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Research Article

Technology-enhanced learning through virtual laboratories in chemistry education

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ABSTRACT

This research studied the impact of integrating virtual laboratories in chemistry lessons among 22 pre-service teachers who were enrolled in a Bachelor of Education program, focusing on middle and high school science. These participants were systematically divided into an experimental group (EG) and a control group. Both groups engaged in the same organic chemistry lesson and subsequent lab session, the only difference being that EG received additional training via a virtual laboratory prior to the hands-on lab session. A survey, conducted both before and after the experiment, was utilized to measure participants' attitudes towards the use of virtual laboratories. The quantitative data analysis revealed a significant positive shift in EG's attitudes post-intervention, suggesting that virtual laboratory experiences enhance their learning and engagement. Specifically, participants exhibited improved understanding of the educational methodologies and heightened engagement during the physical lab work. However, no significant differences were observed between the two groups concerning the technical aspects of the experiments, implying that the virtual labs' impact on perspectives about the technical components of a chemistry lab was consistent across both groups. These findings support the view of virtual laboratories as a viable supporting tool for science education, promoting technology integration into teaching practices to meet the demands of 21st century learning outcomes. This research concludes with recommendations for future studies to explore further the implications of virtual labs on various aspects of science education.

Keywords: virtual laboratory, chemistry, organic chemistry, pre-service teacher, training, science education, laboratory

INTRODUCTION

Chemistry, a core science subject, comprises theories, facts, and laws that have been explored and validated through rigorous experimental procedures (Ural, 2016). Its importance in diverse scientific domains such as medicine, pharmacy, and environmental science underscores its inclusion in the K-12 curriculum. A significant facet of chemistry education is understanding the interactions of elements and compounds, and the practical implications of these reactions in daily life (Ural, 2016). The advent of technology has profoundly impacted the field of chemistry education (Cetin-Dindar et al., 2018). From enhancing experimental accuracy to facilitating comprehensive understanding of complex concepts, technology's integration into education has been pivotal (Ali & Ullah, 2020). However, the optimal utilization of technology in education demands a defined set of professional standards to ensure efficacy and facilitate proper understanding among students.

Focusing on organic chemistry, it involves the study of carbon-hydrogen bonded compounds, their properties, reactions, and structures (Denmark, 2009). Given the countless organic compounds that exist due to carbon's ability to form chains with other atoms, the instructional methods in this area must incorporate practical activities to provide a hands-on understanding of reactions and compounds.

Hands-on laboratory sessions and experiments have traditionally been the preferred methods of teaching chemistry, as they stimulate creativity, problem-solving skills, and foster observational learning (Musengimana et al., 2021). However, such methods are often hindered by logistical challenges, such as the high cost of equipment, lack of resources, and time constraints for preparation (Ali & Ullah, 2020). This challenge was further accentuated during the COVID-19 pandemic when access to physical laboratories became severely limited (Babinčáková & Bernard, 2020).

Against this background, the integration of technology into education has been underscored as an essential strategy by organizations such as UNESCO, as part of its sustainable development goals (SDG) (Zhu & Liu, 2020). Virtual labs, an application of technology in education, serve as platforms for students to simulate real-world problems and reactions in a virtual environment (Mutlu & Acar Sesen, 2016). This tool offers students the flexibility to repeat experiments and interact with various aspects of the experiment, thus fostering a deeper understanding of the concepts.

Several studies indicate that the use of virtual labs enhances students' understanding and performance in chemistry (Gambari et al., 2018). They also suggest an increase in students' motivation and engagement levels (Mutlu & Acar Sesen, 2016). Moreover, virtual labs serve as a cost-effective teaching tool that enables pre-emptive practice before real-world experiments (Tuysuz, 2010).

Despite the potential benefits, the successful integration of technology into education is contingent on the preparedness of the educators to leverage it effectively. Therefore, training pre-service teachers to use technology, particularly in practical subjects like chemistry, is crucial for their future roles. Some studies have noted a correlation between the incorporation of technology in teacher preparation programs and the readiness of the teachers to use technology in their practice (Chittleborough, 2014).

Given the above context, this study seeks to compare the perceptions and experiences of pre-service science teachers regarding the use of virtual labs for organic chemistry, in comparison to traditional laboratory methods. The study aims to ascertain the potential benefits of virtual labs in fostering creativity and problem-solving skills among future science teachers. It fills a gap in current literature by focusing on the specific context of pre-service teachers in organic chemistry, an area that has been less explored in previous studies.

Benefits of Virtual Labs in Teaching & Learning Science

There are many benefits to using virtual labs in education. According to Lynch (2016), benefits include the followings:

1. **Flexible access:** Students can access the virtual lab from any location and at any time. They no longer need a brick-and-mortar laboratory.
2. **Instant feedback:** Students in the virtual labs receive immediate feedback from the software.
3. **Lower costs:** Virtual labs require smaller budgets for equipment, materials, and tools. They use software and Internet access.

