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EVALUATING THE EFFECTIVENESS OF VIRTUAL, BLENDED AND REAL LABORATORIES IN ENHANCING STUDENTS' PERFORMANCE, PROFICIENCY AND CONFIDENCE WITH SCIENTIFIC INSTRUMENTS IN REAL CHEMISTRY PRACTICAL

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Abstract

This study investigated the effectiveness of virtual laboratory, blended laboratory, and real laboratory approaches in enhancing students' proficiency, performance, and confidence levels in chemistry practical. The study aimed to determine the impact of these approaches on students' learning outcomes and identify the most effective method for teaching Chemistry Practical.

The study adopted a non-equivalent pre-test, post-test, and control group quasi-experimental design. The population consisted of all Secondary School Two (SSII) Chemistry students in Ondo State, with a sample of 42 students selected using a multi-stage sampling procedure. The students were assigned to two experimental groups (Virtual Laboratory and Blended) and a control group (Real Laboratory). The study employed three research instruments: the Titration Laboratory Instrument Proficiency Assessment (TLIPA), Chemistry Practical Performance Test (CPPT), and Chemistry Students' Confidence Questionnaire (CSCQ). Experts validated the instruments, and their reliability was determined using Cronbach's Alpha for TLIPA (0.69) and CSCQ (0.72), and Pearson Product-Moment Correlation (PPMC) for CPPT (0.79).

The findings revealed that students in the Blended Laboratory group achieved the highest proficiency level ($\bar{x} = 22.8333$), performance ($\bar{x} = 23.6667$), and confidence level ($\bar{x} = 23.4167$). The ANOVA results indicated a significant difference in students' proficiency levels ($F = 67.136, p < .000$), performance ($F = 67.136, p < .000$), and confidence levels ($F = 73.134, p < .000$) when exposed to different laboratory activities.

The study concluded that Blended Laboratory activities are the most effective approach to enhancing students' proficiency, performance, and confidence levels in chemistry practical. Based on the findings, it was recommended that educators and policymakers incorporate Blended Laboratory activities into chemistry curricula to improve students' learning outcomes.

Keywords: *Virtual learning, Blended learning, Real Laboratory, Enhancing Students' Performance, Proficiency, Confidence, and Scientific Instruments*

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Introduction

Chemistry practicals remain a vital component of science education, offering students essential hands-on experience and fostering practical skills in conducting experiments and scientific investigations. Recent studies emphasise that experiential learning through laboratory activities enhances students' engagement and deepens their understanding of scientific concepts and principles (Ajayi & Olayemi, 2025). These practicals also promote scientific inquiry and critical thinking, contributing significantly to academic achievement in science subjects such as chemistry and biology (Al-Mansoori, 2020). Furthermore, laboratory experiences cultivate problem-solving abilities, critical thinking, and scientific literacy, equipping students with competencies necessary for real-world applications (Okon & Adeyemi, 2025).

Chemistry practicals are hands-on learning experiences that deepen students' understanding of scientific concepts while building critical thinking, problem-solving, and experimental skills. By applying theoretical knowledge in a practical setting, students can reinforce their understanding of complex concepts and develop a more nuanced appreciation of scientific principles.

Despite the importance of chemistry practicals, the utilisation of physical laboratories in Nigeria faces numerous challenges. One major challenge in the implementation of practical chemistry is the lack of adequate infrastructure and resources, including outdated equipment, insufficient laboratory reagents, and poor facilities (Afolabi, 2018). Large class sizes and limited supervision can also compromise the quality of laboratory experiences (Ogunleye, 2019). Furthermore, safety concerns, such as inadequate ventilation and lack of personal protective equipment, pose risks to students and instructors (Ezeh, 2020). These challenges can hinder students' ability to conduct experiments and investigations, ultimately affecting their understanding and performance in chemistry.

The integration of virtual laboratories in chemistry education has the potential to revolutionise the way students learn and engage with complex concepts. A virtual laboratory is a digital simulation that allows students to conduct scientific experiments interactively, fostering inquiry and understanding without the constraints of a physical lab. Virtual Laboratories provide a safe and controlled environment for students to conduct experiments, eliminating the risks associated with handling hazardous chemicals and equipment (Brinson, 2015; Bakas & Mikropoulos, 2022). This safe environment enables students to explore complex chemical reactions and phenomena without physical danger. Additionally, virtual Laboratories offer flexibility and accessibility, allowing students to conduct experiments remotely and at their own pace (Khan, 2021). This feature is particularly beneficial for students in resource-constrained schools or those in remote areas without access to standard laboratories.

