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Using virtual science labs for physical science formal experiments in schools

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Abstract

This study investigates the utilisation of virtual laboratories as a supplement to conventional laboratory settings for conducting formal science experiments. Although previous research acknowledges the growing integration of digital tools in science education, there remains limited empirical evidence comparing the effectiveness of virtual and traditional laboratory experiences in supporting conceptual understanding. Addressing this gap, the study aimed to examine whether virtual laboratory instruction enhances academic achievement in physical sciences to the same extent as traditional laboratory methods. A quasi-experimental design was employed using pre- and post-test achievement scores, and the treatment involved conducting an acid-base titration activity through a virtual laboratory. The participants consisted of two hundred and eleven grade eleven physical science learners selected through random sampling. Data were analysed using independent t-tests and analysis of variance. The findings indicate that the type of experimental environment influences learner performance, yet no meaningful difference was found between virtual and traditional laboratory groups. Both approaches contributed similarly to improved conceptual comprehension. The study implies that virtual laboratories can serve as viable alternatives where conventional facilities are limited, supporting flexible and accessible science instruction.

Keywords: Conceptual comprehension; physical sciences; virtual laboratories; science education; traditional laboratories.

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1. INTRODUCTION

Computers are used in the artificial educational environment to replicate reality (Haleem et al., 2022). Thus, emerging technologies in education offer opportunities to improve teaching strategies and enhance conceptual understanding (Sağıroğlu et al., 2025; Akcil et al., 2021). Teachers may create a dynamic and engaging classroom environment that meets the different needs and learning styles of their learners by integrating technology tools such as virtual science laboratories (VL) into their teaching techniques (Shihab et al., 2023; Jiang et al., 2024). Virtual science laboratories have changed the teaching approaches over the past 20 years and are beneficial for carrying out experiments and teaching challenging science topics, in different countries in the world (Kolil & Achuthan, 2024; Huang, 2019; Laurillard et al., 2009; Marquez et al., 2016).

The benefits of using virtual experiments in science to promote scientific skills are well documented in the literature, but there is limited research evidence to indicate to determine if the virtual labs bring the same effect as the use of traditional laboratories in carrying out Physical Science 'formal' experiments in South African schools (Nhauro, 2021). The Curriculum Assessment Policy Statement (CAPS) document for Physical Sciences provides lists of prescribed practical activities for formal assessment in grades 10, 11, and 12. Many schools in South Africa fail to manage formal experiments for varying reasons, including a lack of infrastructure and resources (Oguoma 2018). According to Gudyanga & Jita (2019), the difficulties in the implementation of formal experiments are due to teachers complaining about overcrowded classes, a lack of specialised equipment to carry out formal experiments, and inadequate laboratory facilities. Such previous findings motivated the researcher to investigate the possibility of using virtual labs instead of traditional lab experiment techniques to alleviate the highlighted.

1.1. Literature review

1.1.1. Traditional lab experimentation

As per the definition provided by the Collins dictionary, a science laboratory in an educational institution is a space equipped with scientific apparatuses where learners get instruction in science topics, including biology, physics, and chemistry. Therefore, a traditional science laboratory (TL) refers to a building designed specifically for teaching science concepts and carrying out experiments, as used before the introduction of the remote digital methods of carrying out such science activities. TLs are essential to science education because they give learners practical experiences that improve their comprehension of scientific ideas. These laboratories are essential components of learning science subjects (Shana & Abulibdeh, 2020). Learners participate in hands-on experiments and exercises in typical laboratory settings, which supplement the theoretical information they have learned from textbooks and lectures. The incorporation of laboratory work is essential as it facilitates the application of theoretical concepts in practical settings, develops critical thinking abilities, and advances a more profound comprehension of scientific principles (Gericke et al., 2023). In South Africa, most well-resourced science laboratories are found in schools that can afford to purchase laboratory equipment and chemicals. Schools in rural and townships struggle to maintain or have such a type of laboratory; as a result, not so many formal experiments are carried out (Tsakeni et al., 2019).

Hofstein (2017) posits that TSLs provide a secure setting where learners may experiment with different tools and equipment and learn scientific procedures. The importance of laboratories is supported by Duban et al. (2019), who say that learners acquire important skills in observation, data collecting, analysis, and hypothesis testing via these hands-on projects. This aids in their comprehension of the scientific process and fosters critical thinking and problem-solving abilities, which are useful in many facets (Gudyanga & Jita, 2019).