Virtual Labs vs. Traditional Labs

The integration of virtual labs in education has yielded numerous benefits in science learning and teaching. Virtual labs offer a flexible approach to learning by allowing students to access experiments anytime and anywhere, bypassing the constraints of traditional labs (Lynch, 2016). Moreover, students receive real-time feedback, promoting immediate understanding and remediation. Additionally, virtual labs contribute to cost efficiency as they require fewer resources compared to traditional labs (Lynch, 2016). The fundamental differences between traditional and virtual labs have been explored by researchers such as Babateen (2011). Unlike traditional labs, which are constrained by physical location and time, virtual labs offer multimedia resources and promote collaborative or individual learning experiences. Traditional labs, however, rely on specific schedules, learning from teachers, and books, often within larger group settings.

Research has delved into impacts and perceptions of virtual labs in science education. Peechapol (2021) investigated the effects of virtual lab simulation in chemistry on student achievement, self-efficacy, and learning experiences. Results indicated that the experimental group (EG), which utilized virtual lab, scored significantly higher in achievement tests and displayed greater self-efficacy compared to control group (CG).

Elkhouly (2021) sought to understand the attitudes of students, lecturers, and lab assistants towards virtual labs at Qatar University. The findings revealed positive perceptions towards virtual labs among all participants, highlighting their potential in learning and teaching. Distor et al. (2022) evaluated the efficacy of virtual labs in an anatomy and physiology course, demonstrating that virtual labs significantly improved student learning outcomes and perceptions.

Research by Kay et al. (2018) on the use of virtual labs in an allied health program further reinforced the positive attitudes of students towards virtual labs. Despite some reported challenges, a majority of the students agreed that virtual labs helped prepare them for traditional labs.

Despite the extensive research on virtual labs, a gap persists in our understanding of their impact on pre-service teachers' skill development, especially in organic chemistry. Furthermore, studies have not adequately compared the effects of using virtual labs prior to actual lab experience versus traditional lab-only approaches. Therefore, this study aims to fill this gap by exploring the effects of virtual labs on pre-service science teachers' creativity and problem-solving skills in the context of organic chemistry, providing insights into the potential role of virtual labs in teacher education.

Purpose

It is possible to adopt and incorporate 21st century skills into school curriculum using a virtual approach. Teachers must be trained on specific tools pertaining to 21st century skills and distance learning. This study was designed to establish a virtual lab training course for a CG of pre-service science teachers, aiming to integrate 21st century skills with core content. Chemistry was the core subject in the current study. The goal of the project was to provide training on the use of technology while learning a core subject. Then, it explored the perspective of those who were trained (EG) and those who were not (CG). 21st century skills in learning required competent teachers who were skilled and able to integrate technology into their classes while teaching. The research question asked: Are there statistically significant differences between EG (those who experimented with virtual labs) and CG when looking at educational and technical perceptions related to the organic chemistry lab experiment?

Research Questions

1. Are there statistically significant differences between EG and CG regarding the students' perspective of the practical chemistry lab experiment?
2. Are there statistically significant differences between EG and CG regarding the students' perspective of the practical experiment in the chemistry lab experiment due to educational aspects?
3. Are there statistically significant differences between EG and CG regarding the students' perspective of the practical experiment in the chemistry lab experiment due to technical aspects?

METHOD

To provide a clearer understanding of the research design, the study was divided into multiple phases. The focus of the study was the university and high school level chemistry lesson, "reactions of carbonyl compounds." The selection of this lesson was driven by its importance in organic chemistry, where the carbonyl group (C=O) underlies significant reactions resulting from the polarized carbon-oxygen bond due to the high electronegativity of oxygen atom. The experiment accompanying this lesson involved benzaldehyde-2,4-dinitrophenylhydrazone, a substituted hydrazine compound frequently used for testing aldehydes and ketones in Brady's test (**Figure 1** and **Figure 2**). Students were required to add liquid aldehydes and ketones to 2,4-dinitrophenylhydrazine, creating solid derivatives. Methanol and ethanol were also used in tests to demonstrate that the reaction does not occur with alcohol. The lesson structure included a starter activity, work tasks focused on testing for carbonyl compounds, and a concluding lab activity. The lab activity aimed to enable students to detect the presence of an aldehyde group and differentiate between aldehydes and ketones. The teaching methodology between EG and CG differed in one critical aspect: EG was exposed to a virtual introduction of the experiment prior to the actual lab session. The preparation and execution of the class lecture, along with the lab session for both groups, were conducted under the same conditions.