Virtual Laboratories can also enhance student engagement, motivation, and understanding of complex concepts (Luo et al, 2022). The use of interactive simulations in virtual Laboratories enables students to explore complex chemical concepts and phenomena in a highly engaging and immersive way (Luo et al., 2022). These simulations often include virtual equipment, real-time data analysis, and immediate feedback, allowing students to develop a deeper understanding of laboratory procedures and techniques. Interactive simulations have been shown to improve students' understanding of complex scientific concepts and enhance their engagement with the materials (Pyatt & Sims, 2012).

By adopting virtual Laboratories, educators in Nigeria can provide students with immersive and interactive learning experiences, ultimately improving their understanding and performance in chemistry. Virtual Laboratories can reach a wider audience and provide opportunities for students to engage in hands-on learning experiences that may not be feasible in traditional laboratory settings (de Jong et al., 2013). As such, virtual chemistry laboratories offer a range of benefits for students and educators, including safety, accessibility, and interactive learning experiences.

Research suggests that students' virtual laboratory experience can positively impact their learning outcomes and confidence in performing real chemistry lab practicals. According to a study by Luo et al. (2022), virtual Laboratories can enhance students' understanding of complex

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concepts and improve their ability to apply theoretical knowledge in practical settings. The transfer of knowledge from virtual Laboratories to real-world applications is a critical aspect of laboratory learning. Studies have shown that students who engage in virtual Laboratories tend to perform better in real lab settings, demonstrating improved procedural knowledge and technical skills (Bakas & Mikropoulos, 2022).

The integration of virtual laboratories in chemistry education has revolutionized the way students learn and engage with complex concepts. Virtual Laboratories provide a safe and controlled environment for students to conduct experiments, eliminating the risks associated with handling hazardous chemicals and equipment (Brinson, 2015; Bakas & Mikropoulos, 2022). This safe environment enables students to explore complex chemical reactions and phenomena without physical danger. Research has shown that virtual Laboratories can positively impact students' learning outcomes and confidence in performing real chemistry lab practicals (Pyatt & Sims, 2019). For instance, a study by Khan et al. (2021) found that students who used virtual Laboratories reported increased confidence and reduced anxiety when conducting experiments in physical Laboratories.

However, some studies have reported contradictory findings, suggesting that virtual Laboratories may not be as effective in certain contexts. For instance, a study by Tuysuz et al. (2020) found that students who used virtual Laboratories did not perform significantly better in real lab settings compared to those who did not use virtual Laboratories. This suggests that the transfer of knowledge from virtual Laboratories to real-world applications may be limited. Some researchers argue that virtual Laboratories cannot replace the hands-on experience and tactile feedback that students receive in physical Laboratories (Ma & Nickerson, 2006). Technical issues, such as connectivity problems and poor user interface design, can also detract from the learning experience and reduce the effectiveness of virtual Laboratories (Hsieh & Lee, 2018).

The effectiveness of virtual Laboratories in translating to real-world proficiency with scientific instruments remains a subject of investigation. Virtual chemistry Laboratories offer a range of features that enhance the learning experience for students, including safety, accessibility, and interactive learning experiences (Brinson, 2015). Interactive simulations have been shown to improve students' understanding of complex scientific concepts and enhance their engagement with the material (Pyatt & Sims, 2012). According to a study by de Jong et al. (2013), virtual Laboratories can reach a wider audience and provide opportunities for students to engage in hands-on learning experiences that may not be feasible in traditional laboratory settings.

The challenge of translating online instruction to practical skills is not unique to chemistry education. In medical education, students face unique challenges in developing clinical skills, which require hands-on experience and direct supervision to master procedures and techniques. It is common knowledge that virtual Laboratories and online instruction can effectively teach theoretical concepts but may not provide the same level of hands-on experience as traditional Laboratories (Ma & Nickerson, 2006). To address these challenges, educators can employ a blended learning approach that combines online instruction with hands-on training and simulation-based education (Ruiz et al., 2006). This approach can provide students with the flexibility and accessibility of online learning while still allowing them to develop the practical skills and confidence needed to succeed in their chosen field.