Furthermore, TSLs allow learners the chance to engage in experiential learning and investigation, which can pique their interest in science and stoke their curiosity (Asare et al., 2023). With this practical approach, learners may explore and analyze natural phenomena, leading to unexpected discoveries and a sense of excitement for the topic (Gudyanga & Jita, 2019; Hofstein, 2017). As suggested by Hofstein (2017), laboratory experiences can have a big impact on learners' decisions to pursue careers that require a deeper understanding of science concepts. Traditional laboratories help learners learn practical skills, including working in teams, adhering to safety procedures, and effective communication, in addition to improving their comprehension of scientific subjects (Udin & Ramli, 2020). These abilities can aid learners in developing into well-rounded people and are useful in both scientific and non-scientific circumstances.

Teachers frequently face a variety of challenges while planning laboratory activities (Gudyanga & Jita, 2019). In addition to teaching, science teachers in South Africa must prepare materials and equipment, as well as reagents and solutions for the experiments (Shana & Abulibdeh, 2020; Yalcin-Celik et al., 2017). Usually, the preparation takes up most of their class time. The phenomenon of time limitations is multifaceted. In addition, issues that might result in time restrictions include huge administrative tasks, complicated or large-scale content, large classes, and insufficient practical skills. Even for the most experienced teachers, setting up experiments, supervising learners' practicals, and cleaning up glassware is too much work when there are no laboratory assistants.

1.1.2. Virtual science labs (VL)

According to Chudaeva et al. (2021), a VL is an on-screen simulator or calculator that helps to carry out an experiment or visualize experimental ideas and come out with results. Learners perform experiments without the manipulation of real objects and yield authentic results. For example, they can play around with virtual simulations of laboratory equipment that behaves in almost the same way as it would in a real environment, or they can run codes, and or manipulate the virtual apparatus, and based on results, they can be able to learn scientific concepts (Álvarez-Marín & Velazquez-Iturbide, 2022). This way, a virtual laboratory becomes a meaningful addition to the learning environment. Aljuhani et al. (2018) reiterate that a virtual science laboratory is a teaching and learning environment that is designed to help learners improve their laboratory abilities. They are among the most crucial e-learning resources. Unlike the limitations of actual laboratories, they are found online, where learners may perform several experiments at any time or location. The experiments can be performed using smart gadgets such as cell phones, laptops, desktops, etc (Aljuhani et al., 2018)

Several merits of VL have been highlighted in previous studies. These include learners, being able to collaborate and access additional educational resources with minimal cost Gambari et al., (2017), learners repeatedly practicing an activity until it is mastered, Almufarreh & Arshad, (2023) providing a safe environment for conducting experiments Kuehne, (2020), and eliminating physical limitations of a real laboratory (Asare et al., 2023). In addition, Chudaeva et al. (2021); Monita & Ikhsan (2020); Shambare & Simuja (2022) posit that online science laboratories help learners develop skills that include the following: (i) curiosity and engagement, (ii) scientific visualization, (iii) digital skills, (iv) report-writing and (v) exploration, and (vi) independent learning (Tarmo, 2022). Virtual laboratories also help teachers expedite the preparation of the experiments on a virtual platform and easily explain and present content in a digitally interesting way (Kuehne, 2020).

Teachers are responsible for putting plans into action; they frequently face a variety of challenges when it comes to planning for formal laboratory activities in a traditional hands-on method. In addition to teaching, they must prepare materials and equipment, and purchase reagents, solutions, and equipment for learners to be able to carry out the experiments. In most cases, the Senior management team at the school does not give support to the teacher to source out the required apparatus and chemicals. Therefore, the use of VL becomes handy because no purchase of apparatus and chemicals is required. This implies that all learners are equally exposed to the formal experiments in the same way, whether they are from a well-resourced or disadvantaged school.

In some countries, including Greece, a web-based platform that resembles actual laboratories has been used to alleviate the shortage of equipment and human resources in secondary schools (Monita & Ikhsan, 2020). VL has improved learners' outcomes and performance, and numerous studies have demonstrated its efficacy. One such study used 16 virtual chemistry activities to measure the learners' accomplishments. It was realised that virtual settings raised the learners' interest in chemistry and enhanced their comprehension of the subject (Kolil et al., 2020). Additionally, the learners who used VL outperformed those who utilized TLs in terms of understanding science concepts.