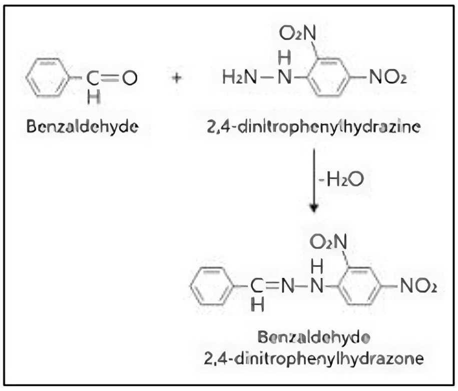

Figure 1. Experiment of benzaldehyde-2,4-dinitrophenylhydrazone (Denmark, 2009)

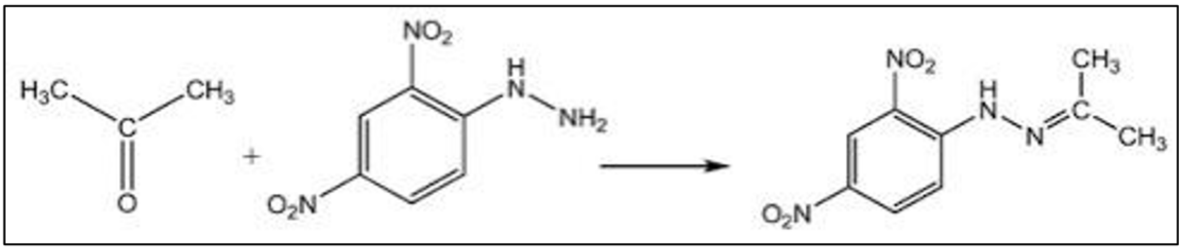

Figure 2. Outcome of benzaldehyde-2,4-dinitrophenylhydrazone (Denmark, 2009)

Participants

The study employed purposive sampling, selecting participants from two sections of science education majors in College of Education at Kuwait University. These students were specifically chosen due to the requirement of chemistry within their curriculum, and the necessity for them to complete chemistry education prior to instructing middle or high school students. This context provided an opportune setting to examine their perspectives on a fundamental chemistry lesson.

The study divided these participants into two groups: an EG, which engaged with a virtual laboratory learning model, and a CG, which followed the traditional learning method. Each group consisted of 15 students.

In our research, we used two types of groups for the study:

1. **EG:** This group participated in the virtual labs as an integral part of their chemistry coursework.
2. **CG:** This group did not participate in the virtual labs and continued with their traditional, hands-on lab experiences.

Data Instruments

The study utilized Arabicized virtual lab software as an instrument, which covered diverse scientific experiment disciplines. The research team referenced school textbooks to choose the relevant chemistry lesson, aligning it with college-level chemistry lessons. Additionally, a physical chemistry lab was reserved to conduct the experiments for both groups. EG received over six hours of hands-on training on PraxiLabs software and the specific chemistry experiment, "reactions of carbonyl compounds". This was followed by an actual lab session with tangible materials. CG, on the other hand, attended an intensive training course on virtual labs in a computer lab, also utilizing PraxiLabs software for virtual experiments. This training was conducted under the supervision of a chemistry and software expert.

A pre- and post-procedure survey was designed to gauge students' perspectives. The survey, developed by the research team, was divided into two sections. The first section, consisting of 13 items, captured students' views on the educational aspect of the lab experience. The second section, with 10 items, probed into students' opinions on the technical aspects of lab experiences. All instruments were validated by experts in science education and educational technology for reliability.

Table 1. Descriptive results using mean & standard deviation & reliability analysis using Cronbach's alpha with item-rest correlation to measure overall relationship between test A items

	Mean	Standard deviation	Item-rest correlation	If item dropped: Cronbach's alpha
A1	3.712	0.696	0.750	0.944
A2	3.731	0.660	0.848	0.942
A3	3.673	0.706	0.793	0.943
A4	3.596	0.693	0.753	0.944
A5	3.423	0.723	0.779	0.944
A6	3.596	0.693	0.744	0.945
A7	3.462	0.874	0.617	0.949
A8	3.654	0.711	0.815	0.943
A9	3.288	0.893	0.659	0.948
A10	3.712	0.696	0.759	0.944
A11	3.596	0.748	0.739	0.945
A12	3.538	0.779	0.689	0.946
A13	3.673	0.706	0.844	0.942

Note. Overall Cronbach's alpha for part A=0.949

Table 2. Descriptive results using mean & standard deviation & reliability analysis using Cronbach's alpha with item-rest correlation to measure overall relationship between test B items

Item reliability statistics				
	Mean	Standard deviation	Item-rest correlation	If item dropped: Cronbach's alpha
B1	3.392	0.918	0.816	0.961
B2	3.549	0.856	0.876	0.958
B3	3.608	0.850	0.857	0.959
B4	3.490	0.857	0.872	0.959
B5	3.588	0.779	0.890	0.958
B6	3.529	0.731	0.669	0.966
B7	3.569	0.781	0.802	0.961
B8	3.490	0.834	0.884	0.958
B9	3.490	0.809	0.842	0.960
B10	3.451	0.879	0.852	0.959

Note. Overall Cronbach's alpha for part B=0.964

Table 1 and **Table 2** provide detailed information regarding the survey statements. The items we chose for our survey were based on two overarching constructs: the educational aspect of lab experiences (test A) and the technical aspect of lab experiences (test B). These constructs were designed to capture comprehensive insights into the students' perceptions of labs in the context of chemistry education.