Chemistry laboratory proficiency is a critical aspect of scientific research and experimentation, encompassing various skills such as instrument handling and operation, technique and procedure, data recording and calculations, and endpoint detection and determination (Harris, 2019; Skoog et al., 2017; Christian et al., 2013). Mastering these skills require familiarity with various instruments, knowledge of laboratory protocols, and the ability to accurately record and interpret data (Laitinen & Harris, 2018; Miller & Miller, 2018). Effective laboratory practicals, whether virtual or real, play a significant role in improving chemistry laboratory proficiency, with virtual Laboratories offering flexibility and accessibility (Brinson, 2019; Pyatt & Sims, 2017) and real Laboratories providing hands-on experience and tactile learning.

Recent research by Saputra and Irwanto

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(2020) found that virtual labs enhanced students' titration skills, while Widiyatmoko et al. (2021) emphasised the superior effectiveness of real lab experiences in developing hands-on competencies. Agustina et al. (2022) proposed that integrating both approaches offer a balanced and impactful strategy for teaching titration. By blending virtual simulations with physical experimentation, educators can deliver a richer, more inclusive learning experience that accommodates diverse learning preferences and significantly boosts laboratory proficiency (de Jong et al., 2013).

However, there are notable limitations and challenges associated with the use of virtual Laboratories. One of the primary concerns of this study is that virtual Laboratories provide the necessary real-world experience. While virtual Laboratories can simulate experiments and procedures, they cannot fully replicate the experience of working with physical equipment and materials. This can lead to difficulties for students when they transition to hands-on Laboratories, where they are required to apply theoretical knowledge in practical settings.

According to Pyatt and Sims (2012), students who used virtual Laboratories demonstrated improved proficiency in using laboratory equipment and conducting experiments. Specifically, virtual Laboratories have been found to enhance students' ability to read scales on instruments, determine the lowest meniscus, and convert scales. In a related study, Tatli and Ayas (2013) found that students who used virtual chemistry laboratory software showed improved understanding of measurement techniques, including reading scales and determining the lowest meniscus. This is because virtual Laboratories provide students with a safe and controlled environment to practice laboratory procedures and equipment, allowing them to develop their skills and confidence before moving to hands-on Laboratories.

In terms of reporting experiment data, virtual Laboratories have been found to improve students' ability to accurately record and report data. A study by de Jong et al. (2013) found that students who used virtual Laboratories showed improved data collection and reporting skills, including accurate measurement readings and calculation of results. Other activities in the real lab, such as setting up equipment and conducting experiments, have also been found to be positively impacted by virtual lab experience. According to a study by Brinson (2015), students who used virtual Laboratories showed improved laboratory skills and confidence in conducting experiments, including setting up equipment and following procedures. The use of virtual Laboratories can also help to reduce errors and improve accuracy in laboratory experiments. A study by Kang and Keinonen (2017) found that students who used virtual Laboratories showed reduced errors in measurement readings and calculation of results, indicating improved attention to detail and understanding of laboratory procedures.

Conversely, some studies have reported findings that are at variance with the effectiveness of virtual Laboratories in improving students' skills in real Laboratories. Ma and Nickerson (2006) found that students who used virtual Laboratories struggled to apply their knowledge and skills in real-world laboratory settings, suggesting that virtual Laboratories may not provide the same level of hands-on experience as traditional Laboratories. Similarly, Nedic et al. (2003) found that students who used virtual Laboratories did not develop the same level of technical skills as students who used traditional Laboratories, highlighting the importance of hands-on experience in laboratory settings.

Furthermore, Corter et al. (2011) found that students who used virtual Laboratories reported a lack of realism in the simulations, which affected their ability to transfer their skills to real-world laboratory settings. This lack of realism can limit the effectiveness of virtual Laboratories in preparing students for real-world laboratory experiences. Additionally, Scheckler (2003) found that students who used virtual Laboratories were heavily dependent on the technology and struggled when they had to perform tasks in a real lab without the aid of the virtual lab. These contradictory reports from different studies suggest that while virtual Laboratories may have some benefits, they may not be a replacement for traditional hands-on laboratory experiences.