However, other earlier research has shown that there are drawbacks to using virtual laboratories, including denying learners the opportunity to manipulate real laboratory apparatus in a hands-on way that is crucial to science learning (Shambare, 2021) and the lack or presence of a mentor to facilitate the practical process (Manyilizu, 2023). The study's focus was on learners' understanding of concepts based on the virtual teaching approach. There is limited empirical evidence in the literature comparing traditional methods of carrying out experiments and virtual methods. In addition, there are no documented studies on the use of virtual experiments within the context of township schools in Nelson Mandela Bay, which makes the study original and necessary. A quasi-experimental design was utilized, and pre- and post-achievement scores were used to test the hypothesis.

The discussion over the use of virtual science laboratories in South African classrooms has shifted from debating whether they should be adopted for formal experiments to whether they offer the same quality learning experiences as the traditional science lab technique. In many South African schools, it is difficult to carry out experiments, particularly the formal experiments in the Further Education Training (FET) phase, because schools have limited or no access to the physical laboratory, equipment, and consumables are expensive, and or the laboratories are overcrowded. Teachers resort to teaching theory only and sometimes fake the results of formal experiments**.** The researcher investigated the feasibility of using VL as an instructional medium to overcome the difficulties of using physical equipment in carrying out experiments. Therefore, the study explored the feasibility of VL as an alternative to carrying out formal experiments.

1.2. Theoretical framework

Science education pedagogies have changed to accommodate the usage of various technologies because of technological innovation. Computer-based simulations such as virtual science laboratories are becoming more and more used as teaching tools in science subjects. It is believed that these technologies enhance scientific conceptual comprehension and learning. This study is grounded in the Technology Acceptance model as the theoretical framework. TAM is supported by the constructivist and the connectivism teaching theories.

1.2.1. The technology acceptance model

The Technology Acceptance Model (TAM)'s underpinning logic is that the use of technology is not linked to behavioural intention and general attitude toward behavioural intention, but by specific beliefs related to technology (Ajibade, 2018; Surendran, 2012). TAM assumes that the use of information technologies as a teaching strategy can bring immediate and long-term benefits to the learner, such as improved performance, time efficiency, and convenience, irrespective that the learner had behavioural intentions or not (Ajibade, 2018). The fundamental assumption of the Technology Acceptance Model (TAM) is that when it comes to the use of technology, particular ideas about technology usage, rather than a general attitude toward behavioural intention, impact behaviours (Marikyan & Papagiannidis, 2024). The TAM believes that using technology as a teaching technique has short- and long-term benefits. These benefits include increased performance, convenience, and time efficiency.

Therefore, the use of VL benefits the learner in the long run over time, and the benefits should not be compared to the effort/costs they put in to perform the activities (Marikyan & Papagiannidis, 2024; Sapriati et al., 2023). Ultimately, the use of the VL in this case is determined by an evaluation of the impact it has and the perceived usefulness it brings to the understanding and performance of the tasks.

1.2.2. Connectivism learning theory

A novel approach to education called connective suggests that learners should embrace the integration of ideas, theories, and information that they encounter when utilizing technology to learn efficiently (Utecht & Keller, 2019). Connectivism learning theory (CLT) builds on already-established learning theories (Behaviourism, Cognitivism, and Constructivism) to propose that technology is changing what, how, and where we learn (Herlo, 2017). Connecting individuals to the distributed knowledge base created in social environments is essential in our acquisition of new knowledge. Learners are influenced by social environmental trends, educational life, and new learning demands to find new ways to explain what is truly vital for the evolution of learning concepts, both now and in the future, through connections using technology

(Herlo, 2017; Kizito, 2016).

The use of CLT allows learners to promote group collaboration and discussion, permitting different viewpoints and perspectives regarding decision-making, problem-solving, and making sense of information (Hendricks, 2019; Şahin, 2012). Connectivism promotes learning that happens outside of an individual's setting, such as through social media, online networks, blogs, or information databases.