In test A, we aimed to understand the students' educational experiences in the lab. Items such as "hands-on experiences help me achieve the learning objectives of the course," and "practical experiences provide an opportunity for self-learning," were chosen to understand educational value students derived from the labs.

Similarly, in test B, we focused on the technical aspect of lab experiences. Items like "educational institutions provided the necessary equipment for practical experiments," and "instructions regarding the application of practical experiments were clear prior to the start," were chosen to understand the technical feasibility and support provided in the lab environment.

The overarching idea behind choosing these items was to examine whether labs are not only technically feasible but also educationally beneficial for pre-service teachers in the field of chemistry.

Students' perspectives: Educational aspect of lab experiences (test A)

1. Hands-on experiences help me achieve the learning objectives of the course.
2. Practical experiences provide an opportunity for self-learning.
3. Practical experiences make it easier to understand and answer assessment questions.
4. Hands-on experiences simplify curriculum-related concepts.
5. Hands-on experiences fall within my learning style.
6. I was given feedback after completing the practical experience.

7. There was a relationship between practical experience and real-life applications.
8. It provided me with various sources of information linked to practical experiences.
9. Individual differences were considered when applying the practical experiments.
10. Teaching strategies were appropriate to the nature of the experimental method.
11. We deduced the desired benefit from the application of practical experiments.
12. Age group was considered when applying practical experiments.
13. It provided positive reinforcement when applying hands-on experiences.

Students' perspectives: Technical aspect of lab experiences (test B)

1. Educational institutions provided the necessary equipment for practical experiments.
2. Educational institutions considered all aspects of security and safety associated with practical experiences.
3. The educator was trained to perform practical experiments.
4. Educational institutions provid technical support when needed as practical experiences were applied.
5. Instructions regarding the application of practical experiments were clear prior to the start.
6. Educational institutions provided a detailed guide on the method of applying practical experiments.
7. There was an opportunity to do hands-on experiments on my own or with colleagues in the lab.
8. Educational institutions provid me with a suitable science lab for application of practical experiments.
9. There was sufficient time for practical experimentation.
10. Educational institutions provided usable materials for practical experimentation.

Statistical Method

Reliability & statistical analyses

The reliability of the constructs within the survey was assessed using Cronbach's alpha measure. As per Cronbach (1951) and Nunnally and Bernstein (1994), a Cronbach's alpha value exceeding 0.7 confirms the reliability of a construct. In this study, the alpha values ranged from 0 to 1.

The study utilized multivariate analysis of variance (MANOVA) to test the differences between group level, time level, and the intersection of group and time level. Four tests were used within MANOVA: Wilk's lambda, Pillai's trace, Hotelling's trace, and Roy's largest root. For follow-up testing on group differences for each question, F-tests were employed.

All statistical analyses were conducted using the Jamovi software tools (Jamovi, 2022), including the relevant plug-in packages (R Core Team, 2021). To summarize the score result regarding a specific item, researcher used the mean (or average) of the questionnaire Likert scores (1 to3). The mean is calculated by summing up all the numerical responses and dividing by the number of responses. Then, MANOVA was used to test the differences between group level, time level, and group cross time level.

The constructs in this study included "attitudes toward virtual laboratory experiences," "engagement level during the virtual lab," "conceptual understanding after the virtual lab," and "perceived effectiveness of the virtual lab for practical skill enhancement." Each of these constructs represents an underlying attribute or idea we are interested in and are inferred from participants' responses to our survey.

For example, the construct "attitudes toward virtual laboratory experiences" is not directly observable, but it can be inferred from specific survey questions such as "I found the lab engaging."

When we mention the reliability of the constructs within our survey, we're talking about the consistency of the survey questions tied to each construct. If the pre-service teachers understood and responded to these questions in a similar manner, it indicates that our survey accurately captured their attitudes and perceptions regarding each construct. This is what we assessed using Cronbach's alpha measure.

Table 3. Multivariate tests using MANOVA test, Pillai's trace, Wilks lambda, Hotelling's trace, & Roy's largest root analysis at a significance level of 5% (alpha=0.05) for students' scores in tests A & test B

		Value	F	df1	df2	p-value
Group	Pillai's trace	0.104	2.890	2	50	0.065
	Wilks' lambda	0.896	2.890	2	50	0.065
	Hotelling's trace	0.116	2.890	2	50	0.065
	Roy's largest root	0.116	2.890	2	50	0.065
Time	Pillai's trace	0.082	2.219	2	50	0.119
	Wilks' lambda	0.918	2.219	2	50	0.119
	Hotelling's trace	0.089	2.219	2	50	0.119
	Roy's largest root	0.089	2.219	2	50	0.119
Group*time	Pillai's trace	0.034	0.869	2	50	0.425
	Wilks' lambda	0.966	0.869	2	50	0.425
	Hotelling's trace	0.035	0.869	2	50	0.425
	Roy's largest root	0.035	0.869	2	50	0.425