The disparity and contradictions in reports on the efficacy of virtual Laboratories in teaching and transferring skills to real-world practice underscore the need for a comprehensive study to

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compare the effects of virtual Laboratories, real Laboratories, and a combination of both on students' performance, confidence, and manipulation skills in lab instruments. This study seeks to identify the most effective pedagogical strategies for teaching laboratory skills by critically examining the strengths and limitations of both real and virtual laboratory methods, with a particular focus on their applicability and scalability in managing large classroom settings, such as those commonly found in Ondo State. This was therefore set out to determine the impact of virtual laboratory instruction on students' proficiency with scientific instruments in chemistry practicals, compare the performance of students who use virtual Laboratories with those who do not in terms of handling and operating scientific instruments, and assess the level of confidence students have in using scientific instruments after participating in virtual lab activities.

Research Questions

The following research questions were raised to guide the study:

1. What is the students' proficiency level in the use of scientific instruments in chemistry practical when exposed to real laboratory, virtual laboratory, and blended laboratory activities?
2. Is there a difference in the performance of students in Chemistry when exposed to a real laboratory, a virtual laboratory, and blended laboratory activities?
3. What are the students' confidence levels when they participate in a real laboratory, a virtual laboratory, and blended laboratory activities?

Hypotheses

Based on the research questions raised, the following hypotheses were formulated and tested at 0.5 confidence level to guide the study:

1. There is no significant difference in students' proficiency level in the use of scientific instruments in chemistry practical when exposed to real laboratory, virtual laboratory, and blended laboratory activities.
2. There is no significant difference in the performance of students in Chemistry when exposed to a real laboratory, a virtual laboratory, and blended laboratory activities.
3. There is no significant difference in students' confidence levels when they participate in a real laboratory, a virtual laboratory, and blended laboratory activities.

Research Method

The study adopted a non-equivalent pre-test, post-test, and control group quasi-experimental design to investigate the effect of virtual laboratory, blended, and real laboratory approaches on students' proficiency in using laboratory instruments in titration experiments. The target population consisted of all Secondary School Two (SSII) Chemistry students in Ondo State, with a sample of 156 students selected using a multi-stage sampling procedure. The students were assigned to two experimental groups (Virtual Laboratory and Blended) and a control group (Real Laboratory) based on the availability of specific facilities. The study employed three research instruments: the Titration Laboratory Instrument Proficiency Assessment (TLIPA), Chemistry Practical Performance Test (CPPT), and Chemistry Students' Confidence Questionnaire (CSCQ). The TLIPA assessed students' proficiency in using laboratory instruments, while the CPPT evaluated their practical skills, and the CSCQ measured their confidence. To ensure validity, the instruments were validated by experts, and modifications were made based on their observations. The reliability of the instruments was determined using Cronbach's Alpha for TLIPA (0.69) and CSCQ (0.72), and Pearson Product-Moment Correlation (PPMC) for CPPT (0.79). The study involved three stages: pre-test, intervention, and post-test. The pre-test stage assessed the students' equivalence at the entry level, the intervention stage involved teaching using the different approaches, and the post-test stage evaluated the effect of the intervention on students' proficiency, academic performance, and confidence. The Virtual Laboratory used Praxi Laboratories simulation software, the Blended Approach combined virtual and real laboratory settings, and the Real Laboratory involved traditional practical chemistry sessions. The data collected were analysed using descriptive statistics and Analysis of Variance (ANOVA) to test the hypotheses.

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Results

Research Question 1: What is the students' proficiency level in the use of scientific instruments in chemistry practical when exposed to real laboratory, virtual laboratory, and blended laboratory activities?

To answer this research question, the post-test proficiency scores of students in the Virtual Laboratory, Blended, and real Laboratory were subjected to descriptive analyses of mean and standard deviation, and the results are presented in Table 1.

Table 1: Descriptive Analyses of Post-test Proficiency Scores of Students in Virtual Laboratory, Blended, and Real Laboratory

Students ' Proficiency Statistics					
	N	Minimum	Maximum	Mean ( )	Std. Deviation
Virtual Laboratory	14	13.00	21.00	17.8571	2.82454
Blended	12	19.00	26.00	22.8333	2.44330
Real Laboratory	16	10.00	18.00	12.6875	2.08866
Valid N (listwise)	12				

Table 1 shows that students in Blended Laboratory activities achieve the highest proficiency level ($\bar{x}$ = 22.8333) in handling scientific instruments, indicating that combining real and virtual experiences is particularly effective. Virtual Laboratory settings show moderate proficiency ($\bar{x}$ = 17.8571), while Real Laboratory settings have the lowest proficiency ($\bar{x}$ = 12.6875). Overall, Blended Laboratory activities are the most effective in enhancing students' proficiency in using scientific instruments in chemistry practicals.