According to connectivism learning theory, to complete a task, learners integrate ideas, material, and general knowledge. Connectivism suggests that technology alters what, how, and where learners learn by building on pre-existing learning theories (Kizito, 2016; Utecht & Keller, 2019). It acknowledges that technology plays a significant role in education and that staying connected always allows us to make decisions about how children learn (Herlo, 2017). Additionally, it encourages group debate and participation, allowing for various opinions and points of view when it comes to making decisions, solving problems, and interpreting data. Therefore, the CLT encourages learning through blogs, social media, internet networks, simulations, and information databases. For instance, the use of simulations, or VL, engages learners in deep learning that empowers understanding as opposed to surface learning that only requires memorization. They also make the school environment more engaging and enjoyable. Instead of receiving instruction via a textbook or in-person lecture, learning happens via various technology devices that are accessible.

1.2.3. Constructivist theory

The second theory supporting the study is constructivist learning theory, which maintains that learners actively develop knowledge via their experiences and interactions with the environment (McKinley, 2015; Yilmaz, 2008). VL, which provides immersive and dynamic learning settings that enable learners to engage with scientific concepts, alter variables, and see outcomes in a controlled setting, provides credence to this theory. According to Sapriati et al. (2023), learning takes place in a social and cultural environment. The social interaction and cultural context that virtual laboratories may replicate are essential to construct meaning for what the learners acquire. VL also promotes collaborative learning experiences.

1.3. Purpose of the study

The research explored the use of a virtual laboratory in carrying out a titration experiment to communicate effective practical concepts in Physical science at the secondary school level. In particular, the research sought to:

- Investigate how the virtual science laboratory technique affects the mastery of Physical Sciences practical concepts in Grade 11 Physical Science learners.
- Determine whether those learners who use virtual laboratory experiments in the learning of Physical Science perform better than those who use the traditional method.

To achieve the objectives above, the following hypothesis was tested:

H_o: There is no statistically significant difference in mean scores between those who use the virtual experiments to carry out a titration and those who use the traditional method titration experiment.

2. METHODS AND MATERIALS

Quantitative and qualitative methods were utilised. For the quantitative approach, the quasi-experimental strategy was used. Quasi-experiments are observational studies that are like randomised controlled trials (RCTs) in many respects, with the primary exception being that the subjects fall into non-equivalent control groups (Maciejewski et al., 2023). The researcher used this method because the groups chosen (secondary school classes) for the research were non-equivalent. The secondary school classes the researcher used existed as intact groups, and the school's authorities did not allow such classes to be broken up and reconstituted for research purposes. The quasi-experimental design controls for all major threats to internal validity except those associated with interactions of (i) selection and history, (ii) selection and maturation, and (iii) selection and instrumentation (Rogers and Revesz, 2019). In this study, no major event was observed in any of the sample schools that would have introduced an interaction between selection and history.

For the quantitative approach, the open face-to-face interview was utilised, in which the participants were requested to state their perception regarding the use of virtual experiments for formal experiments from a sample of six teachers who were involved in the preparation and facilitation of lessons during the intervention.

2.1. Participants

The target population was drawn from nineteen (19) public secondary schools in the Uitenhage cluster that had Grade 11 learners doing Physical Science. Six schools out of the nineteen secondary schools in the circuit were drawn using the simple random sampling (SRS) technique. The six schools selected were each assigned a number, the numbers were placed in a bowl, and two numbers were picked randomly consecutively from the bowl. The first two schools drawn from the bowl were used as Group **A**, the next two schools as Group **B**, and the last two schools as Group **C**. A total of 211 participants were used in the quantitative approach of the study.

To control for the interaction between selection and maturation, the schools were randomly assigned to the control and treatment groups (Miller et al., 2020). The conditions under which the instruments were administered were kept as similar as possible across the schools by allowing the same person to administer the treatment to control for interaction between selection and instrumentation. This design also required a pre-test and a post-test for a treatment and a comparison group (control).

Table 1 summarises the quasi-experimental design used for this study. Group **A** consisted of two secondary schools that carried out the virtual titration experiment, Group **B** comprised two schools that carried out the traditional (burette method) titration, and Group **C** was a control group where no treatment was given to the two schools in the study. The scores obtained from the learners in the pre- and post-tests for the control and the treated groups were used to explain the variables. The research design is represented as follows:

Table 1
The quasi-experimental design

Group A	Group B	Group C
A – O	B – O	C – O
A x O1	B xx O1	C - O1

Where:

- **A** represents the school/learners who received a pre-test, followed by virtual treatment, followed by a post-test.
- **B** represents the school/learners who received a pre-test, followed by the traditional method of carrying out experiments, followed by a post-test
- **C** represents the school/learners who received pre- and post-tests without undergoing any of the treatments

- O represents the pre-test
- O1 represents the post-test.
- x represents the treatment (virtual experiment)
- xx represents the treatment (traditional experiment)

2.2. Ethical consideration

The ethical clearance was granted by the Nelson Mandela University Ethics Committee. Throughout the study period, the researcher abided by the code of ethics of Nelson Mandela University (NMU). Permission from the Department of Basic Education (gatekeeper) to use the schools and the learners in schools was granted, and all learners voluntarily participated in the study.