Table 4. Univariate tests of between-subjects effects of student scores between group & time levels

	Dependent variable	Sum of squares	df	Mean square	F	p
Group	Part A overall	0.502	1	0.502	5.108	0.028
	Part B overall	0.809	1	0.809	3.375	0.072
Time	Part A overall	0.019	1	0.019	0.188	0.666
	Part B overall	1.003	1	1.003	4.184	0.046
Group*time	Part A overall	0.160	1	0.160	1.631	0.207
	Part B overall	0.016	1	0.016	0.068	0.796
Residuals	Part A overall	5.016	51	0.098		
	Part B overall	12.224	51	0.240		

Note. Estimate independent mean difference for part A & part B test score

DATA ANALYSIS AND RESULTS

Reliability Analysis for Pre- & Post-Test

To evaluate the consistency of data for the constructs, a reliability index was applied. The internal consistency of the survey items in the pre-test and post-test was assessed using Cronbach's alpha. The value of Cronbach's alpha for the pre-test and post-test was 0.95 (**Table 1**) and 0.96 (**Table 2**), respectively, suggesting a high level of consistency in the questionnaire.

All items in the survey demonstrated an item-rest correlation value greater than 0.20 (Abdulameer & Sahib, 2019), which indicates their appropriateness for inclusion in the study. It's important to note that the items used in the pre- and post-tests were identical to ensure comparability. Each item in the survey was presented as a statement, with respondents providing their level of agreement on a four-point Likert scale, ranging from "strongly disagree" to "strongly agree". These items were designed to capture students' perspectives on both general and specific aspects of their lab experiences, including the hands-on activities specific to this study's chemistry lesson.

MANOVA: Test for Significant Differences Between Group Level, Time Level, & Group Cross Time Level

Table 3 shows MANOVA tests for group, time, and interaction of group and time (all were not significant).

1. **Group:** Pillai's trace=0.104; Wilk's lambda=.896; Hotelling's trace=.116, Roy's largest root=0.116; F=2.890; p-values for all four tests=0.065.
2. **Time:** Pillai's trace=0.082; Wilk's lambda=0.918; Hotelling's trace=0.089, Roy's largest root=0.089; F=2.219; p-values for all four tests=0.119.
3. **Group*time:** Pillai's trace=0.034; Wilk's lambda=0.966; Hotelling's trace=0.035, Roy's largest root=0.035; F=0.869; p-values for all four tests=0.425.

The results of follow-up tests for the main effect of group and time and for the interaction effect of group*time are reported in **Table 4**.

Table 5. Compare two means of student scores between group levels for part A test scores

Condition	Mean	95% confidence interval (CI)		S	n
		Lower	Upper		
Experimental group	3.734	3.644	3.825	0.247	30
Control group	3.542	3.391	3.694	0.378	25
Difference	0.192	0.022	0.362	0.313	55

Note. Comparison on unpaired data; equal variance assumed; S in row for difference is pooled SD; $d_{unbiased}$=0.60 95% CI [0.07, 1.19]; standardized effect size is $d_{unbiased}$ since denominator was SDpooled, value of 0.313, standardized effect size corrected for bias; bias-corrected version of Cohen's d is also (confusingly) called Hedges' g; & decision for this hypothesis is there are significant differences between group level regarding overall scores for test A (t=2.264, df=53, & p-value=0.028)

Table 6. Compare two means of student scores between group levels for part B test scores

Condition	Mean	95% confidence interval (CI)		S	n
		Lower	Upper		
Experimental group	3.722	3.595	3.850	0.348	30
Control group	3.479	3.223	3.734	0.637	25
Difference	0.244	-0.028	0.515	0.500	55

Note. Comparison on unpaired data; equal variance assumed; S in row for difference is pooled SD; $d_{unbiased}$=0.48 95% CI [-0.05, 1.05]; standardized effect size is $d_{unbiased}$ since denominator was SDpooled, value of 0.500, standardized effect size corrected for bias; bias-corrected version of Cohen's d is also (confusingly) called Hedges' g; & decision for this hypothesis is there are significant differences between group level regarding overall scores for test A (t=1.799, df=53, & p-value=0.078)