Research Question 2: Is there a difference in the performance of students when exposed to a real laboratory, a virtual laboratory, and blended laboratory activities?

To answer this research question, the post-test performance scores of students in the Virtual Laboratory, Blended, and real Laboratory were subjected to descriptive analyses of mean and standard deviation, and the results are presented in Table 2.

Table 2: Descriptive Analyses of Post-test Performance Scores of Students in Virtual Laboratory, Blended, and Real Laboratory

Students ' Performance Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Virtual Laboratory	14	15.00	24.00	21.2857	2.39963
Blended	12	20.00	28.00	23.6667	2.38683
Real Laboratory	16	13.00	18.00	15.0000	1.41421
Valid N (listwise)	12				

Table 2 showed that students exposed to Blended Laboratory activities achieve the highest performance ($\bar{x}$ = 23.6667), indicating that combining real and virtual experiences is particularly effective. Virtual Laboratory settings show notable performance ($\bar{x}$ = 21.2857), while Real Laboratory settings have the lowest performance ($\bar{x}$ = 15.0000). Overall, Blended Laboratory activities are the most effective in enhancing students' performance.

Research Question 3: What are the students' confidence levels when they participate in a real laboratory, a virtual laboratory, and blended laboratory activities?

To answer this research question, the post-test confidence scores of students in the Virtual Laboratory, Blended, and real Laboratory were subjected to descriptive analyses of mean and standard deviation, and the results are presented in Table 3.

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Table 3: Descriptive Analyses of Post-test Confidence Scores of Students in Virtual Laboratory, Blended, and Real Laboratory

Students' Confidence Statistics					
	N	Minimum	Maximum	Mean ( )	Std. Deviation
PostCSCQ1	14	12.00	20.00	16.3571	2.73460
PostCSCQ2	12	20.00	27.00	23.4167	2.19331
PostCSCQ3	16	9.00	16.00	12.2500	2.29492
Valid N (listwise)	12				

Table 3 reveals that students participating in Blended Laboratory activities exhibit the highest confidence level ($\bar{x}$ = 23.4167), indicating that combining real and virtual experiences is particularly effective. Real Laboratory settings show moderate confidence ($\bar{x}$ = 16.3571), while Virtual Laboratory settings have relatively lower confidence ($\bar{x}$ = 12.2500). The Blended Laboratory group also demonstrates the most consistent confidence levels (SD = 2.19331). Overall, Blended Laboratory activities are the most effective in enhancing students' confidence.

Hypotheses Testing

Hypothesis 1: There is no significant difference in students' proficiency level in the use of scientific instruments in chemistry practical when exposed to real laboratory, virtual laboratory, and blended laboratory activities.

To test this hypothesis, the post-test of students from the Virtual, Blended and Real Laboratories was subjected to ANOVA and Scheffe's Post-hoc analyses and the results are presented in Tables 4 and 4a.

Table 4: ANOVA table for Students' Proficiency in Practical Chemistry Laboratory

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	576.762	2	288.381	67.136	.000
Within Groups	167.524	39	4.295		
Total	744.286	41			

Table 4 shows the ANOVA results indicate a significant difference in students' proficiency levels when exposed to Real Laboratory, Virtual Laboratory, and Blended Laboratory activities (F = 67.136, Sig. = .000). This suggests that the type of laboratory activity has a significant impact on students' proficiency in using scientific instruments in chemistry practicals, leading to the rejection of the null hypothesis which states that there is no significant difference in students' proficiency level in the use of scientific instruments in chemistry practical when exposed to real laboratory, virtual laboratory, and blended laboratory activities.

Since a significant difference existed, there is a need to run the post-hoc and the result is presented in Table 5.

Table 5: Scheffe's Post-hoc Analysis of Students' Proficiency in Practical Chemistry

Multiple Comparisons						
Dependent Variable: Proficiency Scheffe						
(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Virtual Laboratory	Blended Laboratory	-2.3810*	.8153	.021	-4.456	-.306
	Real Laboratory	6.2857*	.7585	.000	4.356	8.216
Blended Laboratory	Virtual Laboratory	2.3810*	.8153	.021	.306	4.456
	Real Laboratory	8.6667*	.7915	.000	6.653	10.681
Real Laboratory	Virtual Laboratory	-6.2857*	.7585	.000	-8.216	-4.356
	Blended Laboratory	-8.6667*	.7915	.000	-10.681	-6.653

*. The mean difference is significant at the 0.05 level.