2.3. Data collection instrument

An achievement test (AT) designed by the researcher was administered to pupils. A pre-test was administered first, before the treatment was given, and a post-test was administered after the treatment. The treatment carried out an acid-base titration using the conventional apparatus (Hands-on manipulation of the apparatus) for Group **A**, and for Group **B**, the treatment was the use of a virtual apparatus for the acid-base titration, whilst Group **C** schools were the control groups (no practicals were used). The objective of the study was to investigate the effectiveness of virtual strategy in carrying out experiments. The dependent variable measured was the mark obtained from the pre-and post-achievement scores. Higher marks implied the effectiveness of the treatment.

The achievement test questions were pilot tested in two secondary schools, which were not selected for the research, although they were picked from Nelson Mandela Bay. The subjects in the pilot study had similar characteristics to those selected for the research. Cronbach's alpha, α, was used to obtain the reliability of the pre-and post-instruments (Taber, 2018). According to Mohamad et al. (2015), the reliability item can be accepted if the alpha, α, is 0.70 to 0.99, whereas Mallah et al. (2020) limit the α value to within the 0.80 to 0.90 range. The Cronbach's alpha value obtained for this study was 0,88 for the pre-test and 0.82 for the post-test, and these values were acceptable.

2.3.1. Intervention

The teaching materials used in this study were based on the Study Guide of 2022 for Physical Science for Grade 11, which is an extract from the Curriculum Assessment Policy (CAPS), and a post-test was administered at the end of the intervention (Department of Basic Education, 2020). The main teaching methods used for the groups were lecturing, questions and answers, and group discussions. The instructional materials were issued for ten days just after the pre-test, teaching methods used for the groups were lecturing, questions and answers, and group discussions. The lessons were used to introduce basic theory on acids and bases for five days. On the ninth day, Group **A** was given an orientation on how to carry out a virtual titration experiment using a computer or cell phone. The virtual science Laboratory technique, the LearnSci application software designed by Stellenbosch University-South Africa, was utilized by Group **A**. The application was installed on either a cell phone or a laptop for the learners. Group **B** obtained an orientation on the physical titration apparatus. Group **C,** which was the control group, continued with the theory on the topic.

2.4. Data analysis technique

An independent t-test was calculated to determine the differences in group means for the pre- and post-test scores for Group **A**, **B** schools, and **C** schools. An independent t-test was used because of its superior power in detecting differences and statistical errors between the two means. One-way analysis of variance (ANOVA) was performed to determine the differences in the three mean scores of the post-tests for the three groups **A**, **B,** and **C**. An F-test was used to determine whether the differences were significant concerning the hypothesis stated above. For qualitative data analysis, the interview responses were quoted as presented by participants, and the meaning of the statements was sought according to how the researcher interpreted the statements in a way that did not compromise the original meaning expressed by the participants.

3. RESULTS

In Table **2,** the results of the pre-test and post-test scores for all the groups used in the study are summarised.

Table 2

Summary of the results of the achievement test scores for the three groups.

Treatment	Group	Sample size (N)	Mean (%)		Standard deviation	
			Pre-test	Post-test	Pre-test	Post-test
Virtual	A	74	33.3	46.3	10.5	13.5
Traditional	B	74	32.5	44.3	10.0	13.7
Control	C	63	30.8	39.5	10.4	11.6
TOTAL		211				

The mean (%) of the three groups used in the study before the treatment was almost the same: 33.3 (SD = 10.5), 32.5 (SD = 10.0), and 30.8 (SD = 10.4) for the virtual, traditional, and the control groups, respectively. The virtual group had a smaller mean % of 40.5 (SD =13.5) compared to the 44.3 (SD = 13.7) mean % for the traditional group.