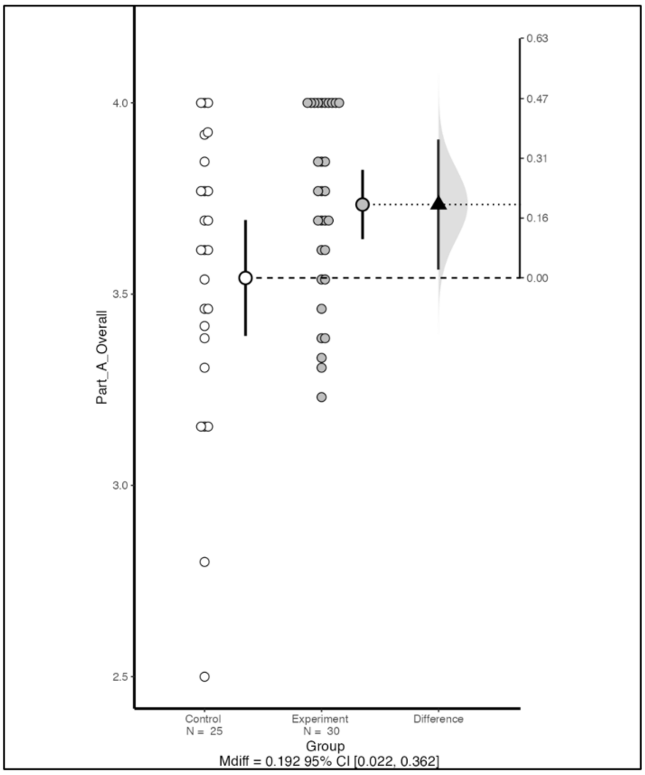

Figure 3. Students' scores comparison in part A test between CG & EG as well as differences between them (Source: Authors)

The results of follow-up tests show that the scores of the students in test A differ significantly in EG and CG condition (p=0.028). Additionally, a significant difference in student scores was observed in the pre- and post-test (p=0.046).

A significant difference was observed in students' scores under experiment and control conditions in test A (t=2.264, df=53, p-value=0.028). The mean score of students under experiment condition (mean [M]=3.734) was high as compared to the mean score of students in CG (M=3.542) (**Table 5**).

Moreover, the finding shows no significant difference (t=1.799, df=53, p-value=0.078) in students' scores under experiment and control condition in test B (**Table 6**).

Figure 3 and **Figure 4** show mean value of students' scores for EG and CG for test A and B, respectively.

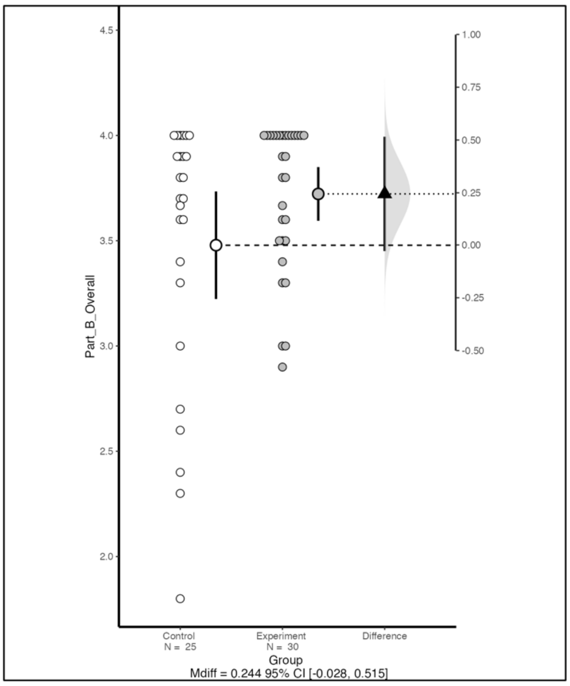

Figure 4. Students' scores comparison in part B test between CG & EG as well as differences between them (Source: Authors)

Figure 5. Violin plot shows average scores for both tests (A & B) on group level (EG vs. CG) & time level (pre- & post-test) with differences in scores measured by independent t-test (Source: Authors)

Violin Plots to Compare Groups Cross by Time (Pre- & Post-Test)

Figure 5 illustrates the results of the t-test that was conducted to examine the difference in students' scores in pre- and post-test for both groups (EG and CG) in tests A and B. A significant difference was observed in student scores in pre- and post-test for EG in test B only (t_{welch}[23.42]=2.60, p=0.016).

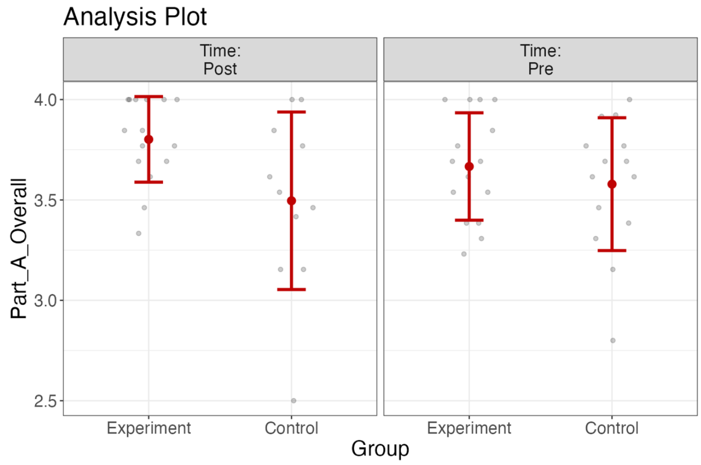

Figure 6. Analysis plot for overall scores in test A (Source: Authors)