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The post hoc analysis in Table 5 reveals significant differences in proficiency levels between the groups. Specifically, the Blended Laboratory group outperforms both the Virtual Laboratory group (mean difference = 2.3810, Sig. = .021) and the Real Laboratory group (mean difference = 8.6667, Sig. = .000). Additionally, the Virtual Laboratory group shows significantly higher proficiency levels compared to the Real Laboratory group (mean difference = 6.2857, Sig. = .000). These results indicate that Blended Laboratory activities lead to the highest proficiency levels, followed by Virtual Laboratory, and then Real Laboratory.

Hypothesis 2: There is no significant difference in the performance of students when exposed to a real laboratory, a virtual laboratory, and blended laboratory activities.

To test this hypothesis, the post-test performance score of students from the Virtual, Blended and Real Laboratories was subjected to ANOVA and Scheffe's Post-hoc analyses and the results are presented in Tables 6 and 7.

Table 6: ANOVA Table for Students' Performance in Practical Chemistry Laboratory

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	576.762	2	288.381	67.136	.000
Within Groups	167.524	39	4.295		
Total	744.286	41			

The ANOVA results indicate a significant difference in the performance of students when exposed to different laboratory activities (Real Laboratory, Virtual Laboratory, and Blended Laboratory). The F-statistic is 67.136, with a significance level (Sig.) of .000, which is less than the typical alpha level of 0.05. This suggests that the null hypothesis stating that there is no significant difference in the performance of students when exposed to a real laboratory, a virtual laboratory, and blended laboratory activities is rejected. The Between Groups Sum of Squares (576.762) accounts for a substantial portion of the total variability (744.286), further supporting the significance of the differences between the groups.

Since the difference is significant, there is a need to examine the post-hoc analysis to see where the significance lies, and the results are presented in Table 5a.

Table 6: Scheffe's Post-hoc Analysis of Students' Performance in Practical Chemistry

Multiple Comparisons

Dependent Variable: Performance
Scheffe

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Virtual Laboratory	Blended Laboratory	-2.38095*	.81534	.021	-4.4559	-.3060
	Real Laboratory	6.28571*	.75848	.000	4.3555	8.2159
Blended Laboratory	Virtual Laboratory	2.38095*	.81534	.021	.3060	4.4559
	Real Laboratory	8.66667*	.79147	.000	6.6525	10.6808
Real Laboratory	Virtual Laboratory	-6.28571*	.75848	.000	-8.2159	-4.3555
	Blended Laboratory	-8.66667*	.79147	.000	-10.6808	-6.6525

*. The mean difference is significant at the 0.05 level.

Table 6 shows that the post hoc analysis reveals significant differences in performance between the groups. Specifically, the Blended Laboratory group outperforms both the Virtual Laboratory group (mean difference = 2.38, Sig. = .021) and the Real Laboratory group (mean difference =

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8.67, Sig. = .000). Additionally, the Virtual Laboratory group shows significantly better performance compared to the Real Laboratory group (mean difference = 6.29, Sig. = .000). These results indicate that Blended Laboratory activities lead to the highest performance, followed by Virtual Laboratory activities, and then Real Laboratory activities.

Hypothesis 3: There is no significant difference in students' confidence levels when they participate in a real laboratory, a virtual laboratory, and blended laboratory activities.

To test this hypothesis, the post-test confidence score of students from the Virtual, Blended and Real Laboratories was subjected to ANOVA and Scheffe's Post-hoc analyses and the results are presented in Tables 7 and 8.

Table 7: *ANOVA Table for Students' Confidence Score in Practical Chemistry Laboratory*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	859.345	2	429.673	73.134	.000
Within Groups	229.131	39	5.875		
Total	1088.476	41			

Table 8 is the ANOVA results which indicate a significant difference in students' confidence levels when participating in different laboratory activities (Real Laboratory, Virtual Laboratory, and Blended Laboratory). The F-statistic is 73.134, with a significance level (Sig.) of .000, which is less than the typical alpha level of 0.05. This suggests that the null hypothesis stating that there is no significant difference in students' confidence levels when they participate in a real laboratory, a virtual laboratory, and blended laboratory activities is rejected. The Between Groups Sum of Squares (859.345) accounts for a substantial portion of the total variability (1088.476), further supporting the significance of the differences between the groups.