Table 3

An independent sample t-test for pre-test scores of the Virtual and control groups

Variable	**Independent Samples Test**							
	t-test for Equality of Means							
Score			Significance				95% Confidence Interval of the Difference	
	t	*df*	One-Sided *p*	Two-Sided *p*	Mean Difference	Std. Error Difference	Lower	Upper
	1.28	135	.102	.204	2.32	1.82	-1.27	5.9

Table 3 shows a summary of the results of the independent *t*-test for the pre-test scores of the virtual and control groups. The results indicate a significant difference between the virtual (M = 33.3, SD = 10.4) and control (M = 30.8, SD = 10.4), [*t*(135) = 1.28, *p* = .102 > .05]. Consequently, we fail to reject the null hypothesis that there is no difference between the sample means.

Table 4

An independent sample t-test for pre-test scores of the Traditional and control groups

Variable	**Independent Samples Test**							
	t-test for Equality of Means							
Score			Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
	t	*df*	One-Sided *p*	Two-Sided *p*			Lower	Upper
	2.18	135	.098	.228	17.78	1.75	14.33	21.24

An independent samples *t*-test was conducted to determine whether there was a significant difference in pre-test scores between the traditional and the control groups. As reported in Table 4, there is no significant difference between the traditional (M = 32.5, SD = 10.0) and control (M = 30.8, SD = 10.4), [*t* (135) = 2.18, *p* = .098 >.05]. Consequently, we fail to reject the null hypothesis despite the traditional group attaining higher mean scores than the control group. The results confirm that the virtual and the traditional groups exhibited similar characteristics suitable for the study before the treatment.

Table 5

An independent sample t-test for pre-test scores of the Traditional and Virtual groups

	Independent Samples Test							
Variable	*t*-test for Equality of Means							
Score			Significance				95% Confidence Interval of the Difference	
	t	*df*	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
	1.37	135	.086	.173	2.46	1.79	-1.09	6.03

Table 5 shows the results of the independent t-test for the pre-test scores of the virtual and traditional groups. The results indicate a non-significant difference between the virtual (M = 33.3, SD = 10.4) and traditional (M = 32.5, SD = 10.0), [*t*(135) = 1.37, *p* = .086 > .05]. Consequently, we fail to reject the null hypothesis; therefore, there is no significant difference between the sample means before the treatment. The groups were, therefore, assumed to be suitable for the study.

Table 6

An independent sample t-test for post-test scores of the virtual and control groups

Variable	Independent Samples Test							
	t-test for Equality of Means							
Score			Significance				95% Confidence Interval of the Difference	
	t	*df*	One-Sided *p*	Two-Sided *p*	Mean Difference	Std. Error Difference	Lower	Upper
	4.65	135	0.000	0.000	9.69	2.08	5.57	13.8

Table 6 reports the independent *t-test* for the post-test scores of the virtual group compared to the control group. The 74 learners who received the virtual experiments intervention method (*M* = 33.3, *SD* = 10.4) compared to the 63 learners in the control group (M = 30.8, SD = 10.4) demonstrated significantly better achievement test scores, [$t(135) = 4.65$, $p < .0001 < .05$].

Table 7

An independent sample t-test for post-test scores of the traditional and control groups

Variable	Independent Samples Test							
	t-test for Equality of Means							
Score			Significance				95% Confidence Interval of the Difference	
	t	*df*	One-Sided *p*	Two-Sided *p*	Mean Difference	Std. Error Difference	Lower	Upper
	1.38	135	0.035	0.044	3.12	2.26	-1.35	7.58

Table 7 reports the independent *t-test* for the post-test scores of the traditional group compared to the control group. The 74 learners who received the traditional experiments intervention method (M = 32.5, SD = 10.0) compared to the 63 learners in the control group (M = 30.8, SD = 10.4), demonstrated significantly better achievement test scores, [$t(135) = 1.38$, $p < .035 < .05$]. An analysis of the results in Tables 5 and 6 indicates that both traditional and virtual intervention methods improved the performance of the learners in understanding practical concepts in Physical Science.

Table 8

Analysis of variance (ANOVA) of the post-test scores for Groups A, B, and C.