Table 7. Estimates & effect sizes for categorical predictors of students' scores in test A

Variable	Level	Estimate	95% confidence interval	
			Lower	Upper
Group	EG	3.72	3.57	3.86
	CG	3.53	3.38	3.67
Time	Pre	3.53	3.38	3.67
	Post	3.56	3.40	3.72

Note. Factors (estimates reported are means)

Table 8. Difference between factor levels for categorical predictors for students' scores in test A

Variable	Comparison	Difference	95% confidence interval		Cohen's d
			Lower	Upper	
Group	EG	0.190	-0.050	0.430	0.600
Time	Post-pre	0.040	-0.200	0.280	0.120

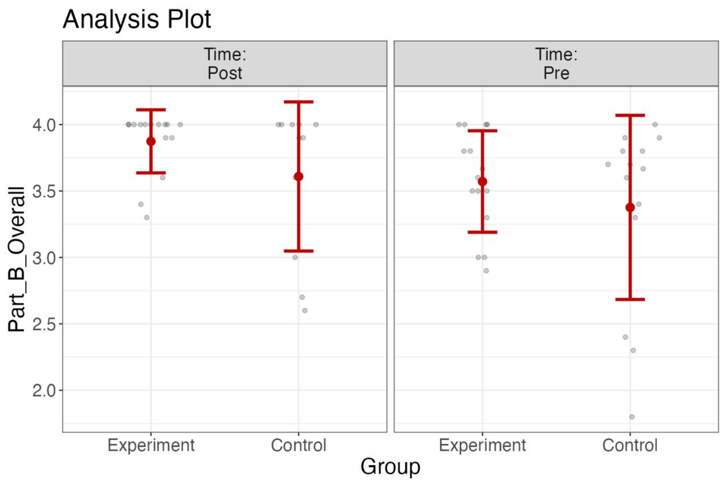

Figure 7. Analysis plot for overall scores in test B (Source: Authors)

General Linear Model

The analysis plot illustrates the mean score of students in test A for both EG and CG in the pre- and post-time (see **Figure 6**). The student score was high in EG for both the pre- and post-duration.

The linear model estimates for test A show that student scores are high in EG as compared to CG. Also, the finding shows that students score more in the post-test as compared to the pre-test (**Table 7**).

The difference in the score of students in EG-CG and the pre-post time is shown in **Table 8**.

Figure 7 illustrates the differences in student scores for test A.

Table 9. Estimates & effect sizes for categorical predictors of students' scores in test B

Variable	Level	Estimate	95% confidence interval	
			Lower	Upper
Group	EG	3.36	3.13	3.59
	CG	3.59	3.37	3.81
Time	Pre	3.36	3.13	3.59
	Post	3.63	3.39	3.87

Note. Factors (estimates reported are means)

Table 10. Difference between factor levels for categorical predictors for students' scores in test B

Variable	Comparison	Difference	95% confidence interval		Cohen's d
			Lower	Upper	
Group	EG	0.230	-0.150	0.600	0.470
Time	Post-pre	0.270	-0.100	0.640	0.560

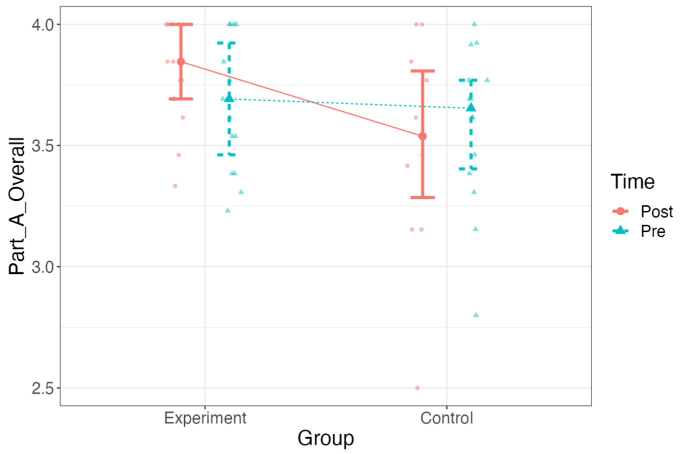

Figure 8. Analysis plot to measure differences in students' scores for part A in test (Source: Authors)

The analysis plot (see **Figure 4**) illustrates the mean score of students in test B for both EG and CG in the pre- and post-time. The students' scores were high in EG for both pre- and post-duration.

The linear model estimates for test B shows that students' scores are high in EG as compared to CG. Also, the finding shows that students score more in the post-test as compared to the pre-test (see **Table 9**).

The difference is shown in **Table 10**.

Figure 8 illustrates the differences in students' scores for test B.

DISCUSSION

This study leveraged a MANOVA to probe into the perspectives of pre-service science teachers regarding the use of virtual labs as a training tool for chemistry lessons. Participants were divided into an EG and a CG. CG engaged in a traditional lecture followed by a hands-on lab, while EG received a lecture, underwent virtual practice, and then conducted the physical lab experiment.