Since the difference is significant, there is a need to examine the post-hoc analysis to see where the significance lies, and the results are presented in Table 8.

Table 8: Scheffe's Post-hoc Analysis of Students' Confidence in Practical Chemistry

Multiple Comparisons						
Dependent Variable: Confidence Scheffe						
(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Virtual Laboratory	Blended Laboratory	-7.05952^{*}	.95355	.000	-9.4861	-4.6329
	Real Laboratory	4.10714^{*}	.88705	.000	1.8498	6.3645
Blended Laboratory	Virtual Laboratory	7.05952^{*}	.95355	.000	4.6329	9.4861
	Real Laboratory	11.16667^{*}	.92563	.000	8.8111	13.5222
Real Laboratory	Virtual Laboratory	-4.10714^{*}	.88705	.000	-6.3645	-1.8498
	Blended Laboratory	-11.16667^{*}	.92563	.000	-13.5222	-8.8111

*. The mean difference is significant at the 0.05 level.

The post hoc analysis from Table 6a reveals significant differences in confidence levels between the groups. The Blended Laboratory group has the highest confidence levels, significantly outperforming both the Virtual Laboratory group (mean difference = 7.05952, Sig. = .000) and the Real Laboratory group (mean difference = 11.16667, Sig. = .000). Additionally,

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the Virtual Laboratory group shows significantly higher confidence levels compared to the Real Laboratory group (mean difference = 4.10714, Sig. = .000). These results indicate that Blended Laboratory activities lead to the highest confidence levels, followed by Virtual Laboratory activities, and then Real Laboratory activities.

Discussion of Findings

This study provides valuable insights into the effectiveness of Real, Virtual, and Blended Laboratory approaches in chemistry education by examining their impact on students' proficiency, performance, and confidence levels. Findings reveal that students exposed to the Blended Laboratory method demonstrated the highest proficiency in handling scientific instruments, followed by those in the Virtual Laboratory and then the Real Laboratory groups. These results align with prior research suggesting that integrating real and virtual experiences enhances students' laboratory skills (Zacharia & Olympiou, 2011; de Jong et al., 2013). The blended approach leverages the strengths of both environments offering hands-on practice and interactive simulations to foster deeper understanding and technical competence. Supporting this, Tatli and Ayas (2013) reported that virtual chemistry labs improved students' grasp of measurement techniques, such as reading scales and identifying the meniscus.

In terms of performance, students in the Blended Laboratory group again outperformed their peers, with the Virtual Laboratory group ranking second and the Real Laboratory group third. These findings are consistent with studies highlighting the effectiveness of combining physical and digital lab experiences to boost academic performance (Pyatt & Sims, 2012; Brinson, 2015). Interactive simulations, in particular, have been shown to promote student-centered learning and engagement, as noted by Kang and Keinonen (2017).

Confidence levels followed a similar trend: students in the Blended Laboratory group reported the highest confidence, followed by those in the Virtual and Real Laboratory groups. This supports earlier research indicating that blended environments can enhance students' self-assurance in laboratory settings (Khan et al., 2021; Luo et al., 2022). Virtual labs, in particular, provide a safe and controlled space for students to practice procedures and build familiarity with equipment, which is especially beneficial in resource-limited contexts (Brinson, 2015).

Overall, the findings underscore the pedagogical value of Blended Laboratory instruction in chemistry education. By combining the tactile benefits of real labs with the flexibility and interactivity of virtual simulations, educators can deliver a more inclusive and effective learning experience. This approach not only accommodates diverse learning styles but also enhances students' laboratory proficiency, academic performance, and confidence—contributing meaningfully to the evolving landscape of science education.

Conclusion

This study provides conclusive evidence that Blended Laboratory activities are effective approach to enhancing students' proficiency, performance, and confidence levels in chemistry practicals. The findings indicate that combining real and virtual experiences leads to significant improvements in students' ability to handle scientific instruments, perform experiments, and develop confidence in laboratory settings.

Recommendations

Based on the findings in the study, the following recommendations were made:

1. Educators and policymakers should incorporate Blended Laboratory activities into chemistry curricula to enhance students' proficiency, performance, and confidence levels in Chemistry.
2. Educators should receive professional development opportunities to learn how to effectively integrate Blended Laboratory activities into their teaching practices for effective teaching of Chemistry.
3. Further research should be conducted to explore the effectiveness of Blended Laboratory activities in different educational settings and contexts.

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