ANOVA						
Source of Variation	SS	*df*	MS	F	*p*-value	*F* crit
Between Groups	15855.08	2	7927.54	53.45	.0001	3.04
Within Groups	29369.16	198	148.33			
Total	45224.24	200				

A one-way between-subjects ANOVA was conducted to compare the effect of experimentation on conceptual understanding of the practicals in virtual, traditional, and no-experiment conditions. Table 5 reports the one-way ANOVA results. The analysis of variances showed that the effect of experimental groups (virtual and traditional) significantly influenced better performance [$F(2, 198) = 3.04$, $p < .0001$]. Based on Tukey's value of HSD = 5.12 (Table 6), the control group (Group C) (M = 39.5, SD = 11.6) was significantly less than in the virtual group (Group A) (M = 46.3, SD = 13.5) and the traditional group (Group B) (M = 44.7, SD = 13.7). The virtual experiment scores did not differ significantly from the traditional group scores.

Table 9

Tukey's HSD Test, HSD [.05] = 5.12

Group	Mean	Mean Difference	
A	46.3	A - C = 6.8	significant
B	44.7	B – C = 5.2	significant
C	39.5	A – B = 4.2	Not significant

4. DISCUSSION

A comparison of the post-test means scores for the three categories A, B, and C, 43,73%, 23,7%, and 23,7% respectively, shows that the use of experiments in the learning of science resulted in higher learner performance. The mean scores where VLs and TLs were used as the treatment had a significantly higher mean score compared to the control group. Therefore, learners performed better or understood the concepts better when they carried out the experiments. The results of this study agree with previous findings (Callaghan & Herselman, 2015; Heradio et al., 2016; Triana Ortiz et al., 2020), which revealed that learners learn better or understand science concepts better through hands-on activities.

A comparison of the VLs and TLs mean scores revealed that there was no significant difference in performance between the group that obtained the VLs to that which obtained the TLs. One possible reason for performance improvement after the interventions was that experimenting resulted in a better understanding of the concepts, thus the hands-on or virtual handling of the apparatus made learners remove the misconceptions. The experiments also improved learners' participation, connecting oneself to the real acid-base titration scenario as suggested by TAM and the connectivism theory of learning. As suggested by the TAM, learners' performance increases using VL (Ajibade, 2018). Using VLs and TLs not only results in better performance but also improves the learners' attentiveness, confidence, and as well as satisfaction.

The use of virtual learning environments is crucial because it enables a larger range of learners, especially those without access to suitable laboratories in their schools, to engage in practical activities. The study results showed that the VL approach is as good as the hands-on method in that it allowed an improvement in learners' comprehension of the science experiments. The findings show that using virtual laboratories has a good effect on learners and is necessary in South African schools where proper laboratories and equipment are not available, as well as where many learners need to do the experiments (Hamed & Aljanazrah, 2020). Moreover, the VL is considered a smart environment where it provides the learners with adequate feedback during the learning process and enables the teacher to follow and assess the student's performance.

The VL promotes the constructivist theory in that it allows learners to be actively involved in developing knowledge via their experiences, manipulating, and interacting with technological gadgets at their own convenience. However, some teachers do not support the use of VL, indicating that the presence of the teacher with learners is necessary to guide the learning process. The study findings are supported by Breunig (2017). who posited that hands-on learning promotes a deeper connection with the subject matter whilst they are interacting with real-world objects. This active engagement allows learners to cultivate critical thinking skills, problem-solving abilities, and a deeper understanding of the subject matter.

5. CONCLUSION

The study has shown that virtual science laboratories are competitive and may be a revolutionary substitute for traditional hands-on laboratory experiences. This comparison analysis has shown that VL is superior to TL in that it fosters social interaction, motivation, and engagement, accessibility, and ease of use. Additionally, the study has given teachers, stakeholders, and curriculum designers insightful information to think about when it comes to how formal experiments should be conducted in classrooms. Although each technique has pros and cons of its own, the constraints, available resources, and specific learning objectives should be taken into consideration when choosing the optimal course of action. When traditional laboratories are not practical, virtual science laboratories (VL) play a crucial role because they may increase accessibility, scalability, and cost-effectiveness. They should not, however, be viewed as a total substitute for practical experiences, which are nevertheless crucial for encouraging a better comprehension of scientific principles and for the development of practical abilities.

The study focused on the feasibility of using virtual labs to carry out formal experiments; therefore, I recommend that the teachers' perceptions regarding the use of VL should be explored. The Department of Education should consider the use of virtual labs to support schools that do not have resources such as laboratories, apparatus, and chemicals.

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