The findings underline that the integration of virtual labs substantially enhanced the experience of EG teachers. This was evinced by higher response rates concerning the educational aspects of the lab work, a finding that mirrors the conclusions drawn by Mutlu and Acar Sesen (2016). Their study revealed amplified student engagement via the introduction of virtual labs and established that such labs offer crucial reinforcement to real-world lab experiences (Mutlu & Acar Sesen, 2016). This corroborates our argument that virtual labs can serve as a critical preparatory tool before actual lab assignments.

Furthermore, the level of engagement was particularly prominent in EG during the physical lab work, likely due to the virtual familiarization process that occurred prior to the real lab experiment. This is consistent with the work of Elkhouly (2021), who suggested that virtual lab experiences can increase students' confidence and readiness for physical lab work.

Additionally, this study's statistical results reveal significantly higher scores within EG compared to CG. This suggests that virtual labs could have a positive impact on learning outcomes. These observations are in line with the findings of Elkhouly (2021), who reported an improvement in students' conceptual understanding following the use of virtual labs, progress that was mirrored in their academic achievements (Elkhouly, 2021).

In line with the work of Peechapol (2021), this study also observed higher post-test scores compared to the pre-test. Peechapol (2021) pointed out that the active learning approach fostered by virtual labs, which stimulate student participation through discussions and tasks, can enhance student understanding and academic performance (Peechapol, 2021).

Significant differences emerged in the responses towards the educational aspects of lab work between EG and CG ($p=0.028$). This suggests that exposure to a blend of conventional and virtual teaching methods broadened EG's understanding of educational methodologies, aligning with the findings of Zhu and Liu (2020), who observed that a blended learning approach can improve student performance.

However, our findings did not show significant differences between the two groups concerning the technical aspects of the experiments. This indicates that the virtual labs' impact on the perspective regarding the technical components of the chemistry lab was uniform across both groups.

To summarize, this research underscores the potential benefits of virtual labs in enhancing the learning experience. However, more comprehensive studies should be undertaken to further explore the effects of virtual labs on various aspects of science education.

CONCLUSIONS

Research in the field of education has generally reported favorable outcomes with the incorporation of technology. Indeed, both students and teachers are found to be more engaged when participating in virtual lab work. This digitally augmented exercise has been observed to significantly benefit the learning process.

Traditionally, conducting laboratory experiments pose a variety of challenges. These can range from logistical issues such as time constraints and costly supplies, to physical limitations such as space and equipment availability. Given these constraints, the integration of technology in the form of virtual labs presents a valuable alternative. These digital platforms could potentially mitigate the aforementioned challenges, thereby facilitating students' performance in science experiments.

Upon analyzing the data and results of this study, it can be concluded that the implementation of PraxiLabs effectively enhances students' learning experiences. It not only stimulates their engagement with the course content but also optimizes their preparation for actual laboratory work. Therefore, integrating virtual labs like PraxiLabs can serve as a significant supplement to traditional teaching methods in science education.

Recommendations

This study makes the following recommendations. First, it is evident that virtual labs improve pre-service teachers' learning experiences in chemistry. Therefore, educators should use this teaching tool to facilitate their teaching of science. Second, pre-service programs should incorporate educational technology into their curriculum. This allows teachers to embrace new skills. Third, pre-service teachers should be exposed to virtual lab experiences prior to reaching a student-teaching level. This allows teachers to be familiar with its use in future classrooms. Fourth, virtual labs should be suggested for chemistry content areas, especially difficult concepts or those that are high-risk in classrooms.

Limitations

The present study had certain limitations that provide avenues for future research. Firstly, the research was conducted on a relatively small scale, with participants drawn from two sections of the science education major during the summer semester. This resulted in a limited number of participants and a lack of sample heterogeneity. For more robust and generalizable findings, future studies should consider a larger and more diverse sample size, inclusive of service teachers.

A second limitation pertains to the duration of the intervention. This study set out to assess the impact of a single exposure to virtual lab experiences on participants' perceptions. However, expecting substantial perceptual changes within such a short intervention might not be realistic. This aspect underscores the necessity for future research to consider extended-term interventions coupled with repeated measures. This approach would likely provide a more accurate representation of potential shifts in students' attitudes towards virtual labs.

In terms of methodology, future research could potentially refine the present study's design. It would be fruitful to investigate relational or causal links between virtual labs and teacher assessments. Additionally, exploring the instructional aspects of the virtual lab could identify beneficial methods to aid teachers in developing their understanding of the nature of science.

Despite these limitations, the current study opens up a rich vein of opportunities in this field. The realm of online learning, particularly the use of virtual labs in chemistry, holds significant potential for the advancement of teaching methodologies and curriculums. As such, the need for continued exploration in this area is both beneficial and crucial.

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Data availability: Data generated or analyzed during this study are available from the authors on request.

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