing its applicability across diverse student populations. Given the growing emphasis on student-centred learning approaches, these findings advocate for the integration of open inquiry into chemistry instruction to foster deeper understanding, independent thinking, and active engagement in scientific exploration.

5. Recommendations

Based on the findings of this study, it is recommended that teachers should adopt open inquiry instructional strategy to enhance students' academic achievement and conceptual knowledge, as the findings indicate its superiority over the traditional lecture method. Professional development programmes should be organised to equip teachers with the necessary skills for effective implementation. Additionally, curriculum planners should integrate open inquiry into the chemistry curriculum to foster critical thinking and problem-solving skills. Future research should explore the long-term impact of open inquiry and the challenges associated with its implementation, particularly in resource-limited schools, to develop practical solutions for wider adoption.